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Valuing Private Sector Incentives to Invest in Food Protection Measures in the Milk and Green Onion Sectors

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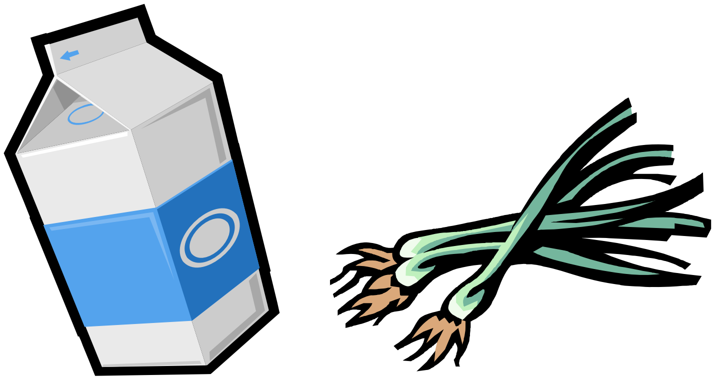

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Abstract

This study provides a framework to value investment strategies to mitigate possible agro-terrorism occurrences in the food supply chain and to determine where these investments would reduce the most risk. This framework is applied to two food sectors that could be at risk: milk and green onions. Stochastic optimization is used to determine the costs and risk premiums of alternative tracking strategies. 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 risk. 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 and green onion supply chains to invest in security measures.

Key words: agro-terrorism, stochastic optimization, real options, game theory, milk, green onions

Highlights

Agro-terrorism, or a terrorist attack on the food supply, has become a major concern since the September 11, 2001 attacks. The potential economic losses from an agro-terrorist attack would be numerous. This study provides a framework to value investment strategies to mitigate possible agro-terrorism occurrences in the food supply chain and to determine where these investments would reduce the most risk. Such a framework could be applied to any food sector at risk from agro-terrorism. In this study, the framework is applied to two products susceptible to contamination: milk and green onions. These products are investigated because of their potential for contamination and widespread damage and also because they represent both the export and import sectors as well as the domestic industry. Milk is produced in the United States for domestic consumption and export, while green onions are largely imported from Mexico.

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. However, this method may be costly and could significantly hinder global food trade. 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 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 and green onion logistic systems. The specific objectives are to 1) determine the costs and risk premiums that the private sector is willing to pay for alternative tracking strategies along the supply chain; 2) determine where and when along the supply chain investments in alternative intervention strategies will reduce the most risk; and 3) derive policy implications for the cost-effective intervention strategy and incentives for the milk and green onion supply chains using game theory.

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 supply chain and the incentives to invest in security measures. The first step is accomplished by using stochastic optimization and the expected utility framework, while the second step uses real options, the portfolio of options framework, and game theory.

Four alternative tracking strategies are analyzed: 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 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. Buyer and seller risks and risk premiums are estimated for each scenario. Buyer risk is the risk that product exceeding tolerances will get into the buyer product stream, and seller risk is the risk that product thought to be within tolerances will be rejected. The risk premium is the difference required for the investor to be indifferent between the alternative tracking strategies.

The core findings from objective one show that as the probability of attack increases, the certainty equivalent and risk premium either does not change or changes minimally. The buyer and seller risks also change minimally when the probability of attack changes, though they do increase when the probability increases. The change in buyer and seller risks, however, could lead to possible moral hazard issues. Findings also show 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. These results show a potential for real-time tracking and containment strategies.

The real option results suggest that in the vertically integrated milk supply chain, 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. 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.

When analyzing the non-vertically integrated milk supply chain, the portfolio of options suggest 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 indicates 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. Sensitivities were then conducted on three different incentives that would affect the decision to facilitate investments at the farm level. The results show that the probability of contamination and the price discounts tend to have a larger effect on the milk producer's decision to invest compared to subsidizing the implementation costs to the farm level.

In the non-vertically integrated green onion supply chain, the net present value/cost ratio is less than one for all segments of the supply chain, and the results show that the retailer and producer should never invest, and the packinghouse, warehouse, and trucking should maybe invest later. In the game theory model, the producer, packinghouse, and retailer all chose to not invest when the probability of attack is 0.01. Compared to the milk model, much greater changes in probability of contamination, investment cost, and prices received are necessary to induce investment by the segments of the green onion supply chain.

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Introduction

Agro-terrorism, or a terrorist attack on the food supply, has become a major concern since the September 11, 2001 attacks. These attacks put terrorism at the forefront of the U.S. domestic and foreign policy and made many realize the vulnerability of the U.S. economy to terrorism (Onyango, Turvey, and Hallman 2005). An attack is termed agro-terrorism if it involves the deliberate introduction of an animal or plant disease with the goal of generating fear, causing economic losses, and/or undermining stability (Monke 2004). 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). The threat to the food supply is real, as it has been discovered that Al Qaeda has studied the U.S. agricultural industry (Pistole 2006), and agriculture has several characteristics that create unique problems for managing the threat of an agro-terrorist attack (Monke 2004). A survey conducted by Stinson et al. (2006) indicates that the public sees an attack on the food sector as being 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.

The potential economic losses from an agro-terrorist attack would be numerous. Monke (2004) suggests that these losses would include 1) 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); 2) the loss of export markets as importing countries would likely place restrictions on U.S. products to prevent the possibility of the disease spreading to their countries; 3) decreased sales by agriculturally dependent businesses (farm input suppliers, transportation, food manufacturing, food service, and retail grocery) and tourism; and 4) significant costs for the government, including containment and eradication costs, and compensation to producers, processors, or retailers. Impacts on the labor markets could be severe as the agribusiness industry is among the largest employers in the United States (Cupp, Walker, and Hillison 2004). Consequently, if there is any intentional tampering by terrorists on the U.S. food system, it could cost the United States billions of dollars in order to control or stabilize the situation due to the effects on the U.S. economy, public health, and consumer confidence (Nganje et al. 2007).

