# AN ECONOMIC EXPLORATION OF PREVENTION VERSUS RESPONSE IN ANIMAL RELATED BIOTERRORISM DECISION MAKING

A Dissertation

by

LEVAN ELBAKIDZE

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

December 2004

Major Subject: Agricultural Economics

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## ABSTRACT

An Economic Exploration of Prevention Versus Response in Animal Related
Bioterrorism Decision Making. (December 2004)
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Chair of Advisory Committee: Dr. Bruce McCarl

Animal disease outbreaks either through deliberate terroristic act or accidental introductions present a serious economic problem. This work concentrates on the economics of choosing strategies to mitigate possible agricultural terrorism and accidental introduction events largely in the animal disease management setting. General economic issues and the economic literature related to agricultural terrorism broadly and animal disease concerns specifically are reviewed. Basic economic aspects, such as the economic consequences of outbreaks, costs and benefits of various mitigation strategies, and stochastic characteristics of the problem are discussed.

A conceptual economic model is formulated to depict the animal disease outbreak related decision making process. The key element of this framework is the choice between *ex ante* versus *ex post* mitigation strategies. The decision of investing in preventative and/or responsive strategies prior to the occurrence of an event versus relying on response and recovery actions after an outbreak event needs careful consideration. Comparative statics investigations reveal that factors that affect this decision are event probability, and severity, as well as costs, benefits, and effectiveness of various mitigation strategies.

A relatively simplified empirical case study is done analyzing the economic tradeoffs between and optimum levels of ex ante detection, as a form of prevention, and ex post slaughter, as a form of response. The setting chosen involves Foot and Mouth Disease management. Empirical investigation is done on the conditions under which it is economically more advantageous to invest in ex ante detection as opposed to relying just on ex post response. Results show that investment in ex ante activities becomes more advantageous as the probability and severity of an agricultural terrorism event increases, response effectiveness decreases, and costs of surveillance decrease. Also spread rate is found to play a key role in determining optimal combination of ex ante and ex post strategies with more done ex ante the faster the disease spread.

Finally, an economic framework is posed for future work given availability of a more detailed epidemiologic model. Access to such a model will allow for incorporation of wider spectrum of strategies including numerous possibilities for prevention, detection, response and market recovery facilitation. The framework allows more localized options, multiple possible events and incorporation of risk aversion among other features.

To
Guram
Marina
and Lali

# ACKNOWLEDGEMENTS

There are a number of people whose contribution to this work merits recognition. First and foremost, I wish to express my sincere appreciation and thanks to Professor Bruce McCarl for giving me an opportunity to work with him. This dissertation was conducted under his methodological guidance, which was essential in developing the conceptual as well as empirical components of this work.

I would also like to express my gratitude to Dr. Richard Woodward, Dr. Jerry Stuth, and Dr. Frederick Boadu for agreeing to serve on my committee and for providing constructive criticism and comments during the final stages of developing the manuscript. I appreciate helpful hints and suggestion of Dr. Stuth whose expertise in Texas cattle industry operations proved to be critical for this work. In addition to formal committee members I would like to acknowledge the contribution of Dr. Morgan Scott whose epidemiologic insight facilitated the development of formal models in this manuscript.

Finally, I wish to thank my family, friends and colleagues for their encouragement, support and inspiration.

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# 1 INTRODUCTION

The dawn of September 11, 2001 began as a typical Tuesday morning for most New Yorkers, Washingtonians and Americans. However, early morning of that day proved to be unlike any other morning in the history. Unsuspecting citizens were shocked and terrified by terrorist attacks on the World Trade Center and the Pentagon. A big question mark was raised in many minds regarding national security and the American way of life. Most instantly upgraded their assessment of the extent of vulnerability that the nation faced. September 11, 2001 proved that, in spite of enormous expenses on national defense, uninterrupted prosperity was far from secure against deliberate terroristic acts. It became clear that military forces alone were not sufficient to ensure peace and stability. The subsequent mail borne anthrax attacks reinforced these feelings. The potential spread of biological/chemical lethal agents became more of a perceived threat. Since those days government agencies, firms and individuals have directed increased attention to safeguarding infrastructure, businesses, and institutions.

One large area of vulnerability is the U.S. agriculture and the consequent food supply. In 2002, agriculture accounted for $250 billion in gross domestic product and employed nearly 1.6 million people (BEA, 2004). Agricultural vitality is essential for human welfare and the economy. Agriculturally related contamination events could have large consequences for consumers, producers and international trade as seen during recent mad cow and Avain flu events as they influenced conditions in the US, Canada, UK, and Asia.

Such vulnerabilities lead many to believe that policy, program and business practice adjustments are needed to secure and protect agriculture. Food and water contamination have been identified by some as a relatively easy way to distribute chemical and biological agents (Khan et al. 2001). As a reaction substantial funds are

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spent on hazardous biological and chemical agents related training and detection in order to prevent deliberate food contamination. In 2003, an increase of $28 million relative to 2002, was proposed to allow for more inspectors, improve FSIS' (Food Safety and Inspection Service) information technology infrastructure, and conduct epidemiologic surveys and risk prevention activities (Veneman, 2002).

This dissertation views agricultural terrorism reviewing the literature, developing a conceptual economic model and conducting a case study to see the types of insights that can be gained.

## 1.1 Basic Economic Issues of Bio-Security Actions

Agricultural terrorism related decision making involves several economic issues. Economic welfare in the form of lost consumers' and producers' surpluses, plus the government costs of ex ante prevention and ex post response strategies are at the forefront of the economic issues. Another substantial issue relates to the stochastic nature of events and the balance between ex ante prevention investments versus ex post event management decisions. In other words, an economic question regarding mitigation of possible agricultural terrorism involves the appropriate combination of investments involving prevention actions, intelligence gathering and response facility installation in comparison with post event expenditures on response and recovery in the face of uncertain probabilities of event occurrence.

