USING STOCHASTIC OPTIMIZATION AND REAL-OPTIONS MODELS TO VALUE PRIVATE SECTOR INCENTIVES TO INVEST IN FOOD PROTECTION MEASURES

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Private Sector Incentives to Invest in Food Protection Measures

By

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ABSTRACT

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Agro-terrorism has become a major concern since the September 11, 2001, terrorist attacks due to characteristics that create unique problems for managing the threat of an agro-terrorist attack. The costs of trucking delays alone were in the tens of millions of dollars. Over the last few years, the government has spent billions of dollars on biological surveillance and record keeping in preventing potential attacks. Several public and private initiatives are currently in use. Examples include 1) the bio-terrorism regulation of 2004 on maintenance of records; 2) establishment of food protection centers for research and teaching excellence; and 3) investments in emerging technology, such as radio frequency monitoring (RFEM) technology, with the potential to track shipments and provide real-time data that can be used to prevent agro-terrorism risks along food supply chains.

This thesis addresses the costs and risk premiums associated with alternative tracking strategies, where and when along the milk supply chain these strategies will reduce the most risks, and what policy implications are associated with the most cost-effective tracking strategy. To accomplish these objectives, stochastic optimization is used to determine the costs and risk premiums of alternative tracking strategies. Next, the real-options method along with a portfolio of options, also referred to as the "tomato garden" framework, is used to determine where and when alternative intervention strategies should be implemented to reduce the most risks. Finally, policy implications are derived on the cost-risk tradeoffs, probability of attacks, and containment efforts if there is an attack by

using game theory to determine the incentives needed to motivate participants in the milk supply chain to invest in security measures.

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STATEMENT OF PROBLEM

Introduction

Background on Terrorism and Intentional Food Contamination

The September 11, 2001, terrorist attacks and subsequent anthrax episode displayed the vulnerability of the United States to a terrorist attack. These events put terrorism at the forefront of the U.S. domestic and foreign policy and made many realize the possible fragility of the U.S. economy to terrorism (Onyango, Turvey, and Hallman, 2005). Unofficial estimates place the economic losses in the United States from the September 11th attacks at $2 trillion, with losses due to delayed trucking alone for the grain industry in the tens of millions of dollars (Nganje et al., 2006; Goldfarb and Robson, 2003).

Even though the risk of a bio-terrorist attack was present before the September 11th attacks, the term "food security" was not generally linked to specific terrorist or violent attacks on the food system (Onyango, Turvey, and Hallman, 2005). However, intentional food contamination or food terrorism risks are real and have occurred in the past. Lyonga et al. (2006) give four examples of deliberate food contamination:

- In September 1984, members of a religious cult contaminated salad bars in Dalles, Oregon, restaurants with *Salmonella typhimurium*. As a result, 751 people fell sick. This was supposedly a trial run for a more widespread attack that was planned to disrupt local elections later that year.
- In 1996, an angry laboratory worker in Texas deliberately contaminated food to be consumed by colleagues, causing sickness to 12 people, by using a reference strain of Shigella dysenteriae type 2.

- In January 2003, the Center for Disease Control (CDC) reported that 92 people fell ill after purchasing ground beef from a Michigan supermarket that was purposely contaminated with nicotine. An employee was charged for deliberately poisoning 200 pounds of meat sold in the supermarket.
- In Irvine, California on July 28, 2004, ground-up castor beans with small amounts of ricin poison were found in two jars of baby food that also included notes that the food had been tainted along with the name of an Irvine police officer.

Terrorist objectives can be to cause death or sickness to animals, plants, and humans; economic damages; or both (Turvey et al., 2003). Terrorism directed towards the food system could have extremely large human health, economic, and psychological consequences, such as loss of human life, economic disruption, and negative impacts on consumer confidence (Onyango, Turvey, and Hallman, 2005). A terrorist attack on the food supply is termed agro-terrorism or "the deliberate introduction of an animal or plant disease with the goal of generating fear, causing economic losses, and/or undermining stability" (Monke, Summary, 2004).

Agro-terrorism has become a major concern since the September 11th attacks, and it has recently been discovered that Al Qaeda has studied the U.S. agricultural industry (Pistole, 2006). According to Monke (2004), agriculture has several characteristics that create unique problems for managing the threat of an agro-terrorist attack. These include:

- Agricultural production is geographically disbursed in unsecured environments. While some livestock are housed in secure facilities, agriculture in general requires large amounts of land that are difficult to secure from intruders.

- Livestock are frequently concentrated in confined locations. Concentration in slaughter, processing, and distribution also makes animal agriculture more prone to large-scale contamination.
- Live animals, grain, and processed food products are routinely transported in bulk and commingled in the production and processing system. These factors could reduce natural barriers that slow pathogenic distribution.
- The presence (or rumor) of certain diseases or pests in a country could quickly stop all exports of a commodity, which can take months or years to resume.
- The past success of keeping many diseases out of the United States may delay recognition of symptoms in case of an outbreak because many scientists and veterinarians lack direct experience with foreign diseases.
- The number of lethal and contagious biological agents is greater for animals and plants than for humans. Most of these diseases are environmentally durable and common in foreign countries, which make it easier for terrorists to acquire, handle, and deploy the pathogens.

A recent survey completed by Stinson et al. (2006), indicates that the public sees an attack on the food sector to be more serious than any other attack and would spend more to protect the food supply than to protect against any other types of attacks listed in the survey, including air travel. Approximately 96% of those surveyed expect another terrorist attack in their lifetime, and about 44% expect a serious terrorist attack on the food supply in the next four years.

Cost of Food Protection Bio-Defense and Investment Opportunities

Monke (2004) mentions what potential economic losses from an agro-terrorist attack could be. First, the losses would include the cost of destroying diseased or possibly diseased products, the value of lost production, and the cost of containment (vaccines, diagnostics, drugs, pesticides, and veterinary services). Second, export markets would be lost as importing countries could place restrictions on U.S. products to prevent possibilities of the disease spreading. Third, multiplier effects would flow through the economy due to decreased sales by agriculturally dependent businesses (farm input suppliers, transportation, food manufacturing, food service, and retail grocery) and tourism. Fourth, the government could bear significant costs, including containment and eradication costs, and compensation to producers, processors, or retailers. Anderson (2004) also indicated that financial institutions and insurance firms may incur millions of dollars in losses. Consequently, if there is any intentional tampering by terrorists on the U.S. food system, the U.S. economy, public health, and consumer confidence could cost the United States billions of dollars in order to control or stabilize the situation (Nganje et al., 2006).

Agro-terrorist attacks can be targeted towards: a) consumption (demand) without causing a structural or behavioral shift in supply, b) production (supply) without causing a structural or behavioral shift in demand, or c) both demand and supply (Turvey et al., 2003). Agro-terrorism also poses a threat to the U.S. economy because of the large export and import markets for food and agricultural products. The United States exports 18% of agricultural production and 9% of the food products consumed domestically are imported (Onyango, Turvey, and Hallman, 2005). Impacts on the labor markets could be severe as agriculture and agribusinesses are the number one employer in the United States, even though relatively few people are employed in actual agricultural production (Cupp, Walker, and Hillison, 2004).

Even though the probability and potential size of a bio-terrorism attack is unknown, Congress has passed new federal legislation that is intended to strengthen the nation's biological surveillance by increasing federal and state biological surveillance funding. Government civilian bio-defense funding has increased considerably over the last few years, from $414 million in 2001 to over $5 billion in 2004. The problem faced with this increased spending on biological surveillance is that the potential benefits from this increased spending must outweigh the costs from an attack to be beneficial to society (Schendier, 2005).

In recent years, alternative tracking devices like radio frequency environmental monitoring (RFEM) technology have emerged as an alternative to track and prevent agro-terrorism risks along food supply chains. The potential benefits of this technology are that RFEM: 1) records real-time data that can be downloaded and analyzed during the process; 2) could be used to screen for malicious tampering of food containers or packages; 3) could pinpoint the location of tampering or more importantly could indicate the possibility that a toxic material or infectious agent was added to the product; 4) could be used for traceability from production to commercialization; and 5) could be used to monitor and record weather conditions, types, amounts, and timing of chemicals applied, disease incidence, insect infestations, and harvest dates (Thompson, 2004).

RFEM devices provide opportunities to track and mitigate food terrorism risks. These opportunities can be valued as real-options (Nganje, Wilson, and Nolan, 2004).

However, there are several challenges that need to be addressed. These are discussed in the problem statement section.

Problem Statement

Some interesting economic questions regarding food protection costs include 1) how much should we spend to protect America's food supply against terrorism, 2) should the spending come from the private or public sector, and 3) when and where should spending for food defense be allocated to limit the economic damages from terrorism? We will attempt to address these questions in this thesis.

The current method of record keeping and maintenance is called the "one-step forward/one-step backward" method. This method requires persons who manufacture, process, pack, transport, distribute, receive, hold, or import food into the United States to keep records of the immediate previous sources and immediate subsequent recipients of food (FDA/CFSAN, 2004). However, this method may be costly. The annual total record keeping cost is estimated to be $1.41 billion (FDA/Section 4, Part A, 2004). Some foreign countries argue that the result of this record keeping burden will be the elimination of many legitimate and safe food distribution businesses and a serious reduction in global food trade. They also argue that the regulations are likely to increase uncertainty and costs for foreign exporters (FDA/Comment 14, 2004).

Another concern is that this regulation of record keeping will lead to the unintentional consequence of foreign countries imposing the same requirements on U.S. goods in foreign trade (FDA/Comment 14, 2004). The RFEM technology will provide an alternative tracking and record keeping system and eliminate some of the trade barriers associated with the current record keeping method. Containment challenges also arrive from the record keeping system due to the time interval from contamination to containment. RFEM tracking may also minimize this interval and reduce the risk of contaminated product reaching the consumer.

Objectives

The primary objective of this study is to evaluate the cost-effectiveness of the use of RFEM compared to alternative tracking strategies intended to mitigate agro-terrorism risks along the milk logistic system. The choice of milk as a target commodity will be discussed in the literature review section. The specific objectives are to

- Determine the costs and risk premiums that the private sector is willing to pay for alternative tracking strategies along the milk supply chain.
- Determine where and when along the milk supply chain investments in alternative intervention strategies will reduce the most risk.
- Derive policy implications for the cost-effective intervention strategy and incentives for the milk supply chain using game theory.

Hypothesis

It is expected that the RFEM technology will be more cost-effective compared to alternative strategies used in mitigating agro-terrorism risks along the milk supply chain. It is also hypothesized that it will be cost-effective to invest in security measures now, rather than delay investments for latter years.

Organization

Chapter 2 focuses on a literature review about the reasons for using milk as an empirical application. This background includes U.S. exports and domestic production, contamination events, and the steps in the supply chain. This chapter also includes a discussion on the uses of real-options to value hypothetical investments. Chapter 3 develops the theoretical models of stochastic optimization and real-options, and also details the portfolio of options conceptual framework. A game-theory model is used to evaluate strategies to motivate participants along the milk supply chain to invest in security measures. The data and simulation procedures will be discussed in Chapter 4. Chapter 5 will include the results. The main findings and conclusions will be presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

Introduction

The Literature Review is divided into three sections. The first section discusses studies and issues related to milk as a target commodity, which includes bulk transportation along the milk supply chain, domestic production and export of milk, and milk contamination events. The second section discusses the appropriateness of real-option models to determine the timing of investment decisions on food security measures. The third section gives an in depth understanding of the milk supply chain and its core components.

Milk Background

The total U.S. milk production has increased from approximately 18.61 billion gallons in 1998 to approximately 20.95 billion gallons in 2005, and an average of 34% of the milk produced from 1998 to 2005 was exported (USDA/NASS, 2006; USDA/FAS, 2006). However, much of what has been exported has been concentrated to a small group of countries or territories. From 1998 to 2005, 93.4% of the total exported milk was distributed to only five regions: Mexico, Canada, Hong Kong, Taiwan, and the Bahamas with 67.4%, 13.2%, 6.9%, 4.5%, and 1.4% distributed, respectively. In 2005, 97.6% of the total exported milk was distributed to only five regions: Canada, Mexico, the Bahamas, Hong Kong, and the Philippines with 48.5%, 46.1%, 1.9%, 0.8%, and 0.6% distributed, respectively (USDA/FAS, 2006). Bulk transportation characterizes shipments in the domestic and export markets and, as mentioned earlier, this creates a unique problem for managing the threat of an agro-terrorism attack.

Milk Contamination Events and Containment Possibilities

In March of 1982, the pesticide heptachlor was discovered in over 80% of the milk produced in Oahu, Hawaii, which contained 15 times the official acceptable adult level of heptachlor. Eight recalls of milk and dairy products were announced during March and April of 1982. From March of 1982 to May of 1983, 36.2 million pounds of contaminated milk were dumped (Smith, van Ravenswaay, and Thompson, 1988; Liu, Huang, and Brown, 1998).

This incident had a tremendous amount of press coverage on the contamination crisis and milk quality, which contained both negative and positive information. The average daily milk consumption in April compared with February 1982 had dropped over 80%. Consumers were reluctant to buy locally produced milk even though after each recall the government and industry assured the public that the available milk was safe and no evidence existed to suggest further contamination. The consumption of milk returned to normal levels after more than 15 months following the incident (Smith, van Ravenswaay, and Thompson, 1988; Liu, Huang, and Brown, 1998). This experience indicates that deliberate, sustained contamination of milk by terrorists may not only kill humans, but financially handicap the milk industry.

Wein and Liu (2005) illustrate the possibility of an intentional bio-terror attack on the milk supply chain. Their paper evaluates different doses of botulinum toxin, a potential weapon that could be released, and the amount of possible casualties associated with each dose. The assumed deliberate release points of the toxin were either at the holding tank at a dairy farm, a tanker truck transporting milk from the farm to the processing plant, or a raw milk silo at the processing facility. They also completed sensitivities on the amount of botulinum toxin needed at each location to cause casualties.

Even though the case of the milk contamination in Hawaii and the theoretical case of botulinum toxin in milk discusses the impacts of a bio-terror attack on the milk supply, neither provides strategies on how to implement preventive measures to avoid such an attack. Wein and Liu (2005) did suggest, however, that further research on the timeliness of containment efforts and investment in security measures along the milk supply chain are necessary. This allows RFEM to be analyzed as a security measure to increase the timeliness of containment.

Uses of Real Options to Value the Timing of an Investment Decision

Private companies are taking steps toward adopting measures to minimize lost sales and decreased consumer confidence that would result from an agro-terrorism attack. Such measures include traceability, contracting, identity preservation, and surveillance. Public sector investments in the United States include the Customs Trade Partnership Against Terrorism (C-TPAT), the Public Health Security and Preparedness Act of 2002, and the Container Security Initiative (CSI). These private and public sector investments in agro-terrorism protection provide real-option investment opportunities on alternative tracking and risk mitigation technologies. Nganje, Wilson, and Nolan (2004) provide a real-option "tomato garden" framework to evaluate the timing of investment decisions for food security measures. This framework can incorporate uncertainties about the probability of a terrorist attack and the stochastic cost of emerging technologies.

Investment decisions that have been evaluated using real options include investment in farmland and rangeland, capital budgeting valuation, decisions under risk and uncertainty, expected utility analysis, and investments in mitigating the risks of agro-terrorism (Turvey, 2002; Lambert and Harris, 1990; Trigeorgis, 1993; Benaroch, 2002; Isik, 2004; Nganje, Wilson, and Nolan, 2004).

In this study, optimal intervention strategies for each tracking technology are first determined with the use of stochastic optimization models. The real-option portfolio of the options model is then used to evaluate the timing of investment decisions. Policy implications are derived using a game-theory model and data from the stochastic optimization/real-option models. The real-option framework for investments in security measures requires an in-depth understanding of the supply chain and its core participants.

Milk Supply Chain

After visiting with Cass-Clay, a medium-sized milk processor in the upper Midwest, and gathering information from the literature, we were able to provide a schematic of the milk supply chain. The milk supply chain begins at the farm-level with storage of the produced milk (Figure 2.1). The milk that is stored at the farm-level is then transported by truck to the dairy processing plant and stored in milk silos. The truck that transports the milk from the farms to the processing firm may make more than one stop at different dairy farms depending on the size of the farm.