This study provides a framework to value investment strategies to mitigate possible agro-terrorism occurrences in the food supply chain and to determine where these investments would

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reduce the most risks. Such a framework could be applied to any food sector at risk from agro-terrorism. In this study, the framework is applied to two products susceptible to contamination: milk and green onions. These products are investigated because of their potential for contamination and widespread damage and also because they represent both the export and import sectors as well as the domestic industry. Milk is produced in the United States for domestic consumption and export, while green onions are largely imported from Mexico.

Previous health scares related to milk and green onions illustrate the potential for human harm and economic damage. The discovery of the pesticide heptachlor in over 80% of the milk produced in Oahu, Hawaii in 1982 and the resulting drop in milk consumption showed how contamination can financially handicap the milk industry. It could also result in a number of casualties. Wein and Liu (2005) illustrate the possibility of a deadly bio-terror attack on the milk supply chain, as the botulinum toxin could be released 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. Green onions imported from Mexico were found to be responsible for large outbreaks of hepatitis A in the fall of 2003. An outbreak at a restaurant in Pennsylvania in October 2003 caused 601 people to become sick, of which 124 were hospitalized and 3 died (Wheeler et al. 2005). Previous cases of hepatitis A caused by green onion imports have also been found (Dentinger et al. 2001). Green onions require extensive handling during harvesting and preparation, which provides an opportunity for contamination, and the plant surfaces are complex and adherent to viral or fecal particles, which could also make them more vulnerable to contamination (Centers for Disease Control and Prevention 2003).

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 (Food and Drug Administration (FDA)/Center for Food Safety and Applied Nutrition (CFSAN) 2004). However, this method may be costly and could significantly hinder global food trade. The annual total record keeping cost is estimated to be $1.41 billion (FDA 2004). 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, chemical applications, disease incidence, insect infestations, and harvest dates (Thompson 2004).

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 and green onion logistic systems. The specific objectives are to 1) determine the costs and risk premiums that the private sector is willing to pay for alternative tracking strategies along the supply chain; 2) determine where and when along the supply chain investments in alternative intervention strategies will reduce the most risk; and 3) derive policy implications for the cost-effective intervention strategy and incentives for the milk and green onion supply chains using game theory.

The remainder of the paper is organized as follows. The second section details the theoretical framework utilized to meet the objectives of the paper. This framework consists of a stochastic optimization model, a real options model, the "tomato garden" portfolio of options framework, and a game theory model. The third section describes the data and simulation procedures used. Results from the stochastic optimization, real options, and game theory models are presented in the next three sections, and conclusions are discussed in the final section.

Theoretical Models

Investment decisions to mitigate agro-terrorism risk 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 frameworks 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 supply chain and the incentives to invest in security measures. The first step is accomplished by using stochastic optimization and the expected utility framework, while the second step uses real options, the portfolio of options framework, and game theory.

Stochastic Optimization Model

A stochastic optimization model of a vertically integrated firm is 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 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. 2007).

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 the farm, transport from farm to processing facility, milk silo, pasteurization, post-pasteurization tanks, bottling, and transport for export. Stages along the green onion supply chain where testing can be implemented include the farm, transport from farm to packinghouse, packinghouse, transport from packinghouse to warehouse, warehouse, transport from warehouse to retail, and retail. The model is used to estimate the certainty equivalent and quantify the risk premium for the four alternative systems. The risk premium is the difference required for the investor to be indifferent between the alternative tracking strategies. Details of the model can be found in

Appendix A. Cost and risk premium results from the stochastic optimization model 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 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 an investment is made with the intention of never having to use it, but when an attack does occur, a positive payoff is the result from the investment. The value of an option, or an investment opportunity in an agro-terrorism prevention strategy, is defined as the expected present value from investing at the optimal time (Nganje, Wilson, and Nolan 2004). Details of the real options model are provided in Appendix B.

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 5,000. 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 and green onion supply chains is scaled down and assumed to be 0.01, and sensitivities are performed for a range of probability values.

"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 net present value) and the value-to-cost matrix (ratio of the net present value of the 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 net present value (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 1) (Luehrman 1998).