The economic efficiency of possible agricultural terrorism related mitigation options needs to be evaluated individually and in combination in order to design effective mitigation strategies. Some of the agricultural terrorism mitigation activities are: reducing access to chemical and biological materials; increasing security measures at production, processing and distribution facilities; employee screening; using antimicrobial drugs and vaccination; enhancing sanitary standards at production, transportation, storage and retail facilities; and establishing and/or improving detection, surveillance and tracing procedures. Examples of such activities in an animal management/disease setting are animal inspection/disease detection, infected animal slaughter, and vulnerable animal vaccination. Each of these measures has direct and possibly indirect costs, which need to be considered before a strategy is adopted.

From an economic standpoint, a criterion that can be employed in determining the optimal combination of agricultural terrorism mitigation strategies is based on net welfare or cost benefit analysis. On the margin, preventative activities are economically justified only as long as benefits from their implementation outweigh their costs.

The stochastic nature of terrorism events plays a significant role in forming an optimal combination of mitigation strategies. The likelihood of terrorist events, the severity of events and the cost of actions will influence whether it is more beneficial to invest in prevention activities or to wait and respond with control and repair measures in case of an outbreak. At low probabilities of agricultural sabotage, substantial investment in prevention, as well as surveillance and detection, will not look as attractive as in the case of high probability of agricultural contamination.

## 1.2 Purpose and Objectives of the Study

The general purpose of this dissertation is to investigate the economic design of counter animal disease related agricultural terrorism or accidental introduction caused outbreak management strategies. More specifically, an investigation will be done on how the characteristics of outbreak events and characteristics of mitigation options influence the economically optimal choice of policy and management strategies addressing those events. Emphasis will be placed on the amount of use of ex ante pre event alternatives versus ex post after event alternatives as influenced by potential event characteristics. This will be examined through the development of a general model that conceptualizes the situation and then through an empirical case study that illuminates some of the issues.

The case study will be done in the context of actions related to the introduction of FMD (Foot and Mouth Disease). Consideration is given to regional scale policy options to counteract the potential or realized event. Specifically, the study will compare and evaluate relative economic attractiveness of various preventive and responsive strategies in a case study setting. Disease outbreak will be considered in a stochastic environment.

Specific items examined will include:

- identifying and examining the optimal economic amount of ex ante prevention, and detection relative to the amount of ex post response and recovery strategies used in addressing events as the characteristics of events change; and
- developing a framework that would allow policy and sectoral decision makers to examine tradeoffs between the ex ante costs of prevention/detection with more infrequent costs of outbreak management.

## 1.3 Scope of the Study

Although possible threats to food supply in the U.S. are numerous, this study will concentrate on the abstract general case and a specific simplified empirical case study. The case study will mainly revolve around introduction of FMD in Texas as an example of possible agricultural terrorism act but will use a simplistic set of management actions. FMD poses a serious threat to livestock and other related industries. It has been documented that even unintentional outbreaks of diseases such as FMD can cause serious damages to the economy. For example, a recent FMD outbreak had major consequences for the UK economy (Thompson et al., 2003).

The case study region is Texas. This area was chosen because of geographic proximity, data availability and economic importance. In 2002, Texas had roughly 14 percent of total U.S. cattle (NASS, 2002). Cattle are found on more than 150,000 Texas farms and ranches. Sales of cattle and calves comprise the largest portion of State's agricultural cash receipts. Examining the repercussions of an ABS event, as well as the options for prevention, detection and response in a region such as Texas is likely to generate insights relevant to ABS actions for assuring stability of livestock markets. Additionally, examining prevention, detection, response and recovery strategies on a local basis rather than a national level provides a manageable problem while still permitting development of an understanding of economic components of decision support tools. The basic features of the economic approaches in this study are expected to be applicable in broader settings.

## 1.4 Methodology

Empirically I rely on a conceptual framework developed in this dissertation for investigating prevention and response strategies for FMD mitigation. First, the framework will be developed based on theory and problem characteristics then investigated analytically in a comparative statics setting. Second, the framework is empirically applied in a simplified case study setting and used to numerically investigate the optimal amount of ex ante detection, as a form of prevention strategy, and ex post slaughter, as a form of response strategy. Subsequently, more advanced framework is described, which is mainly presented as a model for use in future research given access to a detailed epidemiologic model.

## 1.5 Organization of the Thesis

The thesis is organized as follows: Chapter one provides an introduction to the problem and discusses the goals of the study. Chapter two will provide a literature review on the economic issues related to agricultural biosecurity. Chapter three discusses a model that was developed as a part of this work to examine optimal prevention, detection, response and recovery levels under various threat levels, disease spread, response effectiveness and cost characteristics. Conditions for optimality will be derived and comparative statics results are developed and discussed. Chapter four will empirically specify and employ a version of the model in a simplified FMD case study setting. Sensitivity analysis will be performed to evaluate the results under different scenarios. Chapter five will introduce a more advanced conceptual model for evaluating various mitigation strategies based on availability of an epidemiologic animal disease spread mode. A simplified empirical application of a hypothetical epidemiologic FMD mitigation model, which provides a set of prevention, response and recovery measures, will be demonstrated. Costs of a potential FMD outbreak will be minimized based on various mitigation combinations and the potential for inclusion of risk aversion into decision making will be demonstrated empirically using hypothetical event scenarios and mitigation strategies.

# 2 THE ECONOMICS OF AGRICULTURAL BIO-SECURITY: AN INTERPRETIVE LITERATURE REVIEW

## 2.1 Definitions

Using deliberately contaminated food to cause poisoning has occurred for hundreds of years. However, using a food supply system to cause massive disruption and destruction is a relatively new concept. Consequently, there is no internationally accepted standard definition of agricultural or food terrorism.

One way that *food terrorism* has been defined is "an act or threat of deliberate contamination of food for human consumption with chemical, biological or radionuclear agents for the purpose of causing injury or death to civilian populations and/or disrupting social, economic or political stability"(WHO, 2002). In this definition, chemical agents refer to manufactured or natural toxins, biological agents refer to infectious or non-infectious pathogenic organisms, including viruses, bacteria and parasites, and radionuclear agents are defined as radioactive chemicals capable of causing injury when present at excessive amounts. Clearly the objective of food terrorism act is to cause widespread injuries, inducing terror and panic, and disrupt social order (Sobel and Swerdlow, 2002).