Upon arrival at the processing plant, the raw milk is received, filtrated, and then put into storage silos. The milk is then taken from storage when needed and pasteurized. After pasteurization, the products are sent to post-pasteurization tanks for holding until bottling or other processing. The pasteurized products are then used to process specific products such as butter, cheese, fluid milk, and powder milk (Bosworth, Hummelmose, and Christiansen, 2001).

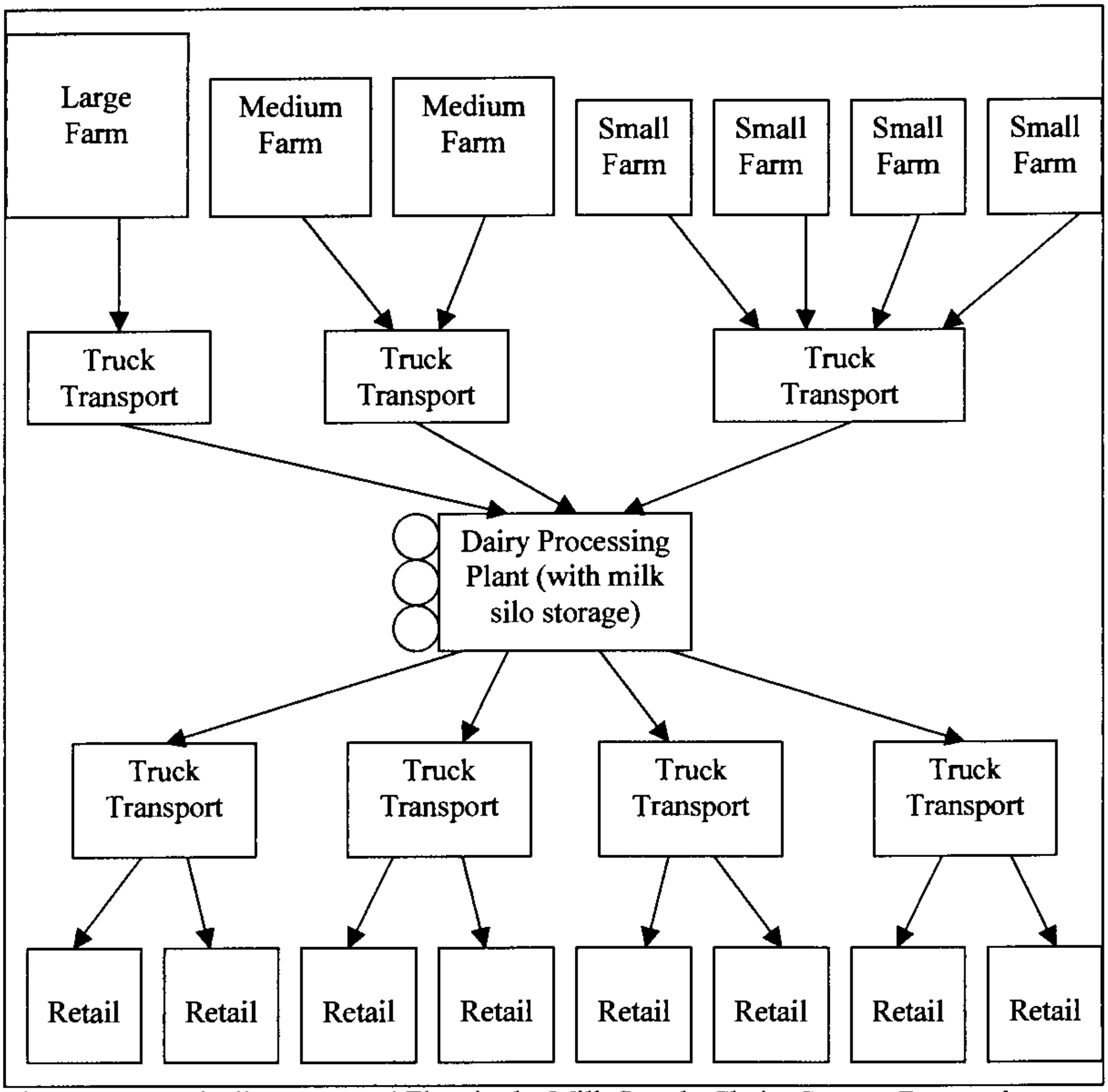

Figure 2.1. Vertically Integrated Firm in the Milk Supply Chain. Source: Bosworth, Hummelmose, and Christiansen (2001).

When the processing is completed, the products are sent to packaging and storage, which includes cold storage for perishable items. After packaging and storing the final products, they are then distributed. The typical milk processing plant produces whole milk, skimmed milk, cream, buttermilk, and butter while some other plants may specialize in butter-making, cheese, and milk powder production (Bosworth, Hummelmose, and

Christiansen, 2001). However, some plants may produce all of these products within one production facility.

Within the milk industry, many of the production companies are regionalized and, therefore, only need to distribute the finished milk products to retail and food service facilities by truck transport. The retail and food service facilities then sell the milk at grocery stores, restaurants, gas stations, and educational facilities. There are three major participants along the milk supply chain: milk producers at the farm, the processor (who generally owns the pick-up and distribution trucks), and the retailer. Larger integrated processing facilities may also market their milk to retailers in export markets.

In the milk logistic supply chain, one farmer could contaminate the subsequent steps in the milk supply system if the concentration of contamination reaches high enough levels. However, resources to protect each farmer may not be available and could lead to over spending. This leads to evaluating the cost-effectiveness of alternative tracking strategies that could contain an outbreak if contamination did occur.

CHAPTER 3

THEORETICAL MODELS

Introduction

Investment decisions to mitigate agro-terrorism risks are made under conditions of risk and uncertainty. Several conceptual frameworks have been used in the literature to model and evaluate investment decisions under conditions of risk and uncertainty (Shi and Irwin, 2005; Liu and Shumway, 2005; Isik, 2004; Nganje, Wilson, and Nolan, 2004; Benaroch, 2002). These range from simple mean-variance graphical comparisons of risk and returns to robust development of the expected utility maximization framework.

The framework that is used in this study consists of two steps: 1) quantifying the cost and risk premium associated with alternative tracking technologies, and 2) identifying areas where investment will reduce the most risk along the milk supply chain and the incentives to invest in security measures. The first step will be accomplished by using stochastic optimization and the expected utility framework while the second step will use real options, the portfolio of options framework, and game-theory.

Stochastic Optimization Model

A stochastic optimization model of a vertically integrated firm in the milk supply chain was developed to determine the costs, risks, and optimal strategies associated with four alternative tracking technologies: 1) random testing with no lock-out tag or RFEM system installed; 2) one-step forward/one-step backward tracking for bio-terrorist events; 3) tracking with RFEM installed, with testing for contaminants allowed when RFEM signals tampering and random testing elsewhere; and 4) tracking with RFEM installed with required testing for contaminants at the milk plant and import facilities. The advantage of stochastic optimization over alternative valuation models is that a risk premium can be estimated with multiple stochastic variables in the model (Nganje et al., 2006).

In this model, the total system costs and optimum premium for each strategy are estimated. Stages along the milk supply chain where testing can be implemented include on the farm, transport from farm to processing facility, milk silo, pasteurization, post-pasteurization tanks, bottling, and transport for export. The total system cost (C_i) is defined as

(1) $$C_i = \sum_{j=1}^{n} T_j \cdot TC_j \cdot S_j \cdot V_j + QL_j + RFEM_j ,$$

where i varies from one to four, indicating alternative tracking technologies; j is the location where tests are conducted; T_j is a binary variable indicating test/no test at location j; TC_j is the cost of testing per unit multiplied by the number of tests conducted ($/test) at location j; S_j is the sampling intensity at location j; V_j is the volume of milk flow at location j; QL_j is the volume diverted multiplied by quality loss cost per unit at location j; and $RFEM_j$ is the cost of installing RFEM or alternative tracking devices at location j.

The model is used to estimate the certainty equivalent and quantify the risk premium for the four alternative systems. The objective function uses a von Neumann-Morgenstern type utility function, with increasing relative risk aversion and decreasing absolute risk aversion (Wilson and Dahl, 2005). This model chooses the optimal testing strategy (where to test and the testing intensity) that maximizes the utility of a vertically integrated firm in the milk supply chain. The objective is

(2) $$MaxU = E(U(W)) = \lambda - EXP(-\Phi W^{\eta}))$$

s.a. $X_j \in Y_j$,

where U is utility; EU is expected utility of the vertically integrated firm in the milk supply chain; W is the wealth of the vertically integrated firm in the milk supply chain; λ is the parameter determining positiveness of the utility function; EXP is exponential power function; Φ and η are parameters which affect the absolute and relative risk aversion of the utility function; X_j is the decision variable vectors of the model; and Y_j is the opportunity cost of the model.

The advantage of using this utility function in the stochastic simulation model is that it is flexible and allows for changes in absolute and relative risk aversion. This utility function also allows us to quantify the cost and risk premium that make the vertically integrated firm in the milk supply chain to be indifferent between a base model (random testing) and the alternative tracking technologies: one-step forward/one-step backward tracking for agro-terrorist events, tracking with RFEM installed with testing when RFEM signals tampering and random testing elsewhere, and tracking with RFEM installed and required testing at the milk processing facility and import facility with random testing elsewhere. The parameters of the utility function λ, Φ, and η are fixed and set to 2, 0.01, and 0.5, respectively.

The risk premium is defined as

(3) $\pi = EV_{BCM} - C_{OSF\text{-}OSB/RFEM}$,

where π is the risk premium; EV_{BCM} is the expected value of the base case model with random testing; and $C_{OSF\text{-}OSB/RFEM}$ is the certainty equivalent of the alternative tracking strategy. The validity of the expected utility framework requires a test for robustness of the results to be evaluated. This is accomplished by performing sensitivity analysis under relative and absolute risk aversion parameters. Cost and risk premium results are used in the real-option and game-theory models to determine the timing of investment decisions and incentives to invest in security measures.

Real-Options Model

The real-options approach to agro-terrorism prevention assumes that an investor has the opportunity to invest in a prevention strategy and that the investor prefers to reduce income volatility. The effect of the uncertainty associated with an agro-terrorism event can be valued using a real-option valuation procedure, which is a form of a European call option, even though the value of the project is not clearly recognized at the time of the investment. The returns from the real-options model work similarly to returns from car insurance investments. Such as an investment is made with the intentions of never having to use it, but when an attack does occur, a positive payoff is the result from the investment. The model assumes that returns follow a Poisson (jump) and a mixed Brownian motion (continuous) process. The continuous movement of the process is due to production and price variability while the discrete jump process can be credited to uncertain agro-terrorism actions (Nganje, Wilson, and Nolan, 2004).

Poisson Component

The Poisson jump process assumes that the amount of time a firm operates before an agro-terrorism event occurs follows an exponential distribution, and if an agro-terrorism event occurs, returns are reduced. The advantage of using the Poisson jump process over typical binomial distributions is that it can account for a specific time period and extreme events that typical binomial distributions may miss.

Mohtadi and Murshid (2005) used extreme value statistics to evaluate the probability of an attack that would cause the number of fatalities plus injuries to exceed

5000. These probability forecasts were determined for now, 5 years, 10 years, and 25 years into the future. The forecasts were broken down into different categories, chemical agents, biological agents, and radioactive or nuclear agents (CBRN). The results showed that the probability increased if no action is taken to prevent an attack. These results were 0.18, 0.22, 0.26, and 0.35, for now, 5 years, 10 years, and 25 years, respectively. These results were for a CBRN attack in general and were not targeted towards the food sector. However, it was determined that the probability of attack will increase over time in the absence of preventive measures. The probability of an attack on the milk supply chain is scaled down and assumed to be 0.01 and sensitivities are performed for a range of probability values.

The amount of time it takes before a "jump" to a lower level of returns is assumed to be a random variable with a range on the interval [0, ∞]. Thus, the probability of the jump occurring at time T is

$$(4) \qquad P(a < T \le b) = \int_a^b \lambda e^{-\lambda t}\, dt,$$

where t is the current time, λ is the positive exponential hazard rate parameter, and e is the natural exponential function. The value exp (-λt) measures the probability of occurrence of an agro-terrorism event sufficient to affect firm revenue, while λ measures the probability of the event occurring just after time t. The expectation of T is inversely related to λ; therefore a subjective determination of the size of λ can be made using the investors' prior beliefs (Pitman, 1993).

Brownian Motion Component

Brownian motion is used to model continuous movement in future returns from an investment. This is also used to describe the probability distribution of the future price of a commodity. Commodity price movements are assumed to follow a normal distribution, with the amount of time that has passed being the only dependent for mean and standard deviation. The following is a typical Brownian motion process equation

(5) $dV = \alpha V dt + \sigma V dz$,

where the increment of the Brownian motion process is represented by dz, with drift parameter α and variance rate σ. According to equation (5) the expected growth rate of V is equal to the sporadic variability plus volatility in the price of the commodity.

Model of Returns to Investment Under Uncertainty

The value of an option or an investment opportunity in an agro-terrorism prevention strategy, F(V), is defined as the expected present value from investing at the optimal time (Nganje, Wilson, and Nolan, 2004)

(6) $F(V) = \max_T E_0[(V_T - K)e^{-\rho T}]$,

where T is the optimal time to invest; V_T is the expected present value of the investment made at time T; K is the sunk cost of the project; e is the natural exponential function; ρ is the discount rate; and E is an expectation operator. The expected present value of the option or investment is a function of state variables (e.g., the decision to invest or not invest in alternative security measures), as well as choice variables (e.g., the amount to spend) at current time t. The objective is to maximize future cash flows from the investment.

This study covers two cases: the impact of an intentional attack in the milk supply chain, and the impact of an unintentional attack in the supply chain. The unintentional attack case is modeled as a dynamic process, which becomes a Bellman equation in continuous time.

(7) $\rho F(V(x,u,t)) = \max_u \left[\pi(x,u,t) + \frac{1}{dt} E[df(V)] \right]$.

According to equation (7) the normal return per unit time that is required to hold the commodity value F(V) is equal to the immediate profit if the investment is made (π(x,u,t)), plus the capital gain or loss expected from holding the option (E[df]). The profit is zero if the investor holds on to the option, and this is the case for the periods before the investment is made. Multiplying this equation through by dt yields

(8) $\rho F(V(x,u,t))dt = E[dF(V)]$.

This implies that the return on the investment opportunity equals the expected gain from holding the option, which in turn depends on the future value of the commodity. As stated earlier, it is assumed that the expected present value of the investment V develops according to a combined geometric Brownian motion and Poisson jump process of the structure

(9) $dV = \alpha V dt + \sigma V dz - V dq$.

The term Vdq is the Poisson jump process, defining the probability of the agro-terrorism event occurring during an extremely small interval of time, dt. If dq and dz are independent, then dq can be defined as

(10) $dq = \begin{cases} 0 \text{ with probability } (1 - \lambda) \\ \phi \text{ with probability } \lambda, \end{cases}$

where ϕ is the percentage by which q will change if the agro-terrorism event or Poisson occurs ($0 \leq \phi \leq 1$). The firm quits operating and continues to remain closed if $\phi = 1$. Hence in the Bellman equation (8), dF can be expanded using Ito's lemma. This is used for the differentiation of stochastic processes. Now an expression in terms of dV is obtained

$$\rho F(V)dt = E\left[F'(V)dV + \frac{1}{2}F''(V)dV^2\right]$$

$$(11) \quad \rho F(V)dt = \alpha VF'(V)dt + \frac{1}{2}\sigma^2 V^2 F''(V)dt - \lambda[F(V) - F((1-\phi)V)]dt$$

$$0 = -(\rho + \lambda)F(V) + \alpha VF'(V) + \frac{1}{2}\sigma^2 V^2 F''(V) + \lambda F((1-\phi)V).$$

This second order homogeneous differential equation is solved for the value of the investment opportunity, F(V), subject to the following constraints

$$F(0) = 0$$

$$(12) \quad F(V^*) = V^* - K$$

$$F'(V^*) = 1$$

where V^* is the optimal expected net present value of the project. Numerical simulation methods with Risk Optimizer (Palisade Corporation, 1998b) were used to obtain V^* because of uncertainty in returns and prices that result from agro-terrorism. Risk-neutral valuation techniques are used to estimate the real-option values for all economic entities along the milk supply chain using a portfolio of options framework.