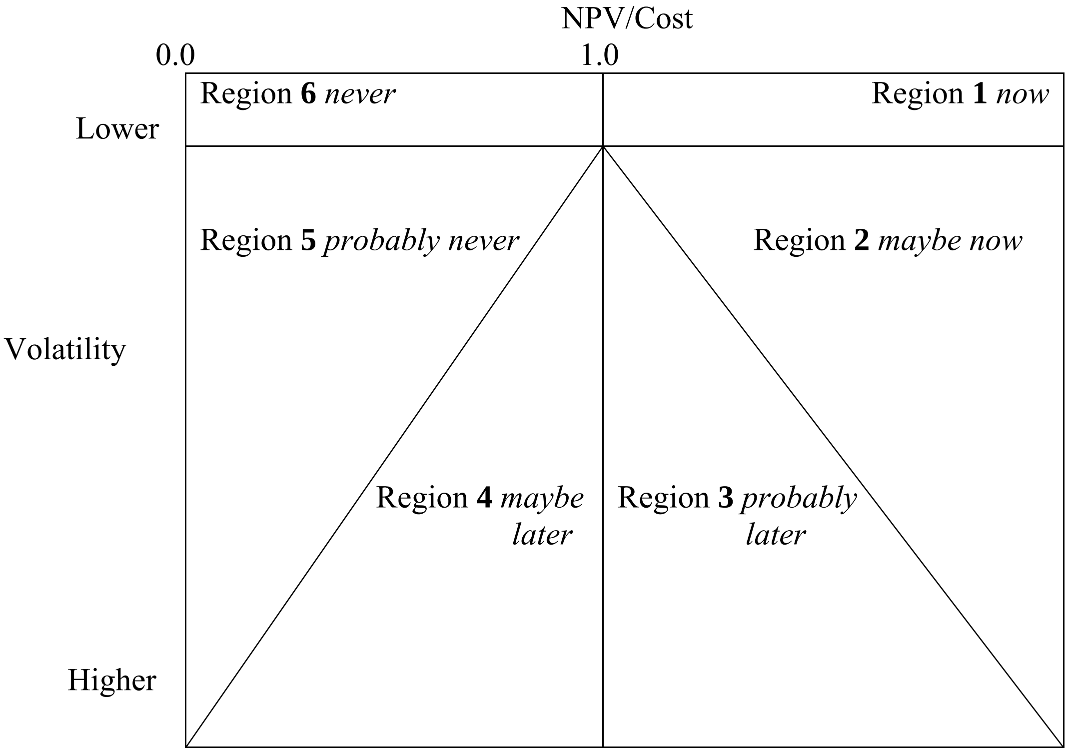

Figure 1. "Tomato Garden" Option Space Framework
Source: Luehrman (1998)

Typical NPV models used in real options formulations provide only two options: invest or don't 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 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 supply chain can be represented as nested options, which allows the total investment to be evaluated more effectively. With this strategy, a sequence of unforeseen events at alternative economic entities can be added into private or public sector investment decisions. For example, it is possible to target public investment in 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 options 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 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. Lastly, the farmer will decide whether to invest. At each level, nature will be included as the probability of an attack on the supply 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 framework of being a sequential equilibrium is due to the end user (retailer/importer) making the decision to 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 for this is that 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.

Data and Simulation Procedure

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 is calculated using the number of farms and total milk cows from 2002-05, obtained from the USDA's Economic Research Service (ERS) (2006a,b). 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. 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, which were obtained from the USDA's National Agricultural Statistics Service (NASS) (2005). The lost 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; U.S. Department of Labor/Bureau of Labor Statistics 2005).

Testing costs, test accuracies, RFEM reliability, and the probability of contamination at each stage in the 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 supply chain by a Poisson distribution with a mean probability of 0.01 (Nganje et al. 2007). The size of contamination, if contamination occurred, is assumed to be equal to the lot size and introduced at the point of occurrence.

Testing costs, test accuracies, RFEM costs and reliability, and the probability of contamination in the green onion model are the same as those in the milk model. The testing locations for green onions are the farm, packinghouse, warehouse, and retail. The lot sizes are 2,500 pounds at the farm level, 10,000 pounds at the packinghouse and warehouse, and 1,000 pounds at retail.

Data on green onion producer and retail prices were obtained from USDA/NASS (2006a,b). The average green onion producer price from 1996-2005 is 11.8 cents/lb, and the average retail price from 1998-2005 is 20.4 cents/lb. The packinghouse and warehouse prices are assumed to be 14.6 cents/lb and 17.5 cents/lb, respectively. Diversion costs are calculated by adding a 6 percent buyback cost and a 2.4 percent clearing cost to these prices, resulting in diversion costs of 12.7 cents/lb, 15.7 cents/lb, 19.0 cents/lb, and 22.1 cents/lb at the farm, packinghouse, warehouse, and retail levels, respectively. These costs are multiplied with the total volume diverted to calculate the quality loss cost for green onions.

Real options values are calculated for the vertically integrated 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 are run to explore their impacts on the real option values. Real option values are also calculated for the major participants along the supply chain.

Simulation Procedures

Three tracking strategies are evaluated. 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 chain and does not contain the lock-out tag or RFEM unit. It is the common tracking practice in the milk supply chain. The base case in the green onion model includes mandatory testing when the product is received at the retail level.

The second tracking strategy is to implement 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 or not 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. In the green onion model, RFEM is implemented, and mandatory testing is required only when RFEM signals, with random testing elsewhere.

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

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 1998a). 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.

Stochastic Optimization Model Results

Domestic Milk Supply Chain

The optimal tracking strategy for the base case in the domestic milk supply chain model is to test only where it is mandatory to test, when milk is received at the milk plant (Table 1). Table 1 shows the buyer and seller risks under each strategy. Buyer risk is the risk that product exceeding tolerances will get into the buyer product stream, and seller risk is the risk that product thought to be within tolerances will be rejected. Buyer and seller risks are minimal in the base case with mean values of 1.11E-07 and 2.05E-17 percent, respectively. These results indicate that 1.11E-07 percent of lots entering the domestic user flows might be contaminated (buyer risk) and 2.05E-17 percent of the lots might be rejected (seller risk). Average systems costs for conducting random testing for pathogens, re-cleaning, and quality loss are \$0.0045/gallon, \$3.43E-11/gallon, and \$0.00/gallon, respectively. The certainty equivalent is \$0.0045/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.

Table 1. Domestic Milk 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	1.105E-07	1.114E-07	1.194E-07
Seller Risk	2.053E-17	2.060E-17	5.322E-07
Costs ($/gal)			
Cost of Testing	0.004545	0.004545	0.03579
Cost of Tag	0	7.636E-05	0
Cost of Re-cleaning	3.432E-11	3.432E-11	3.432E-11
Cost of Quality Loss	0	0	1.837E-06
Certainty Equivalent ($/gal)	0.004545	0.004622	0.03580
Comparison to Base Case	NA	0.00007636	0.03125

*NA is not applicable

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 1). Buyer risks for the lock-out tag system average 1.11E-07 percent with a 95 percent confidence interval of 6.55E-08 to 1.13E-07 percent. Seller risks average 2.06E-17 percent with a 95 percent confidence interval of 4.98E-18 to 2.59E-17 percent. 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 $7.64E-05/gallon, $0.0045/gallon, $3.43E-11/gallon, and $0.00/gallon, respectively. The results indicate that there is a 95 percent confidence interval for quality loss costs to be $0.00/gallon and for total system costs to lie between $0.0046/gallon and $0.0047/gallon.