Agricultural adulteration can have diverse implications. While food contamination at a local restaurant can affect the customers of that particular restaurant, sabotage at centralized food processing or distribution facilities could affect a wide range of the population, even in diverse regions. Thus, food borne diseases caused by intentional or unintentional contamination, could be characterized by the number of exposed people. *Disease bandwidth* refers to the extent of the impact caused by the food borne disease (Khan et. al. 2001). In other words, the more people are likely to be affected, the broader the bandwidth of the food borne disease.

In the context of bio-security, *risk* refers to the probability or probability distribution of agricultural contamination. Introduction of non-indigenous species may or may not result in undesirable agricultural contamination. Shogren (2000) argues that the odds of calamity are low, but with increased trade and easy mobility the risks of invasion by detrimental species are going up.

The most desirable option to combat deliberate agricultural contamination, as well as accidental contamination is *prevention*. Prevention has been defined as preventing agricultural sabotage during production, processing, distribution and preparation (WHO 2002). Establishing new and enhancing existing food safety programs are key components of the counter terrorism agenda. Prevention includes activities such as restricting access to chemical, biological and nuclear agents, increasing security measures such as monitoring at agricultural harvesting, production, processing, manufacturing, storage, transport, retail distribution and food service facilities.

It is nearly impossible to prevent every possible incident of deliberate or accidental agricultural contamination. In those unfortunate cases where suspected or adulterated food has reached the consumer, emergency *response* systems have been activated. Potential response activities include, but are limited to, verification and assessment of threat; identification, tracing and removal of contaminated food; and management of consequences including aiding the affected population.

## 2.2 Economic Aspects of Agricultural Bio Security

From an economic perspective, a major consequence of agricultural terrorism is that it would cause disruptions in agricultural commodity and related markets either because of the events itself or because of potentially expensive and intrusive preventative actions (Henson and Mazzocchi, 2002). Several economic issues are related to agricultural market sabotage. Economic damages of agricultural contamination, in the forms of lost consumer and producer surpluses, and costs of prevention, control and repair strategies are at the forefront of economic issues. In broad terms, economic investigation of agricultural biosequrity research involves quantification of economic damages; evaluation of economic effectiveness of available prevention and response options and policies; and consideration of stochastic nature of terrorism. Later in this work I will concentrate on economic analysis related to prevention versus event management dimensions under the stochastic nature of the problem at hand.

### 2.2.1 Quantifying Economic Damages

Estimating the economic damages caused by either intentional or unintentional agricultural contamination gets rather difficult due to complex nature of agricultural markets (Atkinson, 1999). Issues such as identifying affected parties (Paarlberg et al. 2003; Evans, 2003) and calculating the economic values of damages to those parties, such as reduced sales (Smith et al. 1988, Burton and Young 1996), and assessing the impact time line, are some of the complications related to event damage estimation. Due to highly integrated nature of the agricultural economy, the consequences of agricultural contamination at any given point along the supply chain could be manifested in other sectors of the economy. For example, major economic losses from recent FMD outbreak in the UK came from losses in tourism industry (Mangen and Burrell, 2003).

To estimate potential economic losses from agricultural contamination in the form of infectious animal disease spread, biophysical information is necessary in order to evaluate the extent of physical damages. For example, in case of prospective animal disease related events some level of epidemiological insight is necessary to simulate the scope of an event (Jalvingh et al. 1999, Ferguson et al. 2001) and consequently evaluate the economic costs. In other words, the spread rate of an infectious disease will determine the severity of economic damages and influence the appropriate combination of prevention and response actions.

### 2.2.2 Policy Responses to Terrorism

Policy design and cost estimation entails designing a set of possible effective ABS strategies (Khan et al. 2001), realizing the necessary extent of such activities (Garner and Lack 1995, Ferguson et al. 2001), and calculating the associated monetary and possible non-market costs of those activities. In addition, anti-terrorism policies need to be designed in a way that incorporates the possible moves from all involved parties such as targeted segments of society, government policy makers, and terrorists of various descent using approaches such as those provided by game theory (Sandler and Acre, 2003).

Four broad categories of response polices to agricultural terrorism are prevention, detection, control/repair and recovery management. Prevention is perhaps the most desirable policy option when it comes to agricultural counter terrorism activities as it can prevent damages from occurring. Some of the preventative policy options relate to adjusting farm level production activities such as employing antimicrobial livestock drugs (Mathews et al., 2001) and vaccination (Bates et al., February 2003 a, Schoenbaum and Disney 2003), reducing access to chemical, biological and radioactive materials, etc. Others relate to processing and manufacturing procedures, storage and transportation facilities (Hennessy et al., 1996), retail distribution and food service facilities (Mermin and Griffin, 1999), and trade inspection (Levine et al., 1996, Mahon et al., 1997). The basic purpose of prevention activities is to decrease the probabilities of intentional or unintentional agricultural contamination incidents. However, prevention costs are incurred whether or not events occur and thus can be costly especially for extremely unlikely events. Generally, it is safe to say that desirable global prevention is unattainable at a reasonable cost.

Detection, which could be used as a part of a prevention strategy (Bates et al. September 2003; Akhtar and White, 2003), could facilitate avoidance of deliberate agricultural contamination by eliminating possible venues of agricultural terrorism. Surveillance and detection systems could be designed to identify and remove all affected commodities from the market before a large scale event can occur. Tracking (Diseny et al., 2001) can be an integral part of the detection mechanism. Tracing systems could allow the authorities to identify the sources of outbreaks and remove affected animals. Cost is again a factor as detection costs can be encountered whether or not an event is present.