"Tomato Garden" Option Space Framework

The "tomato garden" option space model, also known as the portfolio of options, involves the estimation of two variables: the volatility matrix (product of square root of time and the standard deviation of the NPV) and the value-to-cost matrix (ratio of the NPV of the agro-terrorism investment to the cost of the investment). Both variables are graphed into a two-dimensional illustration called the option space. The value-to-cost variable contains all of the data normally detained in NPV and real-option problems, but adds the time value of being able to postpone the investment. The volatility variable measures how much the condition of the world can change before an investment decision must be made.

The option space is portrayed by these two variables, with volatility on the vertical axis and NPV/cost on the horizontal axis (Figure 3.1) (Luehrman, 1998).

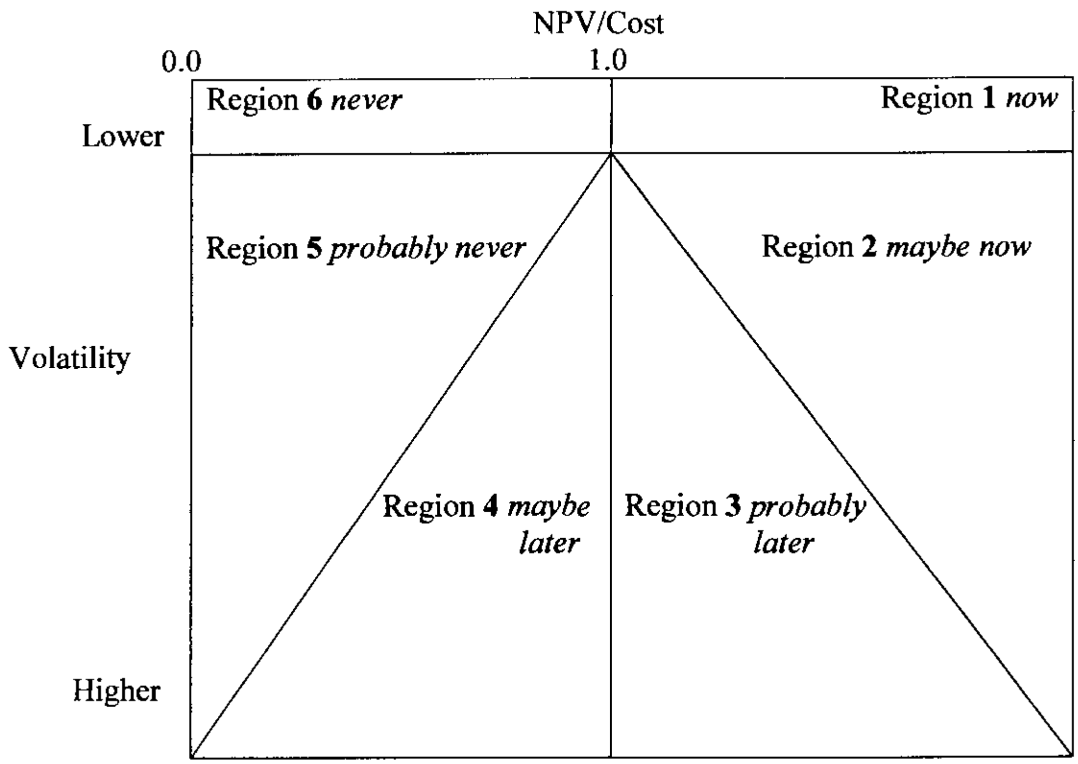

Figure 3.1. "Tomato Garden" Option Space Framework. Source: Luehrman (1998).

Typical NPV models used in real-options formulations provide only two options: invest or do not invest. By extending the real-option analysis into the portfolio of options framework, the investor has the added advantage of having the NPV, two extra metrics, plus six possible actions that reflect what should be done right away and also indicate the likelihood that an agro-terrorism investment will be beneficial in the future. One more advantage of the portfolio of options matrix is that public investment strategies to all economic sectors of the milk supply chain can be represented as nested options.[1] The

[1] A series of options explicitly designed to affect one another (Luehrman, 1998).

nested options formulation allows the total investment on agro-terrorism to be evaluated more effectively. With this strategy, sequences of unforeseen events at alternative economic entities are allowed to be added into private or public sector investment decisions. For example, public investment may target sectors with the greatest amount of risk, evaluate how the investments in these sectors mitigate agro-terrorism risk, and then decide to invest in other sectors with the possibility to further diminish those risks (Nganje, Wilson, and Nolan, 2004). The real-option framework does not directly evaluate incentives for firms to invest in security measures, especially if their perception of risk is uncertain. We use a game-theory framework to evaluate investment incentives and derive policy implications.

Game Theory

According to Vose (2000), a step in the risk-assessment process is to develop a quantitative or semi-quantitative analysis of the risk and associated risk-management options that are available to determine optimal strategies to control risks. While the stochastic optimization and real-option sections have been used to determine where the investments would be beneficial, the game-theory section is used to determine the incentives for the entities along the milk supply chain (farmer, processor, and retailer) to invest in the optimal strategies. The game-theory framework is set up as an extensive form, sequential equilibrium game with the importer/retailer making the first move on whether to undertake the investment in security measures. The processor will then decide whether to invest as well. Last, the farmer will decide whether to invest. At each level, nature will be included as the probability of an attack on the milk logistic chain. The results of the game-theory section will allow policy makers at the firm and federal levels to understand private sector incentives to invest in security measures. The payoffs for each decision to invest (or not invest) are estimated as the change in operating returns.

The algorithm used in this model starts at λ(0) = minLam if delLam > 0, or λ(0) = maxLam if delLam < 0. It then increments according to the formula

(13) $\lambda(t+1) = \lambda(t) + \text{delLam}\ \lambda(t)^{\wedge}a$,

where λ is the probability value of investing or not investing, minLam is the minimum value of λ, maxLam is the maximum value of λ, delLam is the constant used in incrementing, t is the number of increments, and a is the exponent used in incrementing.

The framework of being a sequential equilibrium is due to the end user (retailer/importer) making the decision to invest or not invest first, and then choosing to require investments further along the supply chain. This framework was also chosen as an extensive form game because the players cannot move simultaneously. The reason is because, as security increases, the buyer and seller risks are more likely to increase, which may provide disincentives for producers to invest. Thus, the end user must require the producer to invest, or else the producer may choose otherwise.

CHAPTER 4

DATA AND SIMULATION PROCEDURES

Introduction

This chapter is divided into two sections: 1) a description of the data used for the analysis and data sources, and 2) the simulation procedures used and the assumptions made.

Data

Data were collected for the lot sizes for each of the economic entities (farm-level, processing, and retail) of the milk supply chain: tracking and data-management costs, including the lock-out tag and RFEM costs; re-cleaning costs; the quality loss costs; and milk prices. The average on-farm lot size was calculated using the number of farms and total milk cows from 2002-05 (USDA/ERS, 2006a; USDA/ERS, 2006b). The average milk produced daily, 10 gallons, was obtained from Wein and Liu (2005). The average on-farm lot size is approximately 1,200 gallons. The lot size used for the milk truck is 5,500 gallons, and the lot size for the milk silo is 50,000 gallons. The pasteurization lot size used is a uniform distribution between 50,000 gallons and 60,000 gallons. The post-pasteurization tank lot size is 10,000 gallons. The bottling for domestic user lot size equals the post-pasteurization tank lot size, and the loading lot size for the export user equals the milk truck lot size (Wein and Liu, 2005; Cooper, 2006).

The lock-out tags are placed on the trucks transporting the milk from the farm to the processing facilities. This tag is used on the manhole and the back outlet of the milk truck, and is applied after each cleaning. The tags provide security during transportation. The average cost per tag is about $0.21 (Cooper, 2006). The average cost of an RFEM unit is approximately $0.45 (Thompson, 2004). The RFEM units provide similar functioning as the lock-out tags but can be used to store data on the origin and quantity of milk from each farm or economic unit to another. They can also be programmed to relate real-time data if tampering occurs at any point along the supply chain. Re-cleaning costs occur if one of the lock-out tags is broken before the next pick-up of milk. The average re-cleaning cost is approximately $45.00 per cleaning (Cooper, 2006).

The quality loss cost consists of the recall/dumping costs and the loss sales costs. The recall/dumping costs are represented by a triangular distribution with most likely cost of $1.17/gallon. These costs are calculated using the minimum, average, and maximum prices received by farmers from 1995-2004 (USDA/NASS, 2005). The loss sales costs are based on the past contamination and sales loss incident in Hawaii, and are calculated to be approximately $0.075/gallon of contaminated milk (Smith, van Ravenswaay, and Thompson, 1988). The average pre-processing and post-processing prices of milk from 1998-2004 are $1.18/gallon and $2.84/gallon, respectively (USDA/NASS, 2005; USDL/BLS, 2005).

Testing costs, test accuracies, RFEM reliability, and the probability of contamination at each stage in the milk supply chain are assumed random and represented by distributions. Testing costs for pathogens and toxins are represented by a triangular distribution with a most likely cost of $25/test. Testing accuracies are assumed to be uniform distributions ranging between 0.9 and 1.0 (Cooper, 2006). The reliability of signaling tampering with the RFEM units is assumed to be uniformly distributed between 0.95 and 0.99 (Thompson, 2004). The probability of intentional contamination is reflected at each stage of the milk supply chain by a Poisson distribution with a mean probability of

0.01 (Nganje et al., 2006). The size of contamination, if contamination occurred, is assumed to be equal to the lot size and introduced into the milk flow at the point of occurrence. The data used are summarized in Table 4.1.

Table 4.1. Data Summarization

Variables	Distributions or Mean	Source
Lot Sizes		
Daily Milk Produced	10 gallons/milk cow	Wein and Liu (2005)
Average Number of Cows Per Farm	120 Milk Cows	USDA/ERS (2006a, 2006b)
Farm Lot Size	1,200 gallons	
Milk Truck Lot Size	5,500 gallons	Wein and Liu (2005); Cooper (2006)
Milk Silo Lot Size	50,000 gallons	Wein and Liu (2005); Cooper (2006)
Pasteurization Lot Size	RiskUniform(50000,60000)	Cooper (2006)
Post-pasteurization Tank Lot Size	10,000 gallons	Wein and Liu (2005)
Domestic Bottling Lot Size	10,000 gallons	Wein and Liu (2005); Cooper (2006)
Export Loading Lot Size	5,500 gallons	Wein and Liu (2005); Cooper (2006)
Costs and Probabilities		
Lock-out Tag Cost	$0.21/unit	Cooper (2006)
RFEM Unit Cost	$0.45/unit	Thompson (2004)
Re-cleaning Cost	$45.00/cleaning	Cooper (2006)
Recall/Dumping Costs	RiskTriang(0.93,1.17,1.63)	USDA/NASS (2005)
Loss Sales Cost	$0.075/gallon	Smith, van Ravenswaay, and Thompson (1988)
Pre-processing Price	$1.18/gallon	USDA/NASS (2005); USDL/BLS (2005)
Post-processing Price	$2.84/gallon	USDA/NASS (2005); USDL/BLS (2005)
Testing Costs	RiskTriang(15,25,35)	Cooper (2006)
Testing Accuracies	RiskUniform(0.9,1.0)	Cooper (2006)
Reliability of RFEM	RiskUniform(0.95,0.99)	Thompson (2004)
Probability of Contamination	RiskPoisson(0.01)	Nganje et al. (2006)

Real-option values are calculated for the vertically integrated milk supply chain using the data generated from the stochastic optimization model. The average discount rate used is 0.07, and sensitivities on the probability of contamination (the same probabilities as in the stochastic simulation sensitivities) are run to explore their impacts on the real-option values. Real-option values are also calculated for three major participants along the milk supply chain. These participants or economic entities are farm-level, processor, and importer/retailer. The real-option values for each of these entities are calculated similarly as in the vertically integrated milk supply chain. We assume that the farmers install RFEM and video or surveillance cameras.

Simulation Procedures and Assumptions

Three tracking strategies are evaluated with two variations of the second tracking strategy, and one is assumed to be the base strategy. Any testing conducted is assumed to be for salmonella and botulinum toxin. The base strategy consists of mandatory testing when the milk arrives at the milk plant for both the domestic and export supply chains and mandatory testing when the milk arrives at the importing facility in the export supply chain. This strategy also includes random testing elsewhere along the supply chains and does not contain the lock-out tag or RFEM unit. It is the common tracking practice in the milk supply chain.

The second tracking strategy is by implementing the lock-out tag in the domestic supply chain and the lock-out tag along with RFEM in the export supply chain. This strategy consists of mandatory testing when the milk arrives at the milk plant in the domestic and export supply chains. However, in the export supply chain, two different scenarios are examined. The first is to continue to require mandatory testing at the import facility whether the RFEM unit signals tampering, and the second is to only require mandatory testing at the import facility when the RFEM unit signals tampering. Random testing is still used for all points along the domestic and export supply chain that did not require mandatory testing.

The third tracking strategy is the one-step forward/one-step backward strategy regulation, requiring mandatory record keeping. With this strategy each sector of the domestic and export supply chains is tested to meet the specifications of the record keeping requirements and other product quality and marketing requirements. This strategy did not contain the lock-out tag or RFEM unit.

The stochastic optimization models are simulated within Risk Optimizer (Palisade Corporation, 1998b), a software program that solves optimization problems with uncertainty. The software uses a generic algorithm to identify the optimal testing and sampling strategy (where and how intensive to test) that maximizes utility for a vertically integrated milk producing firm. Each testing strategy is simulated for 5000 iterations. The generic algorithm selects successive sets of choice variables until the optimality conditions are met. The model tracks milk flows throughout the milk supply chain and provides information on buyer and seller risks and elements of the systems tracking costs.

Sensitivities are conducted to examine effects of critical parameters, like costs and risks, on the optimal strategies. These parameters include the probability of contamination, cost of the lock-out tag/RFEM, reliability of the lock-out tag/RFEM, and the cost of recalls.

The optimal NPV and standard deviation values are simulated using @Risk Decision Tool Software (Palisade Corporation, 1998a). The simulation model is iterated 5000 times for each of the domestic and export milk supply chain models, at which time the results are within optimum stopping criteria. These values are then used to determine the two main variables used for the portfolio of options framework, NPV/cost and volatility. The portfolio of options model is used to determine whether to invest and when the RFEM/alternative strategy should be implemented to reduce the most risk.

This model includes three assumptions: 1) market and food terrorism risk comprise the main sources of uncertainty about the returns from the investment; 2) large positive opportunity costs or options values could arise from these uncertainties; and 3) future returns follow a mixed Brownian motion and Poisson process in which continuous movement of the process is probably due to price and production variability while the discrete jump process can be attributed to agro-terrorism events.

CHAPTER 5

RESULTS

Stochastic Optimization Model Results

Domestic Milk Supply Chain: Base Case Results

The optimal tracking strategy for the base case is to test only where it is mandatory to test, when milk is received at the milk plant (Table 5.1). Buyer and seller risks are minimal with mean values of 1.10504 E-07% and 2.05301 E-17%, respectively. These results indicate that 1.10504 E-07% of lots entering the domestic user flows might be

Table 5.1. Domestic Model Optimal Testing Strategy Results

	Base Case Random Testing No RFEM/Tag Mandatory Testing at Milk Plant	Random Testing with Tag and Mandatory Testing at Milk Plant	OSF/OSB
Utility	1.2004	1.2004	1.2004
Test (1=yes, 0=no) and Intensity % Sampled			
On Farm	0-NA	0-NA	1-100%
Milk Silo	0-NA	0-NA	1-100%
Pasteurization	0-NA	0-NA	1-100%
Post-Pasteurization	0-NA	0-NA	1-100%
Bottling	0-NA	0-NA	1-100%
Milk Plant-Truck No Signal	1-100%	1-100%	1-100%
Milk Plant-Truck Signal	NA	1-100%	NA
Buyer Risk	1.10504E-07	1.11372E-07	1.19377E-07
Seller Risk	2.05301E-17	2.05959E-17	5.32244E-07
Costs ($/gal)			
Cost of Testing	0.004545452	0.004545452	0.035793613
Cost of Tag	0	7.63637E-05	0
Cost of Re-cleaning	3.43173E-11	3.43173E-11	3.43173E-11
Cost of Quality Loss	0	0	1.83705E-06
Certainty Equivalent ($/gal)	0.004545452	0.004621816	0.035795458
Comparison to Base Case	NA	0.0000763637	0.031250006

NA = not applicable.

contaminated (buyer risk) and 2.05301E-17% of the lots might be rejected (seller risk). Average systems costs for conducting random testing for pathogens, re-cleaning, and quality loss are $0.004545452/gallon, $3.43173E-11/gallon, and $0.00/gallon, respectively. The certainty equivalent is $0.004545452/gallon, indicating that the decision maker would require a premium of approximately $0.005/gallon to be indifferent between this system and one with no testing.