Installing a lock-out tag system increases the certainty equivalent to $0.0046/gallon from the domestic base case of $0.0045/gallon. This indicates that the decision maker would require a risk premium of $0.000076/gallon to be indifferent between the lock-out tag system and the base case.

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 and there are no optional testing locations. Average buyer and seller risks are 1.19E-07 and 5.32E-07 percent, respectively (Table 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 $0.036/gallon, $1.84E-06/gallon, and $3.43E-11/gallon, respectively. The OSF/OSB system has a certainty equivalent of $0.036/gallon and a risk premium of $0.031/gallon. The tighter the security measure 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.

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 $0.031/gallon to be indifferent between the OSF/OSB system and the base case and $0.031/gallon to be indifferent between the OSF/OSB system and the lock-out tag system.

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. 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 and seller risks and certainty equivalents increase, but minimally.

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 and 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

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 2). Buyer and seller risks are minimal with mean values of 1.49E-13 and 2.22E-23 percent, respectively. Average costs for conducting random testing for pathogens, re-cleaning, and quality loss are \$0.0090/gallon, \$6.71E-11/gallon, and \$0.00/gallon, respectively. The certainty equivalent is \$0.0090/gallon, indicating that the decision maker would require a premium of approximately this amount to be indifferent between this system and one with no testing.

In the 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.

The optimal testing strategy for the lock-out tag and RFEM system is to test only when mandatory testing is required (Table 2). Buyer risks average 1.83E-07 percent with a 95 percent confidence interval of 1.55E-07 to 2.01E-07 percent. Seller risks average 1.67E-09 percent with a 95 percent confidence interval of 2.31E-17 to 7.47E-09 percent. With the lock-out tag and RFEM system, buyer and seller risks, while still minimal, are larger than those in the base case. Average costs for testing, lock-out tags and RFEM, re-cleaning, and quality loss are \$0.0090/gallon, 0.00019/gallon, \$6.71E-11/gallon, and \$8.10E-09/gallon, respectively. The 95 percent confidence interval indicate that the quality loss costs are between \$0.00/gallon and \$3.62E-08/gallon, and the total system costs are between \$0.009218/gallon and \$0.009224/gallon.

Table 2. Milk 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	1.491E-13	1.833E-07	1.865E-07	1.491E-13
Seller Risk	2.223E-23	1.670E-09	1.6670E-09	7.632E-07
Costs ($/gal)				
Cost of Testing	0.009010	0.009010	0.004545	0.04222
Cost of Tag/RFEM	0	0.000194221	0.000194221	0
Cost of Re-cleaning	6.709E-11	6.709E-11	6.709E-11	6.709E-11
Cost of Quality Loss	0	8.095E-09	8.095E-09	2.629E-06
Certainty Equivalent ($/gal)	0.0090010	0.009204	0.004740	0.04222
Comparison to Base Case	NA	0.0001942	-0.004270	0.03322

Installing a lock-out tag and RFEM system increases the certainty equivalent to $0.0092/gallon from the domestic base case of $0.0090/gallon. This indicates that the decision maker would require a risk premium of $0.00019/gallon to be indifferent between the lock-out tag and RFEM system and the base case.

In the next 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 2). Buyer risks for the lock-out tag and RFEM system average 1.87E-07 percent with a 95 percent confidence interval of 1.55E-07 to 2.04E-07 percent. Seller risks average 1.67E-09 percent with a 95 percent confidence interval of 2.31E-17 to 7.47E-09 percent. With the lock-out tag and RFEM system, buyer and seller risks, while still minimal, are larger than those in the base case. Average costs for testing, lock-out tags and RFEM, re-cleaning, and quality loss are \$0.0045/gallon, \$0.00019/gallon, \$6.71E-11/gallon, and \$8.10E-09/gallon, respectively. The 95 percent confidence intervals indicate that the quality loss costs are between \$0.00/gallon and \$3.62E-08/gallon and total system costs are between \$0.00471/gallon and \$0.00474/gallon. The certainty equivalent is \$0.0047/gallon with a risk premium of negative \$0.0043.

The third tracking strategy simulated is one where tests are applied and information stored one-step forward and one-step backward (OSF/OSB). This requires tests on all lots along the 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 in the OSF/OSB system are 1.49E-13 and 7.63E-07 percent, respectively (Table 2). Costs for this system are the highest of the three export systems for testing and quality loss. Costs for testing, quality loss, and re-cleaning are \$0.042/gallon, \$2.63E-06/gallon, and \$6.71E-11/gallon, respectively. The OSF/OSB system has a certainty equivalent of \$0.042/gallon, and a risk premium of \$0.033/gallon.

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 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 \$0.00019/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 \$0.033/gallon to be indifferent between the OSF/OSB case and the lock-out tag and 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.

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. 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 and 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 and seller risks and the certainty equivalent show minimal changes. In each of these sensitivities, the optimal tracking strategy does not change.

Green Onion Supply Chain

For green onions, the optimal strategy in the base case is to test only when the product is being transported to retail (Table 3). Buyer risk is 5.19E-08 and seller risk is zero. The cost of testing is \$0.025/lb and the certainty equivalent is \$0.025/lb, indicating that the decision maker would require a premium of approximately \$0.025/lb to be indifferent between this system and one with no testing.