Response, control, repair and recovery (Bates et al. September 2003; Bates et al., February 2003 b; Schoenbaum and Disney, 2003) are the least desirable options as they are only activated if an event has occurred. Nevertheless they are indispensable parts of a total strategy for ABS event planning. Essentially such policies are intended to minimize the economic damages caused by encountered agricultural contamination event. This process entails stopping the spread of a possibly infectious contamination and minimizing the bandwidth of the sabotage. Recovery measures could involve eliminating the sabotage sources, restoring or replacing the lost food branches along the food supply chain, and rebuilding consumer confidence. Recovery deals with the aftermath of an event and the ways consumers are informed about the safety of the food supply in a way such that demand recovers. Recovery also deals with the management of potentially contaminated resources in a manner so as to minimize the likelihood of future outbreaks from for example soil resident residuals left over after the outbreak.

### 2.2.3 Prevention as a Public Good

The economic dimensions of a preventative strategy carry some of the characteristics of public goods. Specifically, if some of the livestock producers in a given area vaccinate, then it will decrease the probability of infection for not only those farms that vaccinated but also for those that did not. Therefore, some farmers may choose to not adopt preventative strategies and instead hope to “free ride” at the expense of those who adopt such strategies. Anti-terrorism strategies carrying such characteristics have been analyzed as “interdependent security” problem under airline safety scenarios (Heal and Kunreuther, 2004). Under such contexts, mitigation actions adopted by one entity influence security levels of other entities. In case of agricultural bio-security, it needs to be noted that farmers that choose not to prevent cannot be excluded from benefiting from the decreased infection probabilities due to prevention activities of their neighbors. These benefits could also be argued to be non-rival. Specifically, enjoying decreased probability of infection spread by one farmer does not reduce corresponding benefits enjoyed by another farmer in the same vicinity. These characteristics could classify some prevention and response actions as public goods which are known to be under produced by free markets (Hanley et al. 1997). This has been demonstrated in terms of retaliation against terrorism where due to free riding less retaliation has been observed than socially optimal (Dwight, 1988).

### 2.2.4 Mitigation of Agricultural Terrorism

Some of the preventative and control activities at agricultural level involve: reducing access to chemical and biological materials, increasing security measures at central production, processing and distribution facilities (Ryan et al. 1987), employee screening (WHO, 2002), using antimicrobial drugs and vaccination (Schoembaum and Disney, 2003), enhancing and updating sanitary standards at production, transportation (Hennessy et al., 1996), storage and retail facilities, and establishing and/or improving detection, surveillance and tracing (Disney, 2001) procedures. However, in this research, the attention will be concentrated on surveillance and detection, slaughter, and vaccination. Each of these measures has direct and possibly indirect costs, which need to be considered before a strategy is adopted.

A critical question related to response to agricultural terrorism is one of determining the optimal mix of ex ante prevention/detection/tracing investment (APDTI) and ex post control/repair/management (XCRM) strategies. From an economic stand point, the choice of the strategy needs to account for both economic costs of damages that could be brought by agricultural contamination and the ex ante costs of preventing the incident (Berentsen et al. 1992). In other words, a chosen APDTI strategy needs to pass benefit costs analysis, where the benefits correspond to avoided economic damages of agricultural sabotage weighted by the probability of the event while costs correspond to both monetary expenses and non-monetary losses related to executing the strategy. Similarly, XCRM strategies also need to satisfy benefit-cost criteria. In this case benefits entail an anticipated welfare increase from the total situation including the investment costs of the APDTI actions that aim to prevent, rapidly detect and manage agricultural sabotage events and the XCRM events that are directed toward repairing the damaged markets. Costs of such policies would correspond to expenses associated with implementing the strategy.

### 2.2.5 Stochastic Considerations

The choice of optimal mix of prevention and control/repair strategies is heavily affected by the stochastic characteristics of the issue. The sabotage probability values and severity of event consequences will influence whether it is more beneficial to invest in prevention activities or is it better to wait and respond with control and repair measures in the case of an outbreak. At low probabilities of agricultural sabotage substantial investment in prevention, as well as surveillance and detection, will not be as attractive as in the case of high probability of agricultural contamination. The probability of agricultural contamination can be argued to be actually affected by prevention, surveillance and detection strategies (Shogren, 2000). For example, a timely detection and destruction of infected animals will reduce the chances of regional spread of the infection, and thus will decrease the probability of outbreak occurring in the region. In other words, high levels of prevention, detection and surveillance will decrease the probability of a successful agricultural terrorism act. However, further in this analysis I will assume that prevention and response strategies do not affect the probabilities of planned agricultural sabotage but rather influence the severity of the attack. That is the probability of facing an attempt to sabotage agricultural markets could be viewed to be independent of implemented preventative activities. This is in part motivated by uncertainty of prevention effectiveness. The relationship between the terrorists' intention to attack and prevention measures is not clear. Therefore, throughout most of this work I basically assume that if they intend to attack they will find a way to do so even with prevention and other measures in place. However, bandwidth of the attack, and therefore, the severity of it, is directly affected by preventative and response measures. For example, vaccinating the animals before the attack does not decrease the probability of an attack but may decrease the number of infected animals in case of an attack and decrease the probability that a specific farm or a farming community will be infected. Similarly, surveillance and detection activities could be argued to decrease event severity, which could be represented by a probability of a given farm getting infected in case of an attack. Low levels of surveillance and detection, and consequent inability to detect and eliminate the threat in a timely fashion, could result in a severe event having high probability of a given farm getting infected.

On the other hand, high levels of surveillance and detection could allow decreasing the probability of a given farm getting infected.

## 2.3 Economic Implications of Agricultural Sabotage

ABS events can have numerous and diverse consequences, which makes exhaustive estimation of associated economic losses rather difficult. An exhaustive estimate of the economic costs would include effects on

1. producer profits
2. consumer welfare,
3. death
4. lost jobs,
5. lessened consumer demand now and in the future
6. market price effects
7. costs of prevention activities
8. costs of responding to the incidents, such as costs of complying with enhanced regulations, clean up, medical treatment, etc.