Domestic Milk Supply Chain: Lock-Out Tag System Results

In the second model, a lock-out tag system is installed on truck shipments picking up milk from the farm. A mandatory test is applied when the truck arrives at the milk plant, and a mandatory re-cleaning is applied when the lock-out tag is broken before milk pickup.

The optimal tracking strategy for the domestic lock-out tag system is to test only when mandatory testing is required (Table 5.1). Buyer risks for the lock-out tag system average 1.11372 E-07% with a 95% confidence interval that mean values would lie between 6.54687E-08% and 1.13491E-07% (Figure 5.1). Seller risks average 2.05959E-17% with a 95% confidence interval of 4.98362E-18% to 2.59288E-17% (Figure 5.2). With the lock-out tag system, buyer and seller risks, while still minimal, are larger than those in the base case. The more security put on the supply chain, the more the risk of rejection of contaminated products. The policy implications of these results are discussed in the game-theory section.

The average costs for lock-out tags, testing, re-cleaning, and quality loss are $7.63637E-05/gallon, $0.004545452/gallon, $3.43173E-11/gallon, and $0.00/gallon, respectively. Figure 5.3 shows the distribution of quality loss costs in the domestic milk flow. The results indicate that there is a 95% confidence interval for quality loss costs to be $0.00/gallon. Figure 5.4 shows the distribution of total system costs. The results indicate that there is a 95% confidence interval for total system costs to lie between $0.004617117/gallon and $0.0046543/gallon.

Installing a lock-out tag system increases the certainty equivalent to $0.004621816/gallon from the domestic base case of $0.004545452/gallon. This indicates that the decision maker would require a risk premium of $0.0000763637/gallon to be indifferent between the lock-out tag system and the base case.

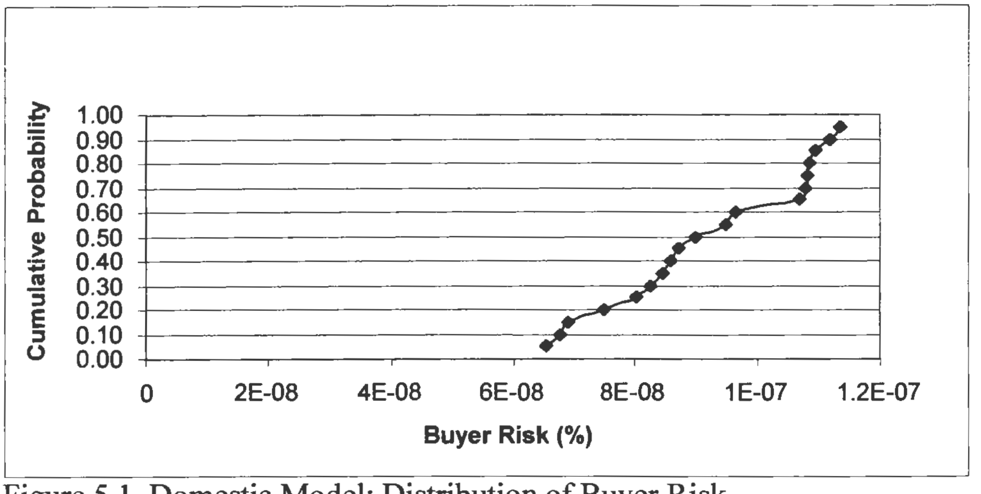

Figure 5.1. Domestic Model: Distribution of Buyer Risk.

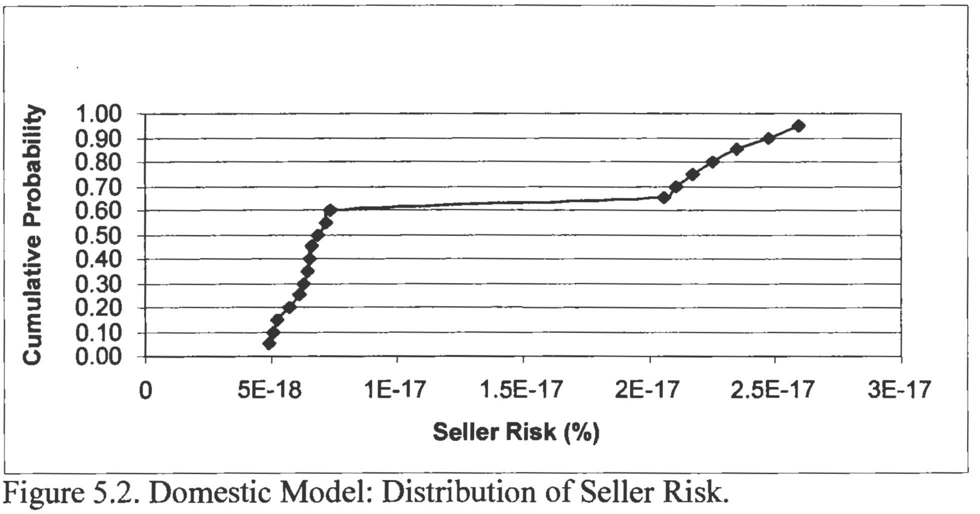

Figure 5.2. Domestic Model: Distribution of Seller Risk.

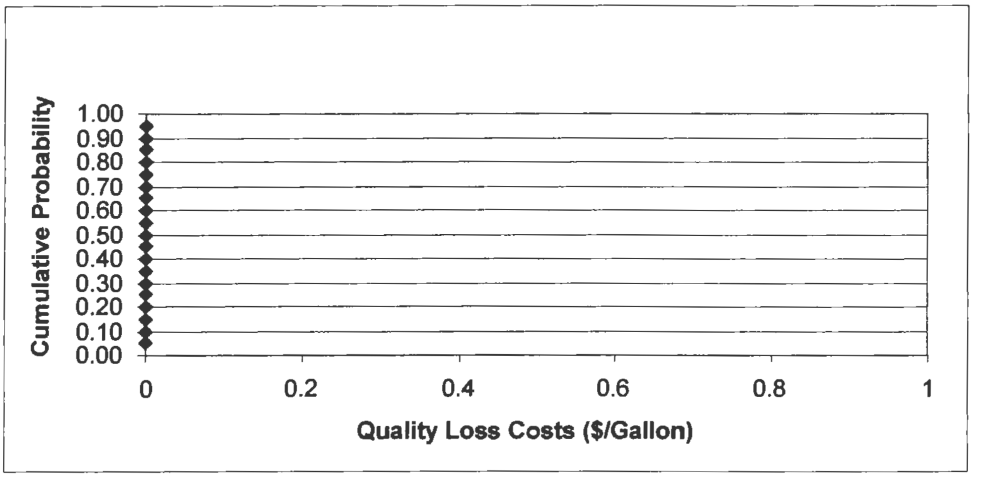

Figure 5.3. Domestic Model: Distribution of Quality Loss Costs.

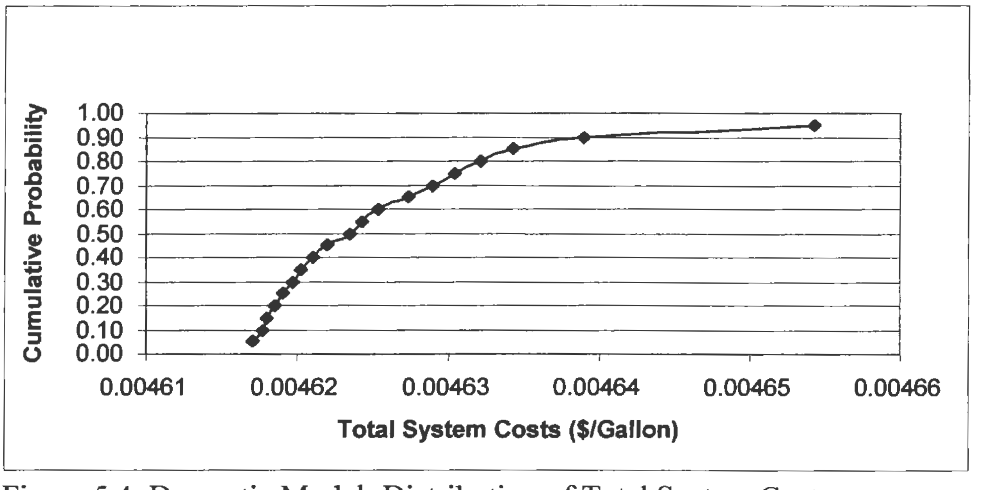

Figure 5.4. Domestic Model: Distribution of Total System Costs.

Domestic Milk Supply Chain: One-Step Forward/One-Step Backward Testing (OSF/OSB) Results

The third model simulated is one where tests are applied and information passed one-step forward and one-step backward. This requires tests on all lots along the domestic milk supply chain. No lock-out tag or RFEM system is installed. No optional testing locations are available.[2]

[2] Note: As there are no optional testing locations in this model, it is simply simulated 5000 iterations to develop distributions for outcomes.

Average buyer and seller risks are 1.19377E-07% and 5.32244E-07%, respectively (Table 5.1). Costs for the OSF/OSB system are the highest of the three domestic systems for testing and quality loss. Costs for testing, quality loss, and re-cleaning are $0.035793613/gallon, $1.83705E-06/gallon, and $3.43173E-11/gallon, respectively (Table 5.1). The OSF/OSB system has a certainty equivalent of $0.035795458/gallon and a risk premium of $0.031250006/gallon. This indicates that the tighter the security measures, the greater the risk premium. This raises several important questions about liability and loss sharing. These questions will be addressed with the game-theory model.

Comparison Across Domestic Models

The buyer risks are similar in all three systems. The seller risks are similar between the base case and the lock-out tag system, but, while still minimal, are higher in the OSF/OSB system. When comparing the costs (testing, lock-out tags, re-cleaning, and quality loss) and risk premiums, the base case has the lowest total costs and risk premium as expected, followed by the lock-out tag system, and the OSF/OSB system has the highest total costs and risk premium. Decision makers would require a risk premium of $0.03125/gallon to be indifferent between the OSF/OSB system and the base case and $0.031173642/gallon to be indifferent between the OSF/OSB system and the lock-out tag system.

Domestic Model Sensitivities

Sensitivities are conducted for the domestic model on the probability of intentional contamination, cost of the lock-out tag, reliability of the lock-out tag, and the recall costs to determine their impact on the optimal strategies, costs, and risk premiums (Table 5.2). Alternative probabilities of contamination ranging from 0.0001 to 0.1 are examined to determine their effect. Over this range of probabilities for contamination, the optimal tracking strategy does not change. Results show that, as the probability of contamination in the supply chain increases, buyer risks, seller risks, and certainty equivalents increase, but minimally.

Table 5.2. Domestic Model Sensitivities

Probability	Base Case Pr 0.01	Pr 0.0001	Pr 0.001	Pr 0.1
Buyer Risk	1.11372E-07	1.89079E-09	1.02908E-08	1.02457E-06
Seller Risk	2.05959E-17	1.47045E-19	7.96314E-19	1.02474E-16
Certainty Equivalent ($/gal)	0.004621816	0.004621816	0.004621816	0.004621852
Cost of Tag ($/tag)	0.21	0.105	0.42	
Buyer Risk	1.11372E-07	1.11372E-07	1.11372E-07	
Seller Risk	2.05959E-17	2.05959E-17	2.05959E-17	
Certainty Equivalent ($/gal)	0.004621816	0.004583634	0.004698179	
Reliability of Tag	0.95, 0.99	0.90, 0.99	0.975, 0.99	
Buyer Risk	1.11372E-07	1.11349E-07	1.11383E-07	
Seller Risk	2.05959E-17	2.05942E-17	2.05967E-17	
Certainty Equivalent ($/gal)	0.004621816	0.004621816	0.004621816	
Cost of Recalls ($/gal)	1.245	0.9298	1.173	1.631
Buyer Risk	1.11372E-07	1.00505E-07	1.00505E-07	1.00505E-07
Seller Risk	2.05959E-17	7.63908E-18	7.63908E-18	7.63908E-18
Certainty Equivalent ($/gal)	0.004621816	0.004621812	0.004621812	0.004621812

By doubling or halving the cost of the lock-out tag, the buyer and seller risks show no change, and the certainty equivalent has minimal changes. When changing the reliability of the lock-out tag, minimal changes occur in the buyer and seller risks, and the certainty equivalent does not change. When fixing the cost of recalls to the minimum, most likely, and maximum values instead of the triangular distribution, the buyer risks, seller risks, and the certainty equivalent show minimal changes. In each of these sensitivities, the optimal testing strategy does not change. One possible explanation for the observed minimal changes is that participants may view terrorist attacks on the food supply as extreme events. Their expectation that the milk supply chain may be attacked carries more weight than the frequency of attack. Similar analyses are performed for the milk export supply chain.

Export Milk Supply Chain: Base Case Results

The export base case model also depicts a vertically integrated firm in the milk supply chain that does random testing for pathogens and toxins. This system contains no lock-out tag or RFEM unit, and mandatory testing is applied on all lots arriving at the milk plant and the importing facility.

The optimal testing strategy for the base case is to test only where it is mandatory, at the milk plant when milk is received and at the import facility when milk is received (Table 5.3). Buyer and seller risks are minimal with mean values of 1.49081E-13% and 2.22251E-23%, respectively. Average costs for conducting random testing for pathogens, re-cleaning, and quality loss are \$0.009009742/gallon, \$6.70864E-11/gallon, and \$0.00/gallon, respectively. The certainty equivalent is \$0.009009743/gallon, indicating that the decision maker would require a premium of approximately \$0.009/gallon to be indifferent between this system and one with no testing.

Export Milk Supply Chain: Results for Lock-Out Tag and RFEM

In this second model, a lock-out tag system is installed on truck shipments picking up milk from the farm, and a lock-out tag and RFEM system is installed on truck shipments from the milk plant to importing facilities. A mandatory test is applied when the truck arrives at the milk plant and at the importing facility.

Table 5.3. Export Model Optimal Testing Strategy Results

	Base Case Random Testing No RFEM/Tag Mandatory Testing at Milk Plant and Import Facility	Random Testing With RFEM/Tag Mandatory Testing at Milk Plant and Import Facility	Random Testing With RFEM/Tag Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility Only When RFEM Signals	OSF/OSB
Utility	1.2004	1.2004	1.2004	1.2004
Test (1=yes, 0=no) and Intensity % Sampled				
On Farm	0-NA	0-NA	0-NA	1-100%
Milk Silo	0-NA	0-NA	0-NA	1-100%
Pasteurization	0-NA	0-NA	0-NA	1-100%
Post-Pasteurization	0-NA	0-NA	0-NA	1-100%
Bottling	0-NA	0-NA	0-NA	1-100%
Import-No Signal	1-100%	1-100%	0-NA	1-100%
Milk Plant-Truck No Signal	1-100%	1-100%	1-100%	1-100%
Import-Signal	NA	1-100%	1-100%	NA
Milk Plant-Truck Signal	NA	1-100%	1-100%	NA
Buyer Risk	1.49081E-13	1.83304E-07	1.86531E-07	1.4908E-13
Seller Risk	2.22251E-23	1.66972E-09	1.66972E-09	7.6315E-07
Costs ($/gal)				
Cost of Testing	0.009009742	0.009009742	0.004545456	0.0422221
Cost of Tag/RFEM	0	0.000194221	0.000194221	0
Cost of Re-cleaning	6.70864E-11	6.70864E-11	6.70864E-11	6.7086E-11
Cost of Quality Loss	0	8.09505E-09	8.09505E-09	2.6285E-06
Certainty Equivalent ($/gal)	0.009009743	0.009203971	0.004739686	0.04222474
Comparison to Base Case	NA	0.000194228	-0.004270057	0.033215

The optimal testing strategy for the export lock-out tag and RFEM system is to test only when mandatory testing is required (Table 5.3). Buyer risks for the lock-out tag and RFEM system average 1.83304E-07% with a 95% confidence interval that mean values would lie between 1.54713E-07% and 2.01009E-07% (Figure 5.5). Seller risks average 1.66972E-09% with a 95% confidence interval of 2.30648E-17% to 7.47412E-09% (Figure 5.6). With the lock-out tag and RFEM system, buyer and seller risks, while still minimal, are larger than in the base case.