The optimal strategy in the RFEM scenario is to test only when the RFEM tags signal. Buyer risk is 1.01E-06 and seller risk is 6.67E-07. The cost for testing, RFEM, and quality loss are \$6.51E-09/lb, \$0.00054/lb, and \$1.11E-07/lb, respectively, resulting in a total cost of \$0.00054/lb. The certainty equivalent is \$0.00054/lb. The total cost and certainty equivalent in this scenario are lower than those in the base case.

In the OSF/OSB system, tests are required at all stages. Buyer and seller risks are \$6.00E-08/lb and \$1.03E-06/lb, respectively. The cost of testing is \$0.071/lb while the quality loss cost is \$1.85E-07/lb, resulting in a total cost of \$0.070/lb. The certainty equivalent is \$0.070/lb. The total cost and certainty equivalent are highest in the OSF/OSB system.

Sensitivities are conducted where changes are made to the probability of contamination, cost and reliability of RFEM, and diversion costs. In most cases, however, the changes in buyer and seller risk, volume diverted, and certainty equivalents are small. Certainty equivalents increase when the cost of RFEM increases, but they do not change when the other factors vary. Buyer and seller risk and volume diverted all increase when the probability of contamination increases.

Table 3. Green Onion Model Results

	Base Case-Random Testing No RFEM Mandatory Testing at Retail Receiving	Random Testing with RFEM Mandatory Testing when RFEM Signals	OSF/OSB
Utility	1.2004	1.2004	1.2004
Test (1=yes, 0=no) and Intensity % Sampled			
Farm	0-NA	0-NA	1-100%
Packinghouse	0-NA	0-NA	1-100%
Warehouse	0-NA	0-NA	1-100%
Retail	0-NA	0-NA	1-100%
Truck-Transit to Packinghouse No Signal	0-NA	0-NA	1-100%
Truck-Transit to Warehouse in U.S. No Signal	0-NA	0-NA	1-100%
Truck-Transit to Retail No Signal	1-100%	0-NA	1-100%
Truck-Transit to Packinghouse Signal	NA	1-100%	NA
Truck-Transit to Warehouse in U.S. Signal	NA	1-100%	NA
Truck-Transit to Retail Signal	NA	1-100%	NA
Buyer Risk	5.185E-08	1.015E-06	6.001E-08
Seller Risk	0	6.668E-07	1.026E-06
Volume Diverted (lbs)	0	253.6	390
Costs ($/lb)			
Cost of Testing	0.0250	6.513E-09	0.07000
Cost of RFEM	0	0.0005400	0
Cost of Quality Loss	0	1.10529E-07	1.84891E-07
Total Costs	0.0250	0.0005401	0.07000
Certainty Equivalent ($/lb)	0.02500	0.0005401	0.07000
Comparison to Base Case	NA	-0.02446	0.04500

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. Results are provided for both a firm that is vertically integrated in the supply chain and also a 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 4). 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 4. Domestic Milk Model: Real Options 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

For a vertically integrated milk supplier with RFEM installed and mandatory testing at the milk plant and import facility, the real option values 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 when the probability of contamination of 0.01 (Table 5). If testing is required only when RFEM signals tampering, the average NPV is $2,802,377, the NPV/cost is 1.72, and the volatility value is 0.0047 when the probability of contamination is 0.01 (Table 6). The investment cost in both scenarios is $1,628,486. Tables 5 and 6 show that the NPV decreases when the probability of contamination drops to 0.0001.

Table 5. Export Model with Mandatory Testing at Milk Plant and Import Facility: Real Options 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

Table 6. Export Model with Mandatory Testing at Milk Plant and Mandatory Testing at Import Facility when RFEM Signals Tampering: Real Options 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 Green Onion Supply

In the vertically integrated green onion supply chain, the NPV is $0 when the probability of contamination is 0.01, 0.001, or 0.0001, while cost is $256,755. When the probability of contamination increases to 0.1, NPV is $126 (Table 7).

Table 7. Vertically Integrated Green Onion Model

	NPV	Cost	NPV/Cost	Volatility
Base Pr. 0.01	$0	$256,755	0.0000	0.0119
Pr. 0.0001	$0	$256,755	0.0000	22.2363
Pr. 0.001	$0	$256,755	0.0000	15.8420
Pr. 0.1	$126	$256,755	0.0005	0.0008

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 options 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 for the vertically integrated milk supplier 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 2).