Currently, most of the existing estimates reflect certain components of total costs of agricultural contamination. For example, medical costs and lost wages due to food borne salmonellosis, only one of many food borne infections, have been estimated to be more than $1 billion/year (CDC, 2003). Non-native species, such as plant pathogens and livestock pests could cause considerable economic losses. Plant pathogens cause crop losses equivalent to approximately $33 billion, while livestock losses due to pests are estimated to be approximately $9 billion per year (Pinmentel et al., 2000). However, plant pathogens could cause additional economic losses in the form of damages to non-crop plants. Livestock pests could harm consumer welfare through increased livestock prices due to decreased production.

The most obvious economic effects of agricultural food contamination are changes in market prices for the affected commodities. For example the prices at retail, wholesale and producer levels in UK are estimated to have fallen by 1.7, 2.25 and 3.0 pence/kg, respectively over the 1990s due to BSE occurrence (Loyd et al., 2001). This implies that the economic consequences of agricultural contamination will vary along the supply chain in terms of magnitude. In addition, to examine the price effects of agricultural contamination, one would need to decompose this price effect into supply and demand effects, combination of which makes up the prices and their changes in the market. For example it was estimated that the long run effect of BSE outbreak in the UK in 1990 was 4.5% reduction of consumer expenditures on beef (Burton and Young, 1996). Clearly, there also were changes in supply environment due to stricter regulations, not related to BSE, which also influenced the market price of beef products, consequently influencing demand for beef products.

Due to the 2001 FMD outbreak in the UK the losses to the agricultural industry were projected to be anywhere from $720 million to $2.304 billion. Expected tourism losses were even higher (Mangen and Barrell, 2003). Schoenbaum and Disney (2003) estimated that net changes in consumer and producer surplus due to a hypothetical FMD outbreak in the United States would amount to $789.9 million annually. However, their estimate was based on the assumption that the consumer demand would not be affected by the outbreak. Taking consumer response into account could potentially alter the estimate. The list of economic impacts could be quite lengthy but it is unlikely that every conceivable consequence could be accounted for.

### 2.3.1 Producers

Outbreaks of diseases through introduction of non-indigenous species affect producers and consumers through changes in agricultural product prices, costs of production and availability of goods. From a producer's standpoint, agricultural contamination implies a ban or at least a substantial reduction in sales of the infected commodities. As a consequence, the producers could suffer significant economic losses, unless compensated by the government. As a result of 1982 milk contamination in Oahu (Hawaii), 36.2 million pounds of milk were recalled. Smith et al. (1988) calculated sales losses due to contamination and subsequent milk bans to be 41.7 million pounds by calculating difference between the projected sales without incident and estimates of actual sales. In 1996, contaminated radish sprouts served in school lunches led to an outbreak of *Eschria coli* 0157:H7 infection in Sakai City, Japan. The outbreak caused meat and fish sales to decline by 40-60 percent. In addition, consumers also responded by purchasing 40-60 percent fewer restaurant meals (Mermin and Griffin, 1999), thus leading to losses in restaurant industry income. The director of the school lunch program in Sakai City committed suicide after the outbreak, which portrays serious social consequences of food contamination.

Agricultural sabotage, such as introduction of animal diseases, could cause a significant decline in agricultural productivity. Although mortality is high among young animals infected with FMD (Ferguson et al., 2001), most animals recover from the infection, but subsequently exhibit permanently reduced weight gain and/or milk yield. Infected animals are usually quarantined and killed as part of prevention efforts, reducing supplies of livestock products and on farm income. These actions result in substantial monetary losses for farmers who incurred costs associated with production of livestock, which can not be sold due to illness. Compensation is an important part of any policy scheme as otherwise farmers have an incentive to hide their animals which can lead to a longer period of infection. In 2001 about £1.1 has been paid to UK producers to compensate for some of their losses. 61% of this amount was compensation for slaughter of animals (DEFRA, 2002).

The 1996 outbreak of BSE in UK affected beef producers in general by decreasing demand and turning their beef into unmarketable products that had to be disposed of. The announcement in March 1996 about possible link between BSE and it’s human version was followed by an immediate drop of 40 percent in sales of beef products. First year losses alone were estimated to be around $1.07-$1.4 billion (Mathews and Buzby, 2001). Between one half and two thirds of total losses from BSE were attributed to fall in the value of the meat production. The remainder of the losses resulted from the costs associated with various public schemes, compliance costs of new legislative requirements, and production adjustment costs. However, beef farmers were about 90% compensated for BSE induced revenue losses (Atkinson, 1999).

### 2.3.2 Supply Chain Effects

Most of the time, production reductions due to disease outbreaks affect the vertical chain of entities on the supply side of the market. For example, in the case of the BSE outbreak in the UK, there were losers as well as winners within the cattle sector. Specialist beef finishers suffered from the joint effect of higher calf prices and lower finished cattle prices. On the other hand, dairy farmers saw improved prices for their calves and cull cows (Atkinson, 1999). Cattle slaughterers, processors, manufacturers and renderers were also among the affected parties. Mainly, the extent of the effect depended on the ability of a party to substitute alternative meat products such as pork, poultry and lamb. Degree of substitutability varies depending on business type. For example, it is easier for a butcher to switch from beef to pork than it is for rancher to switch from cattle to swine.

Impacts of an outbreak of a food borne disease stretch beyond the immediate markets for the contaminated or suspected commodity. For example, due to UK government's announcement of a possible link between BSE and human health various types of firms in the beef and related sectors were impacted. Processors of beef, dairy products, animal feed, and pet food were negatively affected. On the other hand, manufacturers of other meats were positively affected by the announcement (Henson and Mazzocchi, 2002).