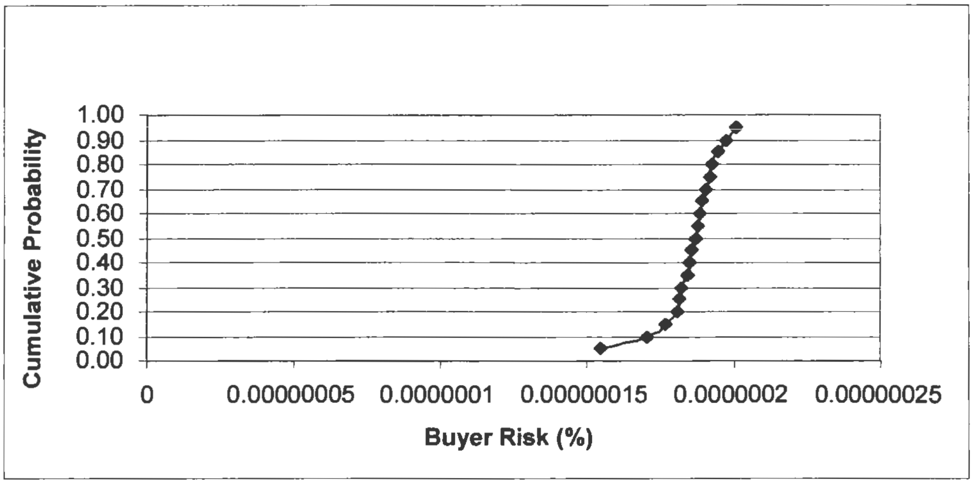

Figure 5.5. Export Model with Mandatory Testing at Milk Plant and Import Facility: Distribution of Buyer Risk.

Average costs for testing, lock-out tags and RFEM, re-cleaning, and quality loss are \$0.009009742/gallon, \$0.000194221/gallon, \$6.70864E-11/gallon, and \$8.09505E-09/gallon, respectively. Figure 5.7 shows the distribution of quality loss costs in the export milk flow. The results indicate that the quality loss costs are between \$0.00/gallon and \$3.62357E-08/gallon with a 95% confidence interval. Figure 5.8 shows the distribution of total system costs. The results indicate that the total system costs are between \$0.009180129/gallon and \$0.009224166/gallon with a 95% confidence interval.

Installing a lock-out tag and RFEM system increases the certainty equivalent to \$0.009203971/gallon from the domestic base case of \$0.009009743/gallon. This indicates

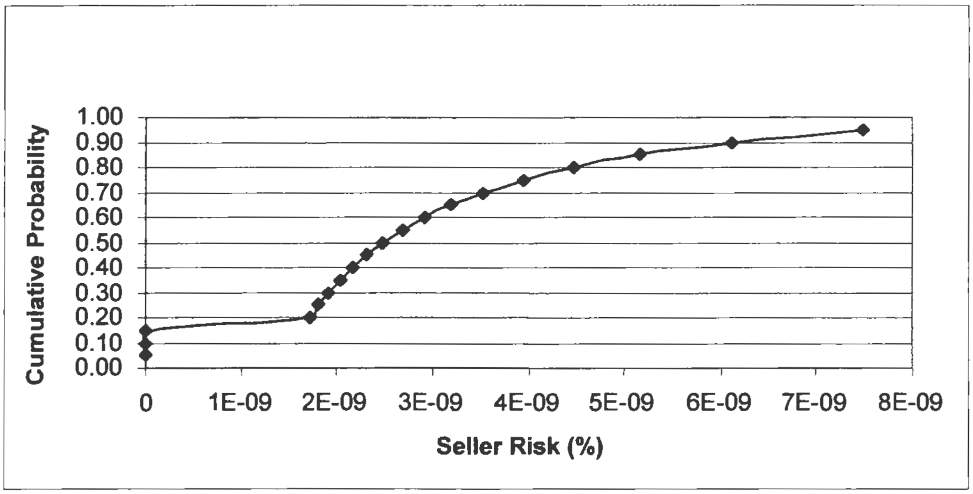

Figure 5.6. Export Model with Mandatory Testing at Milk Plant and Import Facility: Distribution of Seller Risk.

that the decision maker would require a risk premium of $0.000194228/gallon to be indifferent between the lock-out tag and RFEM system and the base case.

Export Milk Supply Chain: Mandatory Testing at Milk Plant and Import Facility Only When RFEM Signals Tampering

In this scenario, a lock-out tag system is installed on truck shipments picking up milk from the farm, and a lock-out tag and RFEM system is installed on truck shipments to importing facilities. A mandatory test is applied when the truck arrives at the milk plant, and testing at the importing facility is only mandatory when the RFEM system signals tampering.

The optimal testing strategy for the export lock-out tag and RFEM system is to test only when mandatory testing is required (Table 5.3). Buyer risks for the lock-out tag and RFEM system average 1.86531E-07% with a 95% confidence interval that mean values would lie between 1.54713E-07% and 2.03577E-07% (Figure 5.9). Seller risks average

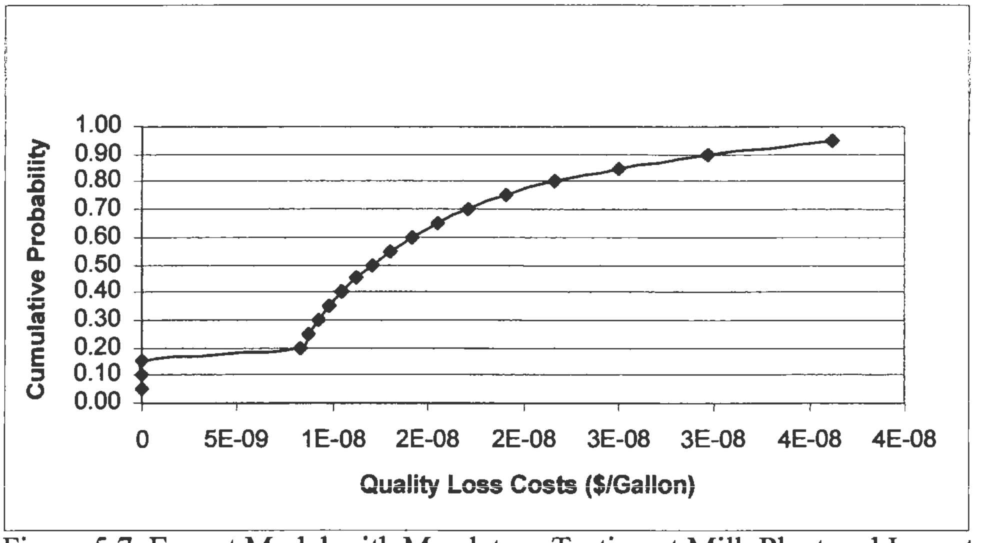

Figure 5.7. Export Model with Mandatory Testing at Milk Plant and Import Facility: Distribution of Quality Loss Costs.

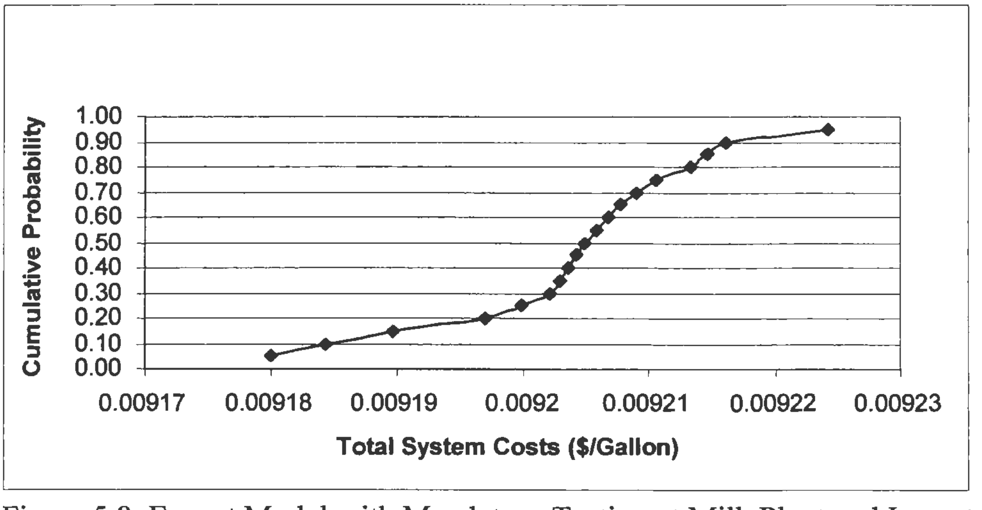

Figure 5.8. Export Model with Mandatory Testing at Milk Plant and Import Facility: Distribution of Total System Costs.

1.66972E-09% with a 95% confidence interval of 2.30648E-17% to 7.47412E-09% (Figure 5.10). With the lock-out tag and RFEM system, buyer and seller risks, while still minimal, are larger than those in the base case.

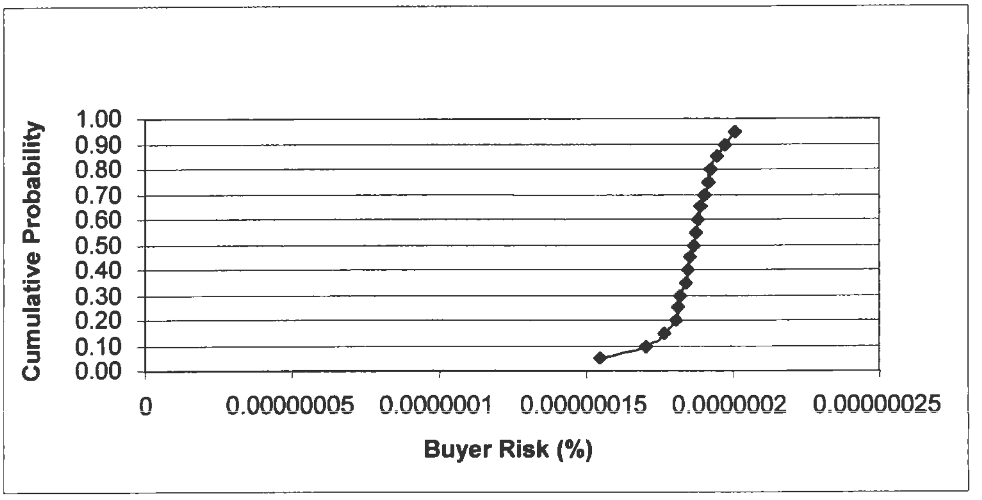

Figure 5.9. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility when RFEM Signals Tampering: Distribution of Buyer Risk.

Average costs for testing, lock-out tags and RFEM, re-cleaning, and quality loss are \$0.004545456/gallon, \$0.000194221/gallon, \$6.70864E-11/gallon, and \$8.09505E-09/gallon, respectively. Figure 5.11 shows the distribution of quality loss costs in the export milk flow. The results indicate that the quality loss costs are between \$0.00/gallon and \$3.62357E-08/gallon with a 95% confidence interval. Figure 5.12 shows the distribution of total system costs. The results indicate that the total system costs are between \$0.004705743/gallon and \$0.004740911/gallon with a 95% confidence interval. The certainty equivalent is \$0.004739686/gallon with a risk premium of negative \$0.004270057/gallon.

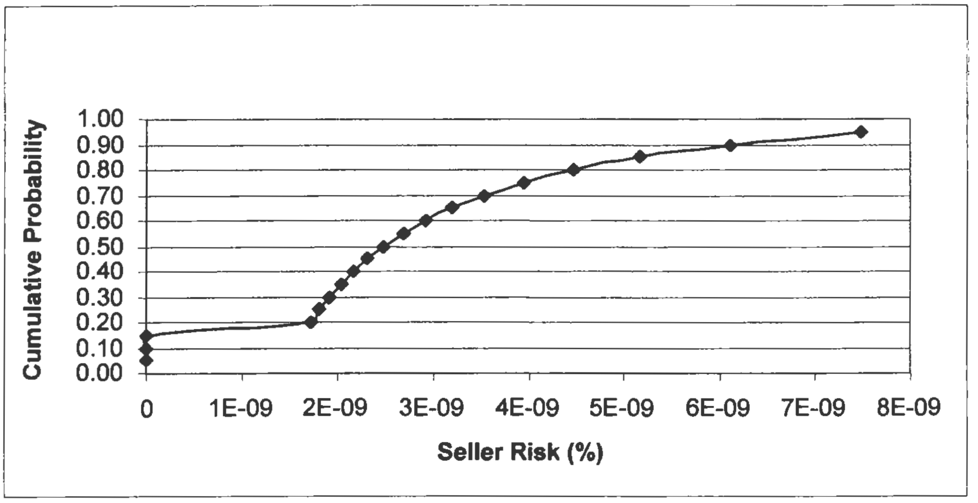

Figure 5.10. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility When RFEM Signals Tampering: Distribution of Seller Risk.

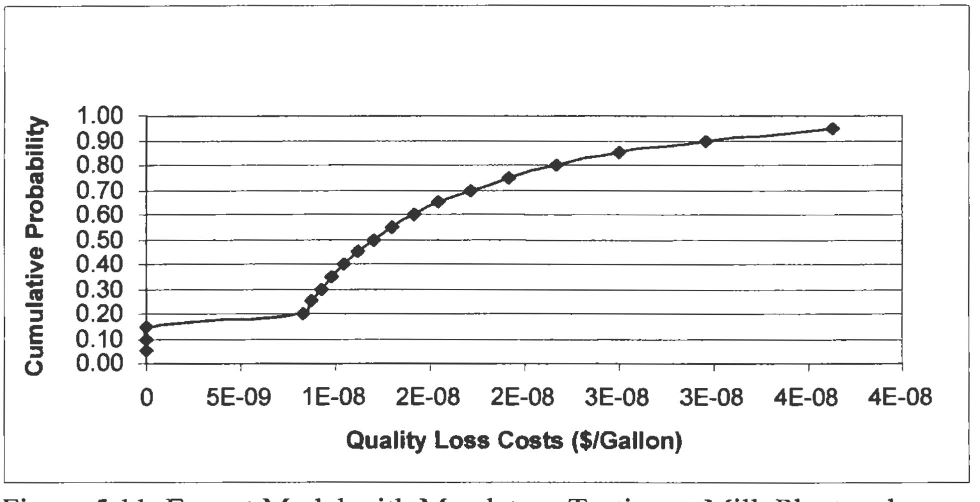

Figure 5.11. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility When RFEM Signals Tampering: Distribution of Quality Loss Costs.

Export Milk Supply Chain: One-Step Forward/One-Step Backward Testing (OSF/OSB) Results

The third tracking strategy simulated is one where tests are applied and information stored one-step forward and one-step backward. This requires tests on all lots along the

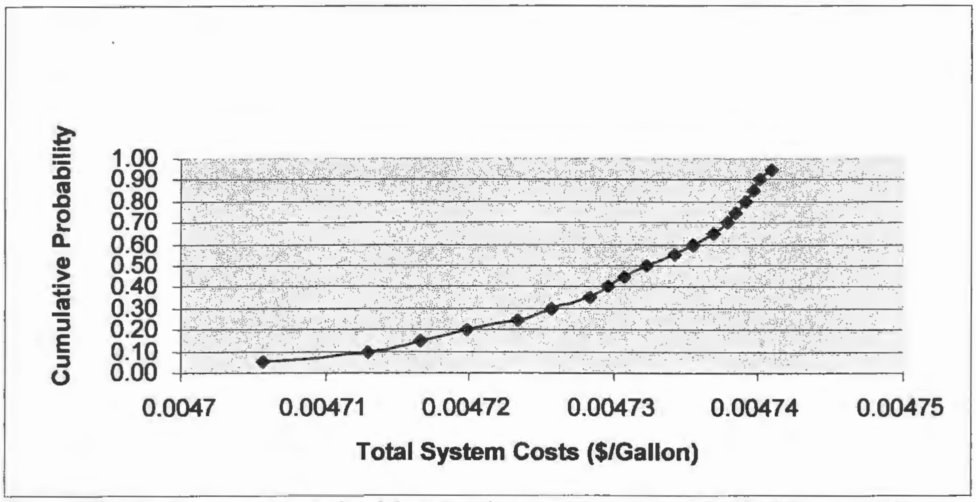

Figure 5.12. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility When RFEM Signals Tampering: Distribution of Total System Costs.

export milk supply chain in conformity with existing quality requirements. No lock-out tag or RFEM system is installed, and there are no optional testing locations.