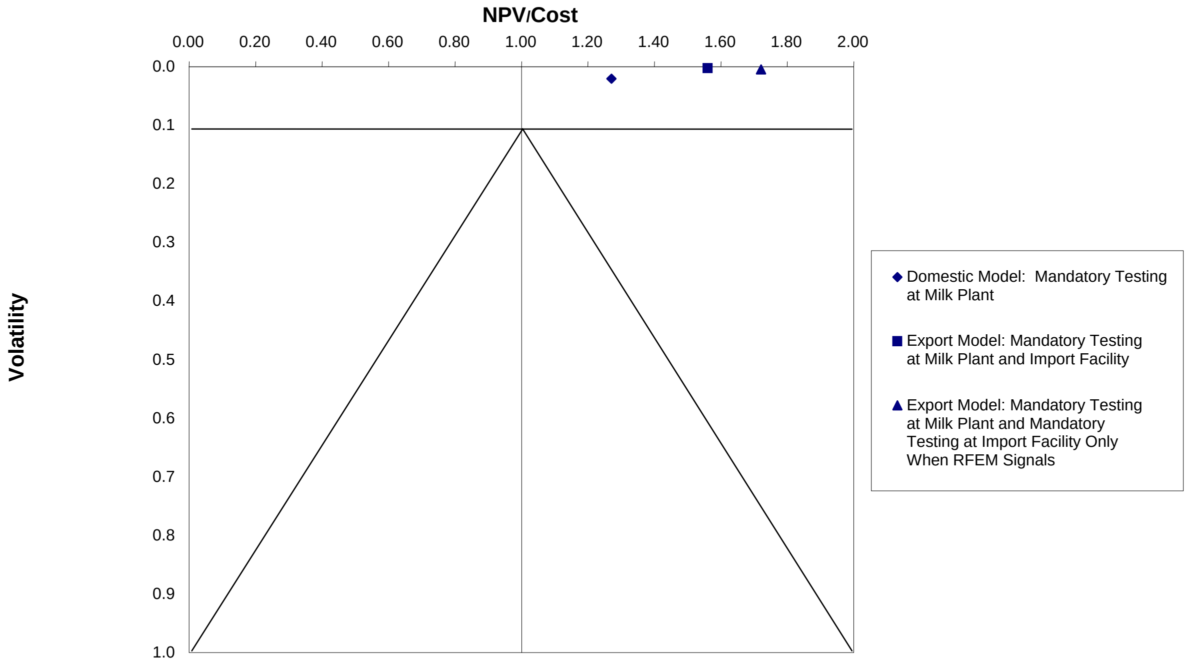

Figure 2. “Tomato Garden” Option Space Framework: Vertically Integrated Milk Model with Probability of Contamination of 0.01

The sensitivity results graphed in the “tomato garden” framework for the probability of contamination of 0.0001 and 0.001 are similar to the base case. These results indicate that in each of the three scenarios for the vertically integrated milk supplier, 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 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.

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 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.

The results in the green onion model differ from those in the milk model. It is not found to be beneficial for the green onion supplier to invest at any of the probabilities of attack. Because of the low NPV to cost ratios, the results from the tomato garden framework show that the vertically integrated green onion supplier should choose to invest never when the probability of attack is 0.01 or 0.1 and probably never when the probability of attack is 0.0001 or 0.001 (Figure 3).

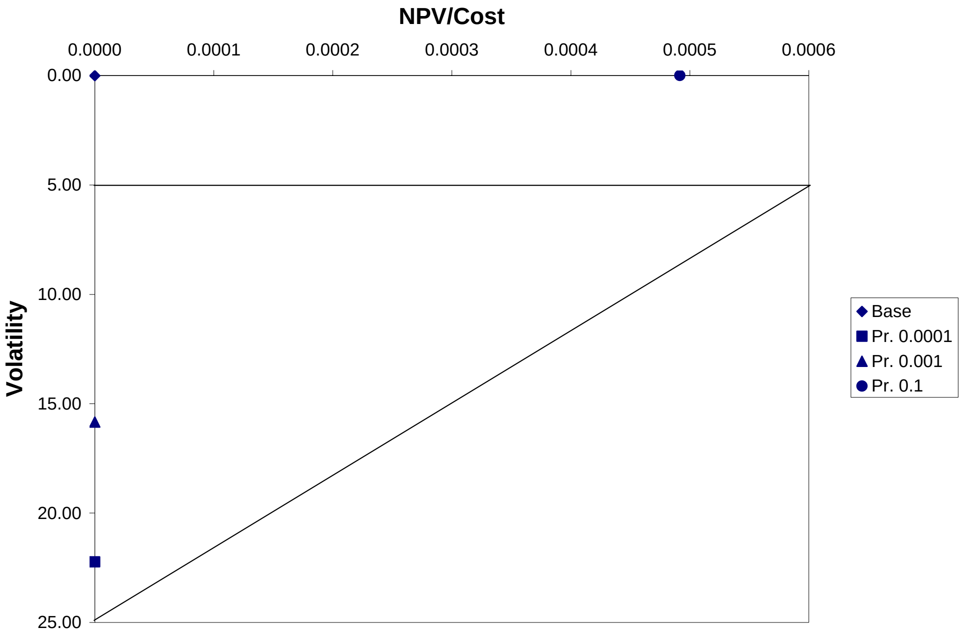

Figure 3. “Tomato Garden” Option Space Framework: Vertically Integrated Green Onion Model

Real Options Results for Major Participants along the Supply Chain

In the non-vertically integrated milk model, simulated real option values at the farm level indicate that the NPV is $107,067, the NPV/cost ratio is 3.59, and volatility is 85,571 (Table 8). NPV, NPV/cost, and volatility are $6,090,714, 102.12, and 4,658,444, respectively, for the processor and $5,525,148, 92.64, and 4,621,554, respectively for the importer/retailer. 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, while the investment strategy would be beneficial probably later for the processor and importer/retailer (Figure 4).

Table 8. Non-Vertically Integrated Milk Supply Chain: Real Options Results

	NPV	Cost	NPV/Cost	Volatility
Producer	$107,067	$29,820	3.59	85,571
Milk Plant/Processor	$6,090,714	$59,640	102.12	4,658,444
Importer	$5,525,148	$59,640	92.64	4,621,554