Food borne disease outbreak could also affect industries other than agriculture and food. For example, effects of BSE and FMD probably spilled over to clothing, furniture and other leather commodity markets. Highly contagious diseases also result in public scares, which affect industries such as tourism. Of the total estimated costs of £7.6-8.5 billion, £3,1 billion was borne by the public sector, farmers and related industries, while £4.5-5.3 billion was estimated to be lost in the tourism and leisure industries (Mangen, and Barrell, 2003)

#### 2.3.2.1 Distribution of Welfare Change

Welfare effects for producers are usually estimated in terms of changes in producer surplus or net income. For an outbreak of a food borne disease and/or for introduction of non-indigenous species, the effects on producer welfare could be measured by the change in producer surplus caused by the outbreak. Figure 2 illustrates a situation with a hypothetical outbreak. As a result of an outbreak supply decreased from $S_0$ to $S_1$, while demand could decrease to $D_1$ or even $D_2$, consequently increasing or decreasing the price. However, for illustrative purposes, suppose demand for uncontaminated food items did not change (the direction of resultant price change is not important for the main argument, which is that not all producers are affected in the same manner). Then the change in producer surplus would be $A_1A_0P_oP_1$. However, this measure of change in aggregate producer welfare does not reflect the income distribution consequences. Not all producers of a commodity will be affected in the same manner (Paarlberg et al. 2003). Producers whose output had to be taken out of the market are affected differently from those whose product survived the outbreak and remained in the market. For producers whose product remained in the market, welfare change could be measured as area to the left of their supply and between the initial and new price (Figure 3a). Consequently these producers could be better off or worse off depending on the direction of price change. On the other hand, for the producers of a banned commodity, welfare is measured by losses in sales revenues, equal to $0P_0CQ_0$ (Figure 3b). Therefore, for cases such as FMD outbreaks, where not all of a given commodity supply is banned from the market, it may be more appropriate to decompose the effects on producers into two parts; the effect on producers who are directly affected by contamination, and the effect on producers whose products are not contaminated.

### 2.3.3 Consumption

A major consequence of agricultural terrorism is the effects of food scares on the demand for agricultural products. Essentially, consumer demand for commodities related to a contamination incident falls. Figure 4 shows the effect of decreased consumer demand caused by a food scare. In this figure, for simplicities case, supply is held constant. As a result of a food scare event the prices of products decrease and so do the quantities. This has a deteriorating effect on consumer surplus.

Usually, detected contamination of agricultural commodities results in bans of infected or suspected products. Consumers are affected by decreased availability of and increased prices for safe food products. At the same time, demand for a commodity, a certain brand of which has been contaminated typically decreases (Smith et al., 1998; Smith et al., 1988; Torok et al. 1997; Henson and Mazzocchi, 2002; Burton and Young, 1996). This implies change of consumer preferences at least in the short run. Although in the long run preferences are likely to return to pre-incident state, it is possible that some changes will occur permanently.

The actual effects of a "food scare" that result from agricultural sabotage in part depend on consumer perceptions, which could deem some commodities to be riskier then others. For example, sales of beef products in Great Britain decreased by 40% immediately after the announcement made by the British government in 1996 regarding a possible link between BSE and it's human version, nvCJD. Household beef consumption decreased by 26% relative to the previous year. However, this decrease was uneven for different cuts of beef. Beef products such as burgers and mince experienced substantially larger decreases in consumption than better cuts, such as high quality steaks (Atkinson, 1999).

Outbreaks of certain food borne diseases could affect the restaurant industry. Demand for eating out is likely to decrease in times of elevated public concerns regarding food safety, regardless of the type of commodity that was contaminated. Consider the case of *E. Coli* outbreak in Japan in 1996 where white radish sprouts served at school lunches were contaminated. As a result sales of fish, meat, and all restaurant meals decreased by 40 to 60 percent (Mermin and Griffin, 1999).

As in a case of advertisement, publicity of food borne disease affects the demand in a dynamic manner. The demand for an infected commodity changes most notably in the short run, while over the long run the effects of "food scare" may decrease or even dissipate. This process applies not only to a commodity with possible infection but also to related goods. For example, Burton and Young (1996) argue that the maximum short run effect of BSE on the demand for beef, pork, lamb and poultry in Great Britain was a 6% reduction in the beef and veal share, which occurred in the summer of 1990 when there was a maximum number of published news articles on BSE (735). In the long run, over the sample period (1961-1993), BSE has decreased the expenditure share of beef by 4.5 percent, while other meats gained in share (Burton and Young, 1996).

#### 2.3.3.1 Distribution of Welfare Change

Measuring the effects of agricultural disease outbreaks on consumer welfare is complicated by asymmetry in possible consumer responses. After contaminated items have been removed from the market, consumers could behave in different manners. One group of consumers could be relatively confident about safety of food commodities that are available in the market, while another *hypersensitive* (Paarlberg et al., 2003) group, might no longer consume the commodity. It has been shown that food-safety knowledge, attitudes and behavior vary depending on sociodemographic characteristics of population subgroups (Nayga, 1996). If, as a result of an outbreak, the price for the commodity decreased, then the group that is still consuming a given commodity experiences increased welfare, while those who completely stopped purchasing suffer welfare loss. If the price increased then both groups experience welfare losses, although to different extents. The proportion of hypersensitive consumers will affect the overall sign of consumer welfare change. Paarlberg et al. (2003) estimate that for a potential FMD outbreak in the US, if the proportion of hypersensitive consumers is less than 7%, then overall consumer welfare increases due to decreased beef prices. However, if the proportion of hypersensitive consumers is greater than 7% then overall consumers lose even with a decreased price for beef. Therefore, it is important to find out how the consumers would react to a potential food contamination in order to estimate welfare effects.

### 2.3.4 Role of Information Media Coverage

The effect of food contamination on consumers essentially manifests itself through information passed on to the consumers. Publicized food contamination creates “food scares”, which have the opposite effect of advertising. The result is that the demand for contaminated or a suspected commodity of brand “A” decreases substantially or disappears. However, the demand for the same commodity of an uncontaminated brand “B” may decrease, increase, or stay approximately the same. Hence, depending on the level of “food scare” and degree of substitutability, the price for brand “B” may increase, decrease or stay roughly unchanged.