Average buyer and seller risks are 1.4908E-13% and 7.6315E-07%, respectively (Table 5.3). Costs for the OSF/OSB system are the highest of the three export systems for testing and quality loss. Costs for testing, quality loss, and re-cleaning are $0.0422221/gallon, $2.6286E-06/gallon, and $6.7086E-11/gallon, respectively (Table 5.3). The OSF/OSB system has a certainty equivalent of $0.04222474/gallon and a risk premium of $0.033215/gallon.

Comparison Across Export Models

The buyer risks are the same in both the base case and OSF/OSB models and, while still minimal, higher in both lock-out tag and RFEM cases. The seller risks are lowest in the base case and highest in the OSF/OSB. The seller risks in both the lock-out tag and RFEM cases are the same. When comparing the costs (testing, lock-out tags and RFEM units, re-cleaning, and quality loss) and risk premiums, the RFEM system with mandatory testing at the milk plant and mandatory testing at the import facility only when the RFEM system signals tampering has the lowest total costs and risk premium, followed by the base case, RFEM with mandatory testing at the milk plant and import facility, and OSF/OSB.

Decision makers would require a risk premium of $0.000194228/gallon to be indifferent between a system with lock-out tags and RFEM units with mandatory testing at the milk plant and import facilities, and a system with mandatory testing at the milk plant and import facilities with random testing elsewhere. Decision makers would require a risk premium of $0.033020769/gallon to be indifferent between the OSF/OSB case and the lock-out tag with the RFEM system with mandatory testing at the milk plant and import facilities. However, when comparing the base case to the lock-out tag and RFEM system with mandatory testing at the milk plant and at the import facility when the RFEM signaled tampering, the lock-out tag and RFEM system shows a negative risk premium. This means that this lock-out tag and RFEM system would actually cost less than the base case system due to the reduction in testing locations.

Export Model Sensitivities

Sensitivities are run for both export models for the probability of intentional contamination, cost of lock-out tag and RFEM, reliability of lock-out tag and RFEM, and cost of recalls (Tables 5.4 and 5.5). Alternative probabilities of intentional contamination ranging from 0.0001 to 0.1 are examined to determine their effect. Over this range of probabilities for intentional contamination, the optimal tracking strategy does not change. Results show that, as the probability of contamination in the supply chain increases, buyer risks, seller risks, and certainty equivalents increase.

By doubling or halving the cost of the lock-out tag and RFEM, the buyer and seller risks show no change, and the certainty equivalent has minimal changes. When changing the reliability of the lock-out tag and RFEM, minimal changes occur in the buyer and seller risks, and the certainty equivalent does not change. When fixing the cost of recalls to the minimum, most likely, and maximum values instead of the triangular distribution, the buyer risks, seller risks, and the certainty equivalent show minimal changes. In each of these sensitivities, the optimal tracking strategy does not change.

Table 5.4. Export Model with Mandatory Testing at Milk Plant and Import Facility Sensitivities

Probability	Base Case Pr 0.01	Pr 0.0001	Pr 0.001	Pr 0.1
Buyer Risk	1.83304E-07	3.25846E-09	1.84802E-08	1.80202E-06
Seller Risk	1.66972E-09	4.85774E-19	2.75504E-18	2.27128E-08
Certainty Equivalent ($/gal)	0.009203971	0.009203964	0.009203964	0.009203986
Cost of Tag/RFEM ($/unit)	0.21/0.45	0.105/0.225	0.42/0.90	
Buyer Risk	1.83304E-07	1.83304E-07	1.83304E-07	
Seller Risk	1.66972E-09	1.66972E-09	1.66972E-09	
Certainty Equivalent ($/gal)	0.009203971	0.009106861	0.009398192	
Reliability of RFEM	0.95, 0.99	0.90, 0.99	0.975, 0.99	
Buyer Risk	1.83304E-07	1.78776E-07	1.85569E-07	
Seller Risk	1.66972E-09	1.66972E-09	1.66972E-09	
Certainty Equivalent ($/gal)	0.009203971	0.009203971	0.009203971	
Cost of Recalls ($/gal)	1.245	0.9298	1.173	1.631
Buyer Risk	1.83304E-07	1.85756E-07	1.85756E-07	1.85756E-07
Seller Risk	1.66972E-09	3.33942E-10	3.33942E-10	3.33942E-10
Certainty Equivalent ($/gal)	0.009203971	0.009203969	0.009203969	0.009203969

Table 5.5. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility When RFEM Signals Tampering Sensitivities

Probability	Base Case Pr 0.01	Pr 0.0001	Pr 0.001	Pr 0.1
Buyer Risk	1.86531E-07	3.25846E-09	1.84802E-08	1.82276E-06
Seller Risk	1.66972E-09	4.85774E-19	2.75504E-18	2.27128E-08
Certainty Equivalent ($/gal)	0.004739686	0.004739678	0.004739678	0.004739867
Cost of Tag/RFEM ($/unit)	0.21/0.45	0.105/0.225	0.42/0.90	
Buyer Risk	1.86531E-07	1.86531E-07	1.86531E-07	
Seller Risk	1.66972E-09	1.66972E-09	1.66972E-09	
Certainty Equivalent ($/gal)	0.004739686	0.004642575	0.004933907	
Reliability of RFEM	0.95, 0.99	0.90, 0.99	0.975, 0.99	
Buyer Risk	1.86531E-07	1.81937E-07	1.88829E-07	
Seller Risk	1.66972E-09	1.66972E-09	1.66972E-09	
Certainty Equivalent ($/gal)	0.004739686	0.004739686	0.004739686	
Cost of Recalls ($/gal)	1.245	0.9298	1.173	1.631
Buyer Risk	1.86531E-07	1.85756E-07	1.85756E-07	1.85756E-07
Seller Risk	1.66972E-09	3.33942E-10	3.33942E-10	3.33942E-10
Certainty Equivalent ($/gal)	0.004739686	0.00473968	0.00473968	0.00473968

Comparison Between Domestic and Export Supply Chains

The results of both the domestic and export supply chains indicate that no random testing is done. The buyer risks tend to be higher in the domestic model while the seller risks tend to be higher in the export model, however, these risks are minimal in both cases. The testing costs and certainty equivalent are lower in the domestic model due to the smaller amount of testing locations and reduced number of tags along the supply chain.

Summary of Core Findings for Objective One

The core findings from objective one show that, as the probability of attack increases, the certainty equivalent and risk premium either do not change or change minimally. This could be caused by the perception of the public that the different probabilities of an attack are not viewed as important as whether there is an attack. The buyer and seller risks also change minimally when the probability of attack changes, but do increase when the probability increases. However, the change in buyer and seller risks could lead to possible moral hazard issues. Findings also show that the alternative tracking strategies cost less than the current record-keeping procedures to implement. These results show a potential for real-time tracking and containment strategies along the milk supply chain.

The stochastic optimization results quantify the systems cost and risk premium. However, these results do not suggest where along the supply chain investments in security measures will reduce the most risks. These will be addressed with the real-option analysis.

Real-Option Model Results

Real-option results compare the cost and benefits, or value, of risk reduction over time and space. Recall that investment opportunities exist when adopting alternative tracking strategies. These opportunities enable firms to decrease variability of income or increase expected value of returns. From the NPV perspective, the increased expected values are compared with the systems costs of the alternative tracking technologies. The results are presented in two main sections: 1) an integrated firm that sells milk to the domestic and export markets and 2) major participants (farmer, processor, and retailer) along the milk supply chain. The reason for this separation is to show the results for both a firm that is vertically integrated in the milk supply chain and a milk supply chain that has the major participants operating together, but are not vertically integrated under the same company.

Vertically Integrated Domestic Milk Supply

Simulated real-option values for the base case model with a probability of contamination of 0.01 indicate that the average NPV is \$1,591,745. The NPV/cost of the model is calculated to be 1.27 with a volatility of 0.0204. Sensitivity analyses are conducted for probabilities of intentional contamination (0.0001, 0.001, and 0.1). The simulated real-option values for these sensitivities indicate that the average NPV is \$1,390,809, \$1,590,364, and \$822,298, respectively (Table 5.6). The corresponding NPV/cost for these probability ranges is 1.11, 1.27, and 0.66, respectively. The corresponding volatility values are calculated to be 0.0187, 0.0249, and 0.0058, respectively. The system cost for the tracking strategy is \$1,252,671, based on the model with tag and RFEM installed.

Table 5.6. Domestic Model: Real-Option Results

	NPV	Cost	NPV/Cost	Volatility
Base Case Pr. 0.01	\$1,591,745	\$1,252,671	1.27	0.0204
Pr. 0.0001	\$1,390,809	\$1,252,671	1.11	0.0187
Pr. 0.001	\$1,590,364	\$1,252,671	1.27	0.0249
Pr. 0.1	\$822,298	\$1,252,671	0.66	0.0058

Vertically Integrated Export Milk Supplier with Mandatory Testing at Milk Plant and Import Facility with RFEM Installed

The real-option values for the base case model with a probability of contamination of 0.01 indicate that the average NPV is \$2,541,260, with a corresponding NPV/cost value of 1.56 and a volatility value of 0.0023 (Table 5.7). The probability of contamination of 0.0001, 0.001, and 0.1 are used to evaluate the sensitivities for this model. The simulated real-option values indicate that the average NPV with these probabilities are \$2,033,066, \$2,371,304, and \$2,541,172, respectively. The calculated NPV/cost values are 1.25, 1.46, and 1.56, respectively, and the volatility values are 0.0028, 0.0042, and 0.0024, respectively. The system costs for the export milk supply chain is $1,628,486.

Table 5.7. Export Model with Mandatory Testing at Milk Plant and Import Facility: Real-Option Results

	NPV	Cost	NPV/Cost	Volatility
Base Case Pr. 0.01	$2,541,260	$1,628,486	1.56	0.0023
Pr. 0.0001	$2,033,066	$1,628,486	1.25	0.0028
Pr. 0.001	$2,371,304	$1,628,486	1.46	0.0042
Pr. 0.1	$2,541,172	$1,628,486	1.56	0.0024

Vertically Integrated Export Milk Supplier with Testing Required When RFEM Signals Tampering

The real-option values for the 0.01 probability of contamination base case model indicate that the average NPV for this model is $2,802,377 with a NPV/cost value of 1.72 and a volatility value of 0.0047 (Table 5.8). The probability of contamination sensitivity values of 0.0001, 0.001, and 0.1 are also used in this model. The simulated real-option values for these sensitivities indicate that the average NPV are $2,338,992, $2,938,368, and $2,799,089, respectively. The corresponding NPV/cost values are 1.44, 1.80, and 1.72, respectively, with volatilities of 0.0024, 0.0048, and 0.0047, respectively. The investment costs for this model are the same as in the previous export model with a cost of $1,628,486.

Table 5.8. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility When RFEM Signals Tampering: Real-Option Results

	NPV	Cost	NPV/Cost	Volatility
Base Case Pr. 0.01	$2,802,377	$1,628,486	1.72	0.0047
Pr. 0.0001	$2,338,992	$1,628,486	1.44	0.0024
Pr. 0.001	$2,938,368	$1,628,486	1.80	0.0048
Pr. 0.1	$2,799,089	$1,628,486	1.72	0.0047

Vertically Integrated "Tomato Garden" Results

The next step in the results process is to use the calculated NPV/cost and volatility values from the simulated real-option results and graph them into the "tomato garden" framework to determine where and when investment in alternative tracking strategies will reduce the most risk or be cost-effective. By examining the base case value of 0.01 for probability of contamination among all three scenarios (Figure 5.13) in the portfolio of options, the results indicate that in each of the scenarios the values fall into the area where the investment strategy would be beneficial to implement now.

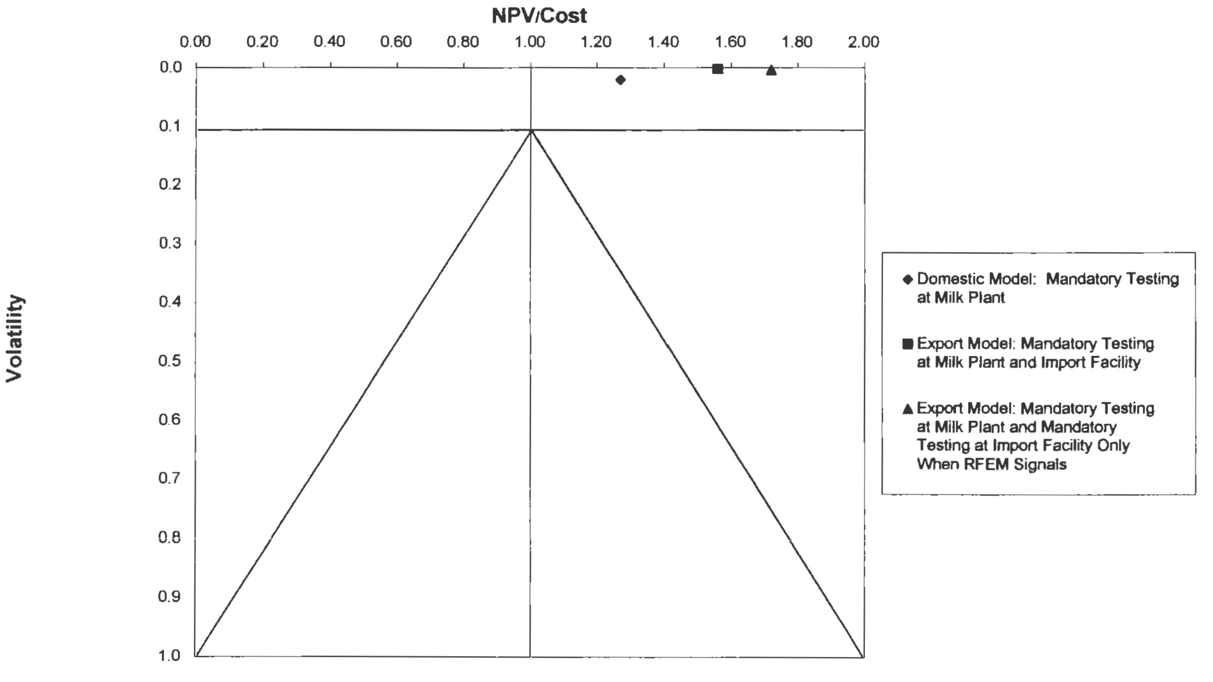

Figure 5.13. "Tomato Garden" Option Space Framework: Base Case Model with Probability of Contamination of 0.01.

The sensitivity results graphed in the "tomato garden" framework for the probability of contamination of 0.0001 (Figure 5.14) and probability of contamination of 0.001 (Figure 5.15) are similar to the base case. These results indicate that in each of the three scenarios the values fall into the area where the investment strategy would be beneficial to implement now. The sensitivity results for the probability of contamination of 0.1 (Figure 5.16) show a change from the base case scenarios. In this sensitivity the results for both export scenarios indicate that the values fall into the area where the investment strategy would be beneficial to implement now, but the domestic scenario results indicate that the values fall into the area where the investment strategy will never be beneficial if implemented.