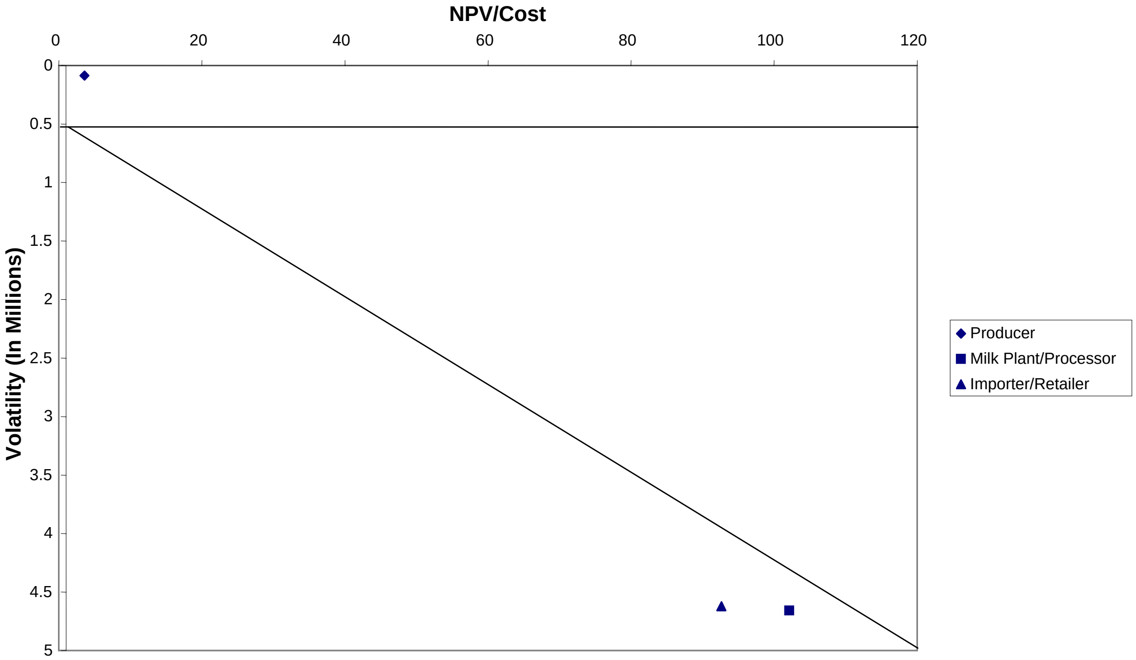

Figure 4. "Tomato Garden" Option Space Framework: Non-Vertically Integrated Milk Supply Chain

In the non-vertically integrated green onion supply chain, the NPV/cost ratio is highest for the warehouse (0.58), packinghouse (0.47), and truck (0.44), but it is less than one for all segments of the supply chain (Table 9). These results show that the retailer and producer should never invest, and the packinghouse, warehouse, and trucking should maybe invest later (Figure 5).

Table 9. Non-Vertically Integrated Milk Supply Chain: Real Options Results

	NPV	Cost	NPV/Cost	Volatility
Producer	$3,466	$29,820	0.12	0.4907
Packinghouse	$27,877	$59,640	0.47	2.4404
Truck	$26,118	$59,640	0.44	2.4510
Warehouse	$34,468	$59,640	0.58	2.9201
Retail	$0	$59,640	0.00	0.3403

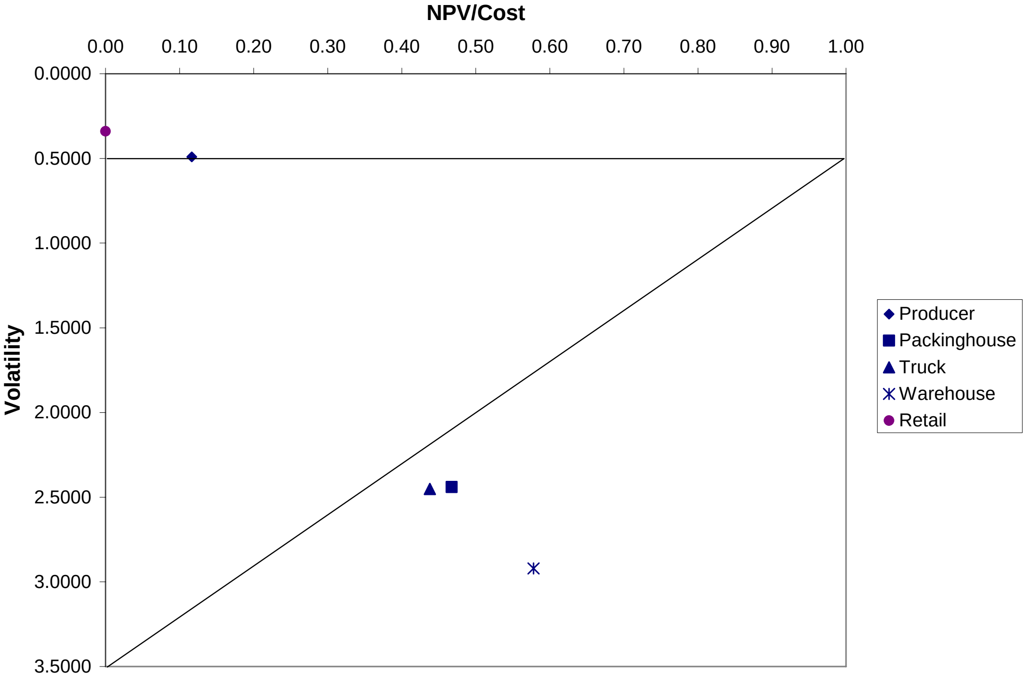

Figure 5. “Tomato Garden” Option Space Framework: Non-Vertically Integrated Green Onion Supply Chain

Game Theory Results

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 to invest or not invest. After they make this decision, 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 or not. Finally the farmer chooses to invest or not invest, and again this is followed by whether there is an attack or not.

The payoffs are calculated for four different scenarios. 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 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 or green onions and the decrease in prices due to loss in 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 options 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.

Milk Supply Chain

In the milk model, 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 10). 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 to 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 increase the probability of an attack to 0.1. 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. The results of this sensitivity show that the farm level would invest if the probability of an attack reached this level.