The extent to which consumers adjust their behavior largely depends on media coverage (Nayga, 1996). Moreover, the information passed on to the consumers will have different effects on consumer behavior depending on the source of information. Sources perceived to have external reasons for asserting that consumers face low risk are likely to have a greater propensity to be discounted. Credibility and trust are two key concepts that determine consumer response to a given information source. Outbreaks of food borne diseases could affect consumer attitudes toward various sources of information. For example, consumer trust in opinions of family and friends, rather than experts, increased immediately after the 1996 BSE outbreak in the UK (Smith et al., 1998).

When it comes to food contamination, the media has two fundamental roles Nayga et al. (2004). One is to inform the public of available details about the incident, such as disease type, affected commodity and brands, contagiousness, precaution and treatment specifics etc. Obviously, the extent and content of information passed on to the population will affect purchasing behavior of consumers. Second is to facilitate restoration of lost consumer confidence. Nayga et al. (2004) show that availability of scientific information on food safety leads to positive effects on consumer perceptions and buying decisions. In the context of intentional food contamination this entails informing the population about safety of unaffected products and about containment of disease. The effectiveness of this coverage will play a significant role in the restoration of consumer confidence. In 1982, 80% of milk produced in Oahu (Hawaii) was contaminated due to heptaclor contamination. Smith et al. (1988) evaluated the effects of media announcements on the demand of milk in Hawaii during the sixteen months following the contamination incident. The model incorporated two types of media coverage. Negative coverage dealt with the recall of contaminated milk, while positive coverage reassured the population that unrecalled milk was safe for consumption. It was concluded that the effect of negative coverage dominated the effects of positive coverage. In other words, positive media announcements that followed negative announcements failed to fully restore consumer confidence lost due to media coverage of contamination incidents.

Media coverage of animal disease outbreaks will play a significant role in determining the response of consumers. Essentially media coverage is argued to alter public perceptions regarding food safety. However, it was found (Piggott and Marsh, 2004) that subsistence level demand for beef would decline by 0.144% in response to 10% increase in the beef safety index, measured by the number of publications that appear in news paper and magazines regarding beef safety. This estimate implies a decline of 0.024 pounds of quarterly beef consumption per person as a result of 10% increase in the beef safety index. Similarly there would be 0.25% decline in subsistence consumption of poultry as a result of 10% increase in poultry safety index. This implies a decline of 0.039 pounds of quarterly poultry consumption as a result of 10% increase in poultry safety publicity. Subsistence consumption of pork would decline by 0.13% as a result of 10% increase of pork safety publicity. Consumer response to food safety issues were found to be statistically significant but economically small especially relative to price effects and other health issues related to meat consumption such as health information.

### 2.3.5 Trade

Contamination of agricultural commodities could have devastating effects on trade. Businesses could potentially be forced into bankruptcy or greatly damaged because sabotage of agricultural production could result in abolishment of exports of a wide range of products related to infected or suspected commodities. For instance, in 1989 four outbreaks of staphylococcal food poisoning in the US were associated with eating mushrooms canned in China (Levine et al., 1996). The incident affected 99 people who ate at a university cafeteria, hospital cafeteria, pizzeria and at a restaurant, 18 of which were hospitalized. Investigations of mushroom plants in China by FDA (US Food and Drug Administration) investigators and consultants found several reasons for mushroom contamination, including widespread sanitation deficiencies at the processing facilities. In response, US FDA restricted imports of all mushrooms produced in China, which was approximately 50 million pounds annually. In 1989 all Chilean grapes were recalled from US and Canadian markets due to cyanide contamination. As a result, several hundred growers and shippers went bankrupt (WHO, 2002).

Due to the announcement of the British government regarding BSE in March 1996, the European Union imposed a ban on all UK beef exports worldwide. As a result, UK lost all of its beef exports which in 1995 were 300,000 tons, worth about 600 million pounds sterling, plus 70 million pounds sterling in live calves. At the same time, the price of beef cattle fell by 25%. In addition, furniture and other leather commodity markets were affected (Atkinson, 1999).

## 2.4 Background on Terrorism towards Agriculture

The basic goal of terrorism acts is to inflict fear and economic disruption. Agricultural sabotage related events represent a serious threat to public health and to the economy, although up to now such events have not been very common compared to other forms of terrorism. Therefore, in the next two subsections I compare agricultural sabotage to other forms of terrorism and discuss various options that are available for terrorists to inflict fear and chaos through agricultural avenues.

### 2.4.1 Agricultural Sabotage vs. Other Forms of Terrorist Threats

Terrorist threats can take a wide variety of forms. Possibilities include hijacking airplanes, planting explosives in populated areas such as shopping malls or public transportation systems, attacking vital infrastructure facilities such as nuclear power plants or hydroelectric dams, contaminating water supplies, spreading lethal biological, nuclear or chemical agents through air or water, food adulteration, etc. In fact it has been demonstrated that if certain modes of terrorism acts become too expensive, for example due to various preventative measures, terrorists are likely to switch to alternative modes of terrorism (Enders et al. 1990; Enders and Sandler 1993). Agricultural contamination is one of the possibilities, which needs to be investigated in order to prevent and, if necessary, respond to such an act of terrorism.

On one hand, agricultural sabotage, such as tampering with food supply might be easier to prevent and mitigate than other means of terrorism such as attacks through air or water. Food safety in developed countries is enforced in both government and private sectors. Infrastructures already exist to deal with food safety regulations and enforcement. Therefore, to account for increased probability of intentional contamination, these safety measures may only need to be enhanced rather than instituted. This aspect makes mitigation of agricultural adulteration a relatively easier task than fighting terrorism in military, transportation, or other areas. Moreover, the diversity of our food supply reduces the chances that the entire food supply will be adulterated. On the other hand, food is very vulnerable to intentional contamination. Centralized and widespread distribution of some agricultural commodities makes massive amounts of people susceptible to individual potential acts of agricultural terrorism. Overall, the complexity of agricultural distribution channels and often massive consumption of certain commodities makes agricultural adulteration mitigation a rather complex task.

### 2.4.2 Potential Agents for Agricultural Contamination

Securing the U.S. or any other country's food supply depends on numerous factors. These factors include economic, political, and international aspects to climatic conditions. Crop and animal diseases have always been a concern of producers as well as consumers. Conceptually, agricultural sabotage could be materialized through introduction of non-indigenous (non-native) species of plants, mammals, microbes, and other biological units, which could disrupt agricultural commodity markets (Pinmentel et al., 2000). In fact, introduction of non-indigenous species into agricultural production could bring substantial costs to society, even if they pose no serious threat to human health. For example, Field Bindweed is estimated to cause over $40 million in crop damages in Kansas alone annually (Shogren, 2000).

Food borne diseases cause approximately 76 million illnesses, 325,000 hospitalizations, and 5000 deaths annually in the United States (Mead et al., 1999). The threats to food supply are distinct and numerous. Recognizing possible agents that could cause such turmoil is essential in order to analyze the effects and prevention options of these threats. Today there are more than 250 documented food borne diseases (CDC, 2003). These illnesses could generally be grouped into four major categories based on causation type. First are bacteria such as *Campylobacter, Salmonella, E. coli O157:H7,* etc. Second are viruses, such as a group of viruses known as *Calicivirus, or Norwalk-like virus, and FMD*. Third are parasites such as *Giardia and Cyclospora.* Fourth, natural or artificial chemicals such as mushroom toxins and heavy metals. Known pathogens cause 38.6 million illnesses, of which 5.2 million are due to bacteria, 2.5 million due to parasites, and 30.9 million due to viruses (Mead et al., 1999). In terms of public health and safety, the CDC has prepared a list of highest priority categories of agents, which include those agents which are easily disseminated, cause high mortality and morbidity, can produce social disruption, and need special actions for public health preparedness (Sobel and Swerdlow, 2002). This list contains a wide range of agents such as *Clostiridium botulinum* neurotoxin, the most lethal substance known to man (which results in death from respiratory arrest if untreated ), *Shigella* spp, which can cause death rates of up to 20% among admitted patients without appropriate treatment, *E coli*, which is a highly infectious organism, *B anthracis*, Samonella serotypes, *Vibrio cholerae*, hepitatis A, *Cryptosporidium,* etc. Operationally any member of these categories could be used for intentional food contamination purposes.

Some of the most widely publicized agricultural contamination cases are FMD and BSE Outbreaks in UK. Prevention practices such as vaccination and plant treatment have been in place for a long time. In fact certain forms of diseases such as FMD and BSE in cattle have been almost completely eradicated by successful prevention practices. However, current situation demands extra caution when it comes to food safety. BSE has serious implications on human health. *Cruetzfield_Jacob Disease* (nvCJD), a human variant of BSE, is known to have caused 100 deaths worldwide. Unlike BSE, FMD is not usually fatal to livestock or humans, and consumption of the meat from infected animals is not considered a food safety issue (Ferguson et al., 2001). However, FMD is more contagious and easier to spread than BSE, which primarily spreads from consuming diseased meat. The spread and variability of FMD outbreaks depend on spatial distribution, size, and species composition of farms (Keiling et al., 2001). There have been around 40 documented cases of FMD in humans worldwide (Mathews and Buzby, 2001). The US has been free of FMD since 1929 (McCauley et al., 1979).

## 2.5 Avenues of Agricultural Terrorism

In order to mitigate possible agricultural terrorism acts one needs to consider a variety of possible scenarios. Reviewing past agricultural and/or food contamination incidents could contribute to identification of vulnerable segments in the agricultural industry. Of particular importance are points of concentration including centralized processing and distribution channels, which, if sabotaged, could pose threats to market stability and potentially result in a disease outbreak with significant bandwidth. It is also important to consider international sources of contamination.

### 2.5.1 Intentional Contamination

Throughout history there have been documented instances of terrorism through food supply with the purpose of causing injury and/or inducing terror on civilian populations. Food adulteration could originate anywhere along the food supply chain, starting from a farm and ending at a restaurant, food store or even a laboratory. For example, in 1996 a laboratory worker deliberately contaminated food to be consumed by co-workers with *Shegella dysenteria* type 2 and caused 12 people to become ill (WHO, 2002). Although this case does not represent a terrorist event of national significance, it portrays a possibility of intentional contamination of food supply. The only difference between this case and a agricultural terrorism event on a national level is the scale of the event, as, as defined earlier, bandwidth. A more serious case of food adulteration occurred in 1984 when members of a religious cult deliberately contaminated salad bars in ten restaurants with the salmonella *serotype typhinurium* in Dalles, Oregon. This resulted in 751 people becoming ill, which caused serious strains on local medical resources and nationwide fear of recurrence (Torok et al. 1997; FSIS, 2003). The authorities responded to the outbreak by closing all salad bars in the town. It took approximately one year of investigative work to link the outbreak to the religious commune, which operated a clinical laboratory where open containers carrying *serotype typhinurium* were found. It was inferred that the bacteria were spread by the customers mainly on salad bars and also in liquid coffee creamer in some restaurants. This case demonstrates how vulnerable the society is to intentional contamination of food. It is unlikely that any regulation could have prevented this outbreak. It would probably be unreasonable to suggest screening of customers at all restaurants where they sell self-serving food items. However, this incident does suggest using enhanced screening procedures when it comes to access to biological or chemical agents, such as those that were used in this incident.

Intentional food contamination could be originated at any level of food supply chain of nearly any agricultural commodity. However, vulnerability varies along the supply chain. Supply points which are most accessible to public are most vulnerable. Unfortunately, as the above examples demonstrate, supply points such as cafeterias and restaurants are difficult to safeguard against intentional food adulteration.

### 2.5.2 Unintentional Contamination

Naturally occurring agricultural introduction of non-indigenous species, which result in food borne disease outbreaks, demonstrate our potential vulnerability to biological and chemical terrorism directed towards food supply. Theoretically, a terrorist organization could sabotage the food supply after assessing the disease bandwidth and investigating the points of vulnerability along the farm to table supply chain. Hence, it is advisable