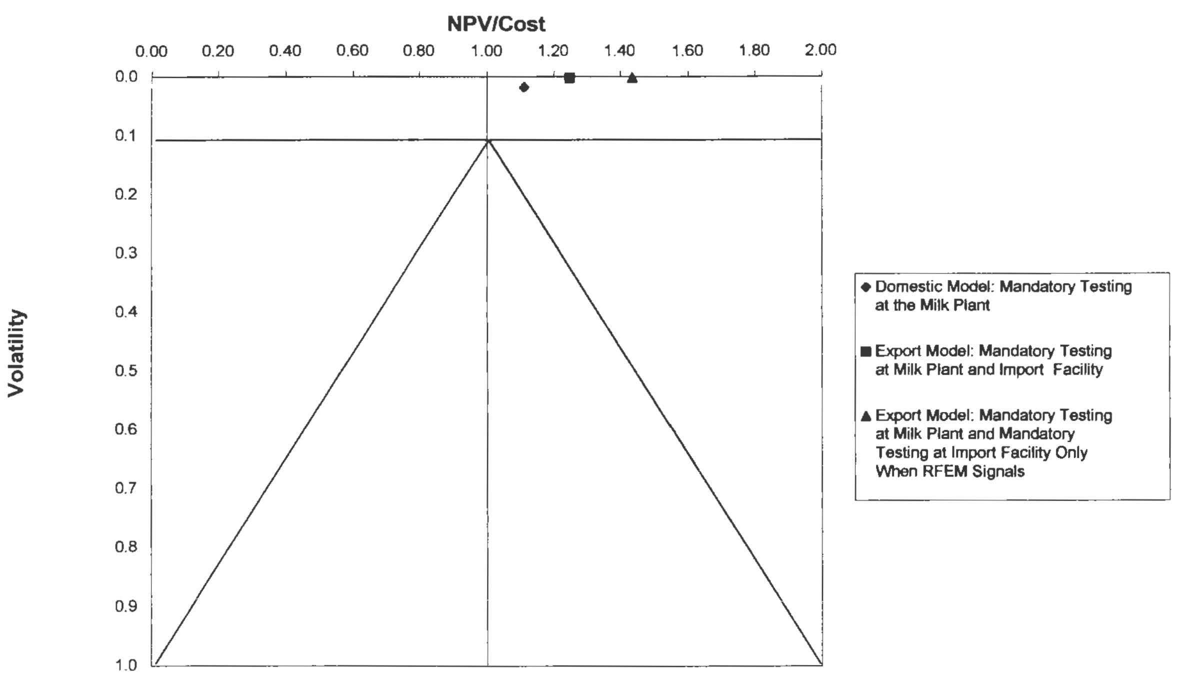

Figure 5.14. “Tomato Garden” Option Space Framework: Probability of Contamination of 0.0001.

Results may seem counter intuitive, suggesting that, as risk or probability of attack increases, a vertically integrated domestic firm will not invest in security measures. However, theory suggests that firms can afford to spend on security measures until the

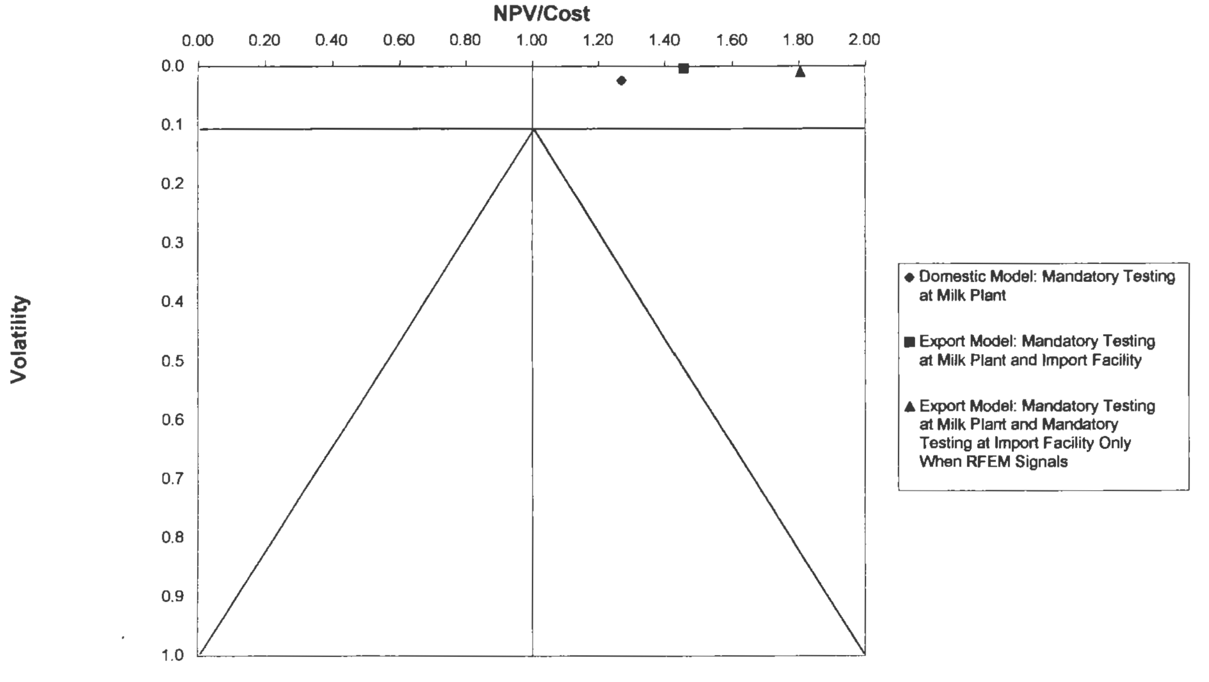

Figure 5.15. "Tomato Garden" Option Space Framework: Probability of Contamination of 0.001.

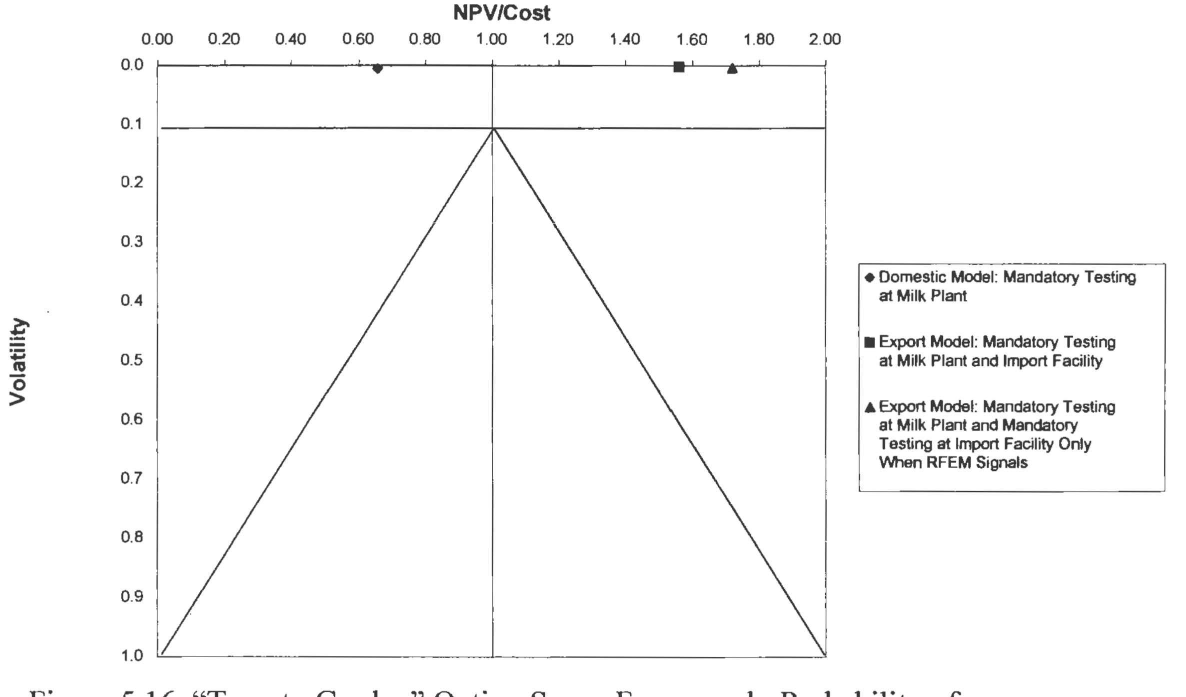

Figure 5.16. "Tomato Garden" Option Space Framework: Probability of Contamination of 0.1.

marginal benefits are equal to the marginal cost. When costs are greater than benefits from investments, this might suggest the need for external incentives. As the probability of attack increases significantly, public and private efforts may be required to mitigate food terrorism risks. This may be especially true to protect domestic consumers against food terrorism events. This also provides a justification for public sector spending to mitigate food terrorism events.

Real-Option Results for Major Participants Along the Milk Supply Chain

Simulated real-option values at the farm-level indicate that the NPV is $107,067 with a NPV/cost ratio of 3.59 and a volatility of 85,571 (Table 5.9). The simulated real-option values for the processor level indicate that the NPV for the processor is $6,090,714 with a NPV/cost ratio of 102.12 and that the volatility is 4,658,444. The importer/retailer simulated real-option value is $5,525,148 with a volatility of 4,621,554 and a NPV/cost ratio of 92.64.

Table 5.9. Non-Vertically Integrated Supply Chain: Real-Option Results

	NPV	Cost	NPV/Cost	Volatility
Producer	$107,067	$29,820	3.59	85571
Milk Plant/Processor	$6,090,714	$59,640	102.12	4658444
Importer	$5,525,148	$59,640	92.64	4621554

Similar "tomato garden" graphs are drawn for the major participants, as in Figures 5.13-5.16. By examining the calculated values of NPV/cost and volatility from the real-option values for each entity, the analysis indicates that, for the farm-level producer, the values fall into the area where it would be beneficial to implement the investment strategy now. For the processor and importer/retailer, the values indicate that the investment strategy would be beneficial probably later (Figure 5.17).

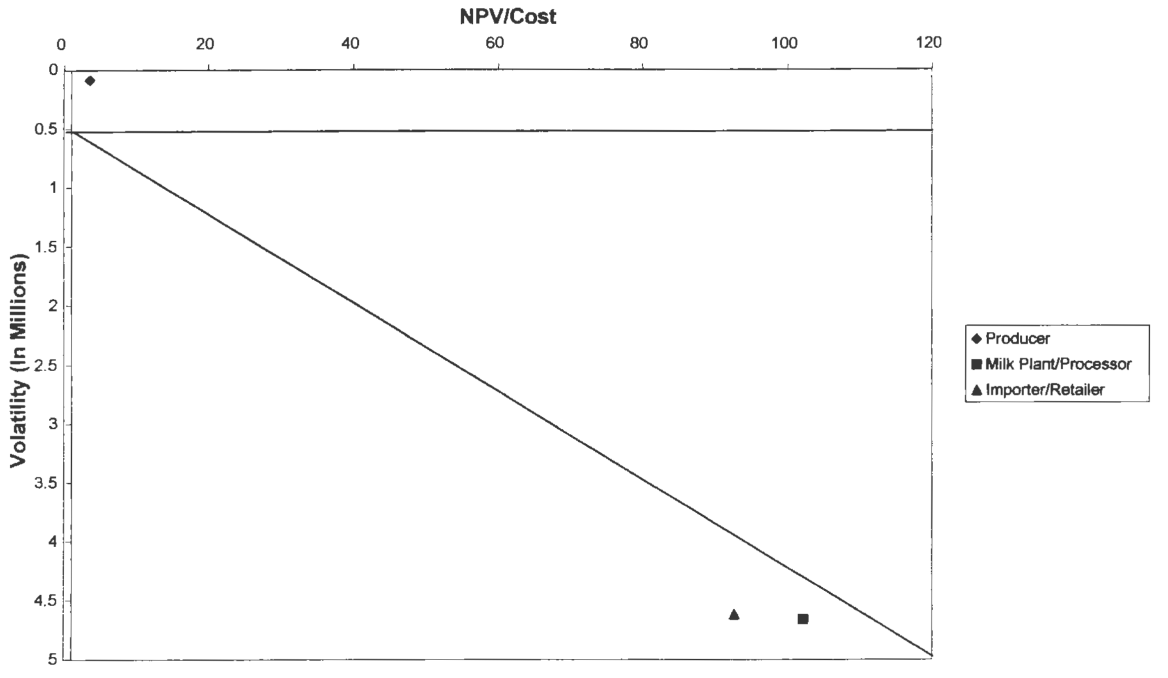

Figure 5.17. "Tomato Garden" Option Space Framework: Non-Vertically Integrated Supply Chain.

Summary of Core Findings for Objective Two

The results from the stochastic optimization models indicate that increased security measures will lead to higher costs and increased risk premiums. It is also noted that an increase in the probability of intentional contamination does not significantly increase the risk premium, possibly because these are extreme occurrences. The real-option results suggest that, in the vertically integrated supply chains, it would be beneficial for the domestic and export suppliers to invest in security measures now to reduce the most risk, with the exception that the domestic suppliers should never invest when the probability of attack is 0.1. In the non-vertically integrated supply chain, farmers should invest in security measures now to reduce the most risk, and the milk plant/processor and importer/retailer should probably invest later. However, farmers may be concerned about liability issues and tracking contamination back to their farms. The game-theory model is used to determine which sector(s) or incentives will induce participants to invest in security measures.

Game-Theory Results

Three parameters are used to evaluate incentives: 1) the perception of the probability of intentional contamination, 2) costs of emerging tracking technologies, and 3) price discounts representing decreased consumer confidence in the event of an attack on the milk supply.

An extensive form game is developed and solved for a sequential equilibrium. Gambit Software (McKelvey, McLennan, and Turocy, 2003) is used to derive solutions for the model. For this problem, the importer/retailer chooses either invest or not invest. After a decision is made, nature moves next with a chance node of either having an agro-terrorist attack or not having an attack. Next, the processor decides to either invest or not invest, and nature again follows with whether there is an attack. Finally, the farmer chooses to invest or not invest, and again, this is followed by whether there is an attack. Figures 5.18 and 5.19 show the entire decision tree where IMP is the importer/retailer, N is nature with a probability of attack at 0.01 and probability of not attacking at 0.99 following the base case for the stochastic optimization and real-option models, PRO is processor, FL is farm-level, A is attack, DA is do not attack, I is invest, and DI is do not invest in security measures.

The payoffs are calculated for four different scenarios each for the importer/retailer, processor, and farm-level. The first scenario is if the entity did not invest and no attack occurred. This payoff is zero in the base case due to no change in the current operations

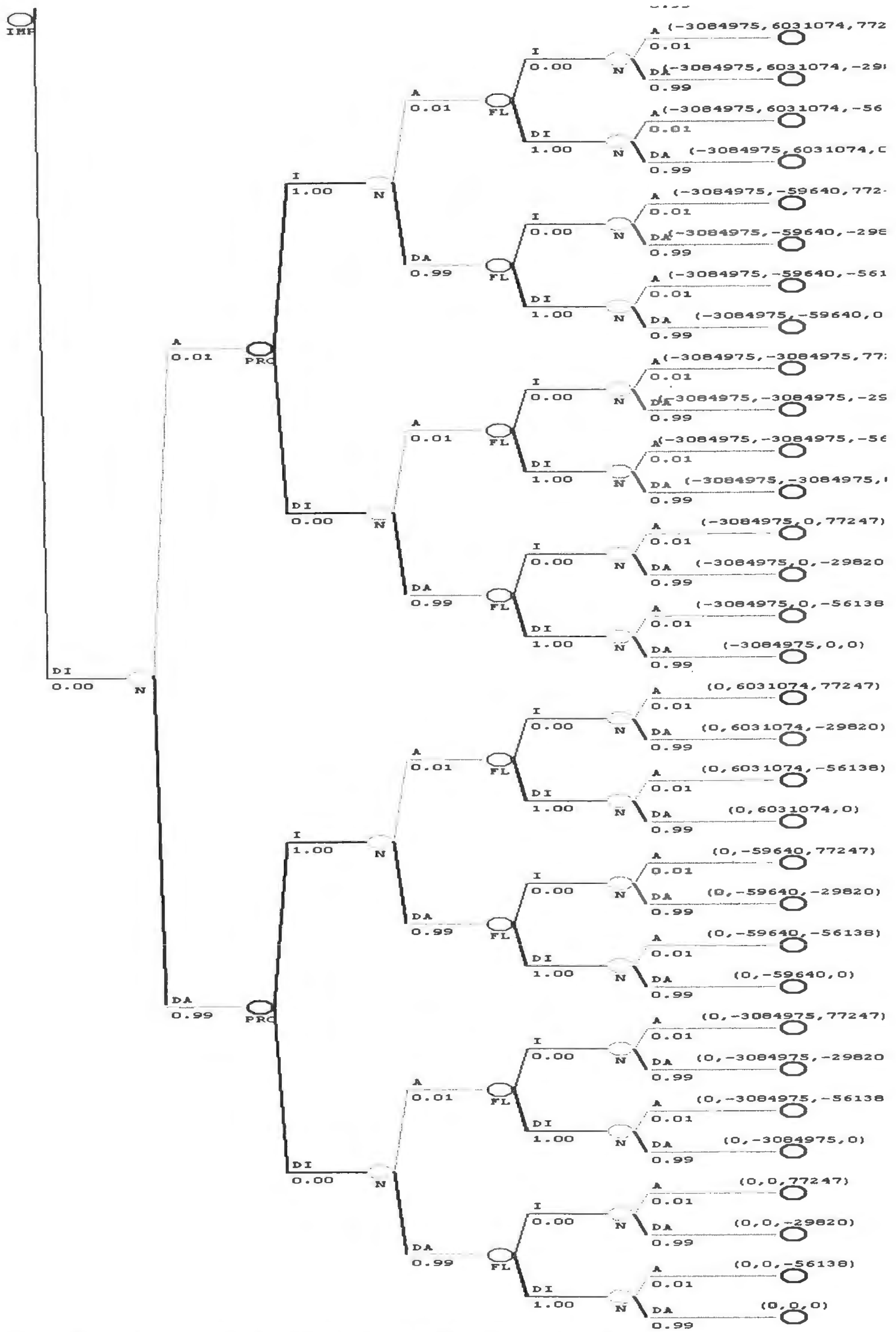

Figure 5.18. Enlarged Image of Top Half of Decision Tree.