Table 10. Game Theory Summarization and Sensitivity Results for the Milk Model

	Probability of Contamination				
	Attack	Do Not Attack	Importer	Processor	Producer
Base	0.01	0.99	Invest	Invest	Do Not Invest
Sensitivity	0.1	0.9	Invest	Invest	Do Not Invest
Sensitivity	0.5	0.5	Invest	Invest	Invest
	Cost Variability	Farm Level	How Often		
Base	$29,820	Do Not Invest	100% of time		
Sensitivity	25% of Base ($7455)	Do Not Invest	98% of time		
Sensitivity	10% of Base ($2982)	Do Not Invest	72% of time		
Sensitivity	$0	Invest	76% of time		
Price/gallon	Price Penalty	Attack	Do Not Attack	Farm Level	How Often
5% off	Estimated Loss	$79,186	$25,855	Do Not 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 cost reduction 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.

Price discounts 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. 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 show the farm level choosing to invest approximately 88% of the time. When prices are decreased by 10%, there is a 100% investment rate.

Green Onion Supply Chain

Results for the green onion model with a probability of attack at 0.01 indicate that the producer, packinghouse, and retailer would all chose to not invest (Table 11). Sensitivities are conducted on the probability of attack, cost of investment, and price of product to determine what would be necessary to induce investment.

If the probability of attack is increased to 0.5, the producer, packinghouse, and retailer still all chose to not invest. Reducing the cost of investment by 10 percent also did not induce investment by any of the segments of the supply chain. If the investment cost is fully subsidized, the producer would chose to invest 97 percent of the time, the packinghouse would invest 100 percent of the time, and the retailer would invest 76 percent of the time.

Another alternative to encourage investment would be to reduce the price received for green onions if they do not invest. Decreasing price by 25 percent would still result in no investment. If price was decreased by 50 percent, the packinghouse and retailer would choose to invest 100 percent of the time, but the producer would still choose not to invest 100 percent of the time.

Table 11. Game Theory Summarization and Sensitivity Results for the Green Onion Model

	Probability of Contamination				
	Attack	Do Not Attack	Retail	Packinghouse	Producer
Base	0.01	0.99	Do Not Invest	Do Not Invest	Do Not Invest
Sensitivity	0.5	0.5	Do Not Invest	Do Not Invest	Do Not Invest

Sensitivity for Investments	Producer	How Often	Packinghouse	How Often	Retailer	How Often
Base	Do Not Invest	100%	Do Not Invest	100%	Do Not Invest	100%
$0	Invest	97%	Invest	100%	Invest	76%
10% of Base	Do Not Invest	100%	Do Not Invest	100%	Do Not Invest	100%

	Estimated loss for 250,000 lbs produced			
Price Penalty	Attack	Do Not Attack	Producer	How Often
5% off	$4,394	$1,469	Do Not Invest	100%
10% off	$5,704	$2,938	Do Not Invest	100%
25% off	$9,634	$7,344	Do Not Invest	100%
50% off	$16,185	$14,688	Do Not Invest	100%
			Packinghouse	
5% off	$21,897	$7,320	Do Not Invest	100%
10% off	$28,423	$14,640	Do Not Invest	100%
25% off	$47,995	$36,600	Do Not Invest	100%
50% off	$80,618	$73,200	Invest	100%
			Retail	
5% off	$26,205	$8,760	Do Not Invest	100%
10% off	$34,014	$17,520	Do Not Invest	100%
25% off	$57,440	$43,800	Do Not Invest	100%
50% off	$96,485	$87,600	Invest	100%

Conclusions

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. The buyer and seller risks also change minimally when the probability of attack changes, but they do increase when the probability increases. The change in buyer and seller risks, however, could lead to possible moral hazard issues. Findings also show 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. These results show a potential for real-time tracking and containment strategies.

The results of both the domestic and export supply chains for milk 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 less testing locations and reduced number of tags along the 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 are addressed with the real option analysis. The real option results suggest that in the vertically integrated milk supply chain, 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. 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. The NPV/cost in the green onion model is at or near zero for all probabilities of contamination analyzed, indicating that public sector spending would be necessary in the green onion industry.

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 in 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 to 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 show that the probability of contamination and the price discounts tend to have a larger effect on the milk producer's decision to invest compared to 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.

In the non-vertically integrated green onion supply chain, the NPV/cost ratio is less than one for all segments of the supply chain, and the results show that the retailer and producer should never invest, and the packinghouse, warehouse, and trucking should maybe invest later. In the game theory model, the producer, packinghouse, and retailer all chose to not invest when the probability of attack is 0.01. Compared to the milk model, much greater changes in probability of contamination, investment cost, and prices received are necessary to induce investment by the segments of the green onion supply chain.

This study provides a framework for valuing investment strategies to mitigate possible agro-terrorism occurrences in the supply chain and determining where these investments would reduce the most risk. This framework is applied to the milk and green onion industries in this paper, but it could also be applied to other food industries that are at risk, which would include various 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).

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Appendix A. Stochastic Optimization Model

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 risk premium is the difference required for the investor to be indifferent between the alternative tracking strategies. 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. 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; W is the wealth of the vertically integrated firm; 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 would make the vertically integrated firm indifferent between a base model (random testing) and the alternative tracking technologies. 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.

Appendix B. Real Options Model

The real options 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). 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.

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:

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

where t is the current time, λ is the positive exponential hazard rate parameter, and e is the natural exponential function. The value exp ($-\lambda t$) 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 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:

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

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.

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):

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

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 not invest or 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 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.

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

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 ($\pi(x,u,t)$), 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

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

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

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

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

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

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

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

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

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

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

$$\begin{aligned} &F(0) = 0 \\ &F(V^*) = V^* - K \qquad (12) \\ &F'(V^*) = 1 \end{aligned}$$

where V^* is the optimal expected net present value of the project. Numerical simulation methods with Risk Optimizer (Palisade Corporation, 1998b) are 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 supply chain using a portfolio of options framework.