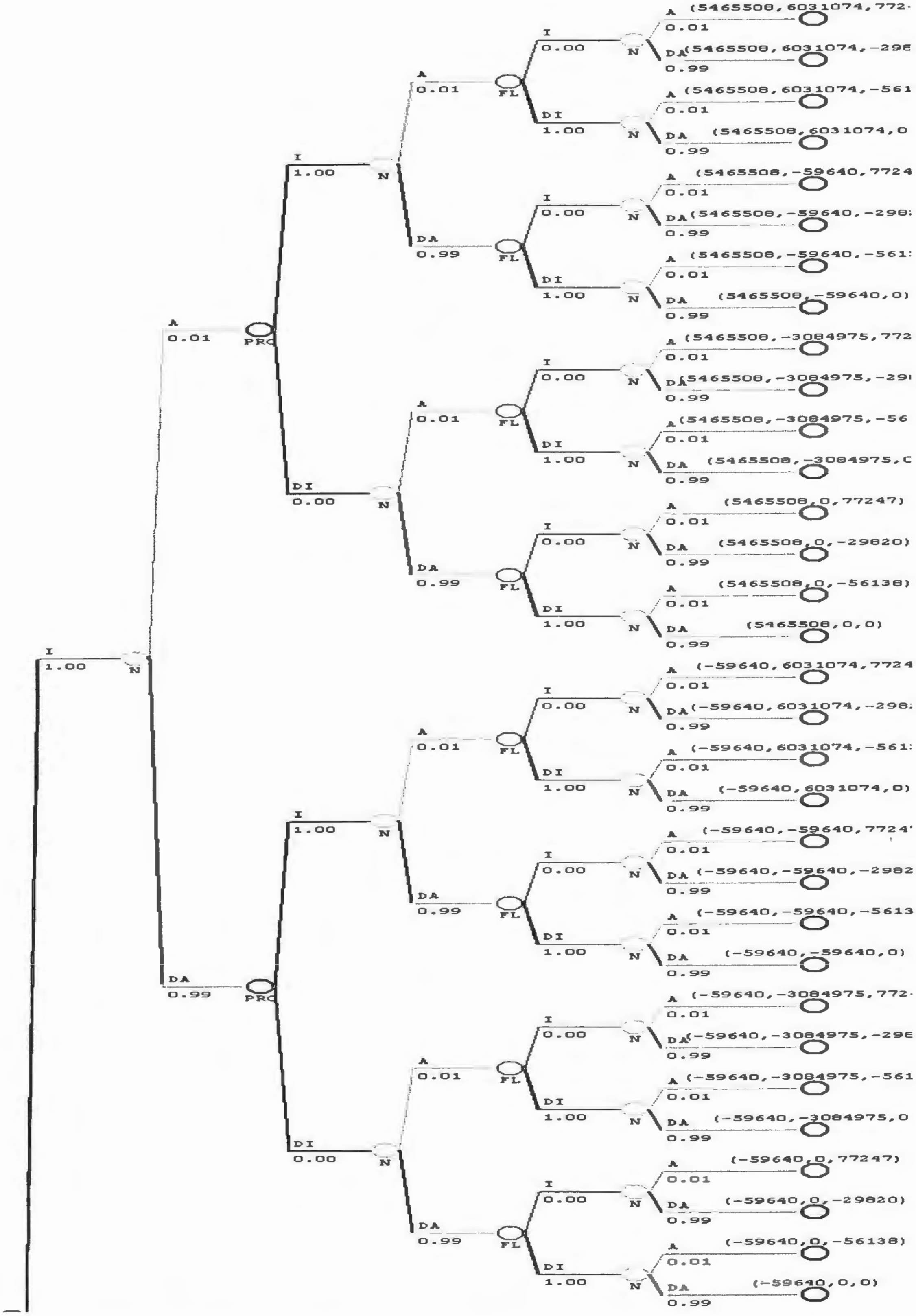

Figure 5.19. Enlarged Image of Bottom Half of Decision Tree.

for each entity. The next scenario is if the entity did not invest and an attack did occur. The payoff is calculated by using the reduction in total milk and the decrease in prices due to loss of revenue from an attack and decreased consumer confidence, which resulted in a negative payoff. The third scenario is if the entity did invest but an attack did not occur. This is calculated by the total costs of investing in a security measure. The result is a negative payoff. The last scenario is if the entity invested and an attack did occur. This payoff is calculated by taking the NPV from the real-option section and subtracting the cost of investment (Smit and Ankum, 1993). The result is a positive payoff for each entity due to increasing revenue by detecting the contamination early and reducing potential economic loss due to intentional attack.

The results for the sequential problem with the probability of attacking at 0.01 and not attacking at 0.99 indicate that the importer/retailer and processor invest, but the farm-level chooses not to invest (Table 5.10). Figure 5.18 shows an enlarged image of this section of the decision tree. These results suggest that the farmers may not find it to their best interest to invest in security measures because of potential liability problems. Another explanation could be that, with the probability of contamination this low, the farm-level does not see any benefit of investing in a strategy. Sensitivities are then conducted on the probability of contamination to see if the farm-level decision not to invest changes. The first sensitivity is to have the probability of an attack be 0.1 and the probability of not having an attack be 0.9. The results of this sensitivity show the same conclusions as the base case probabilities. The next sensitivity is an extreme case with a 0.5 probability of attack and a 0.5 probability of not attacking. The results of this sensitivity show that the farm-level would invest if the probability of an attack did reach this level.

Table 5.10. Game-Theory Summarization and Sensitivity Results

	Probability of Contamination Attack	Don't Attack	Importer	Processor	Producer
Base	0.01	0.99	Invest	Invest	Don't Invest
Sensitivity	0.1	0.9	Invest	Invest	Don't Invest
Sensitivity	0.5	0.5	Invest	Invest	Invest

Sensitivity for Farm-Level Investments	Cost Variability	Farm-Level	How Often
Base	$29,820	Don't Invest	100% of time
Sensitivity	$0	Invest	76% of time
Sensitivity	10% of Base ($2982)	Don't Invest	72% of time
Sensitivity	25% of Base ($7455)	Don't Invest	98% of time

Price/gallon	Price Penalty	Attack	Don't Attack	Farm-Level	How Often
5% off	Estimated Loss	$79,186	$25,855	Don't Invest	84% of time
6% off	Estimated Loss	$83,796	$31,026	Invest	88% of time
10% off	Estimated Loss	$102,234	$51,710	Invest	100% of time

Sensitivities are also conducted on the costs of tracking technologies at the farm-level. In the base case, where the estimated costs of $29,820 are used, the farm-level chooses not to invest. The first sensitivity conducted on the estimated costs is having the costs reduced to $7,455, or approximately 25% of the original costs. The results from this show that the farm-level will choose not to invest approximately 98% of the time. The next sensitivity conducted is to reduce the costs to $2,982, or approximately 10% of the original costs. The results from this sensitivity are better, but show that the farm-level will still choose not to invest approximately 72% of the time. The last sensitivity conducted is to have the farm-level incur no implementation costs for the investment. This resulted in the farm-level choosing to invest the majority of the time; however, the investment rate is only 76%. By completely subsidizing the tracking technology at the farm-level, results show that not all farmers will invest in this technology (Table 5.10). Price discounts, however, provide different results. This penalty is a reduction in prices received by the farmer due to an attack and decreased consumer confidence.

The first price discount sensitivity conducted is to decrease the prices received at the farm-level by 5% if the farmer chooses not to make an investment in tracking technology with all else remaining the same as in the base case (Table 5.10). The results from this sensitivity indicate that with a 5% reduction in prices, the farm-level would still choose not to invest approximately 84% of the time. The next sensitivity conducted is a decrease in price by 6%. The results from this sensitivity are promising with the farm-level choosing to invest approximately 88% of the time. When prices are decreased by 10%, there is a 100% investment rate.

Summary of Core Findings for Objective Three

The game-theory model shows that price discounts and the probability of a terrorist attack may provide better incentives for farmers to invest in security measures rather than subsidizing the implementation costs. This might require extensive education campaigns to help farmers comprehend the importance and timeliness to invest in security measures to reduce risk to the milk supply chain.

CHAPTER 6

CONCLUSIONS AND IMPLICATIONS

Introduction

The first objective of this study was to determine the costs and risk premium that the private sector is willing to pay for alternative tracking strategies along the milk supply chain. The second objective was to determine where and when along the milk supply chain investments in alternative intervention strategies will reduce the most risks. The third objective of this study was to derive policy implications for the cost-effective intervention strategy and incentives for the milk supply chain using game-theory. We summarize the core findings from these objectives in this chapter.

Costs and Risk Premium of Alternative Tracking Systems

The costs and risks of the different investment strategies were analyzed using stochastic optimization. This was accomplished by using Risk Optimizer (Palisade Corporation, 1998b) and running simulations on the different strategies to determine the system's costs and risk premium associated with optimal intervention strategies for each tracking system. The results from the stochastic simulations indicated that the RFEM technology is the more cost-effective tracking strategy compared to the alternative strategies used in mitigating agro-terrorism risks along the milk supply chain. The risk premium was lower for the RFEM tracking investment strategy than in the alternative tracking strategies. In the domestic supply chain, the risk premium was \$0.000076/gallon to be indifferent between the base case and the lock-out tag tracking strategy and \$0.0358/gallon to be indifferent between the base case and the "one-step forward/one-step backward" (OSF/OSB) tracking strategy. In the export model, the risk premium was

$0.00019/gallon to be indifferent between the base case and RFEM tracking system with mandatory testing at the milk plant and import facility and $0.0332 to be indifferent between the base case and the OSF/OSB tracking strategy. However, in the RFEM tracking system with mandatory testing at milk plant and testing at the import facility only when RFEM signals tampering, the risk premium was a negative $0.00427/gallon to be indifferent from the base case, which indicates that this tracking strategy costs less than the base case.

These stochastic simulation results also indicate that in the domestic milk model the buyer and seller risks were lower with the RFEM tracking strategy compared to the OSF/OSB tracking strategy, and in both export models the seller risks were lower in the RFEM tracking strategy compared to OSF/OSB tracking. However, the buyer risks were higher in the RFEM strategy than in the OSF/OSB tracking, but in each model the results for the buyer and seller risks did not vary significantly. In each model the base case buyer and seller risks were the lowest. This indicates that as the security measures are increased the buyer and seller risks increase, which may be caused by a larger amount of rejected milk due to the increased security measures.

Where and When to Implement Investment

To determine where and when an agro-terrorism risk mitigation investment strategy would be beneficial to the milk supply chain, compound real-options in the portfolio of options framework were used. Game-theory was then used in the non-vertically integrated supply chain to determine which entity of importer/retailer, processor, or farm-level would be more likely to choose to invest in a mitigation strategy. The real-option method was used to estimate the NPV and the standard deviation of NPV for each of the investment strategies under uncertainty and the NPV/cost and volatility (standard deviation of NPV multiplied by square root of time) were then calculated. The portfolio of options was then used to determine where and when the investment strategy would be beneficial to the milk supply chain. By using the NPV/cost and volatility values in the portfolio of options the results indicated that in each of the vertically integrated supply chains it would be beneficial to implement security measures now. However, when looking at a non-vertically integrated supply chain the results indicated that it would be beneficial for the farm-level to invest now, but the importer/retail and processor should wait and probably invest later.

After determining where and when an investment would be beneficial by using the portfolio of options, game-theory was used in the non-vertically integrated supply chain for the major participants to determine which entity would most likely invest in the mitigation strategy. By using Gambit Software (McKelvey, McLennan, and Turocy, 2003) in an extensive form game and solving for a sequential equilibrium, the results indicated that the importer/retailer and processor entities would invest, while the farm-level would not invest.

Policy Implications for Investment Implementation

By analyzing the vertically integrated milk supply chain, results show that to reduce the most risk, investments in food security measures should be implemented now the majority of the times in the domestic milk supply chain, and now always in the export milk supply chain under the base case and sensitivity assumptions. Since the results of the domestic supply chain indicate that an investment in food protection measures may not always be beneficial, policy implications may be derived. These policy implications may be that the costs to the domestic milk supply chain should be partly or completely subsidized. This results from the probability of contamination being increased to 0.1. The NPV/cost decreases to below one, which results in the region of never being beneficial in the "tomato garden" option space framework. This provides justification for public sector spending to mitigate food terrorism events.

When analyzing the non-vertically integrated milk supply chain the portfolio of options suggested that the investment strategy would be beneficial to implement now for the farm-level entity and probably later for the milk plant/processor and retail/importer. However, the game-theory model indicated that the farm-level would choose not to invest and the milk plant/processor and retail/importer would choose to invest under the base case assumptions. These results suggest that the farmers may not find it to their best interest to invest in security measures because of potential liability problems and increased seller risks. Another explanation could be that when the probability of contamination is low, the farm-level does not see any benefit of investing in security measures that would cost them extra expenditures. Sensitivities were then conducted on three different incentives that would affect the farm-level decision to facilitate investments at the farm-level.

The results of these sensitivities to the non-vertically integrated supply chain showed that the probability of contamination and the price discounts tend to have a larger effect on the producers decision to invest rather than subsidizing the implementation costs to the farm-level. However, when implementing price discounts, the price reduction to the producers must be higher than the food protection implementation costs that the producers would have to bear to be an effective strategy.

The policy implications that can be assessed from these results are that extensive education campaigns might be required to help producers comprehend the timeliness and importance to invest in security measures. The education campaigns should also address where the investment strategies should be implemented to reduce the most risks.

Recommendations for Further Study

This study provides a framework to value investment strategies to mitigate possible agro-terrorism occurrences in the milk supply chain and to determine where these investments would reduce the most risks. Although the United States has one of the safest food systems in the world, some sectors of the food supply are believed to be at risk and should be evaluated as well. These include products such as produce, honey, peanut butter, seafood, infant formula, baby food, fruit juice, soft drinks, bottled water, and products that use milk as an ingredient, such as yogurt and ice cream (Acheson, 2005).

The United States has many procedures and policies which will eliminate much of the agro-terrorism risk to the food supply however; this causes a problem with implementing overall industry procedures and standards or policies and provides another area that could be evaluated. These standards and regulations also may cause a moral hazard problem. It is important to determine incentives to avoid a "free rider" problem among participants in food supply chains to maximize the effectiveness of the security measures. This may be evaluated by using game theory.

It is also recommended for further studies to be completed on the probability of contamination. This could include evaluating the probability of contamination to determine if the probability of occurrence has a higher effect on consumer reaction or if the consumers are more concerned on whether an attack happens. Also, further studies on the containment efforts of an outbreak are recommended. This would include the time interval from when an outbreak is first noticed to when the outbreak is under control.

RFEM tracking technology may be the tracking technology of the future to detect and contain outbreaks with real-time technology; however, the efficacy and reliability of this technology should be further studied as more information becomes available. Since there is no such thing as zero risk, it is important to evaluate the cost-effectiveness of different intervention strategies.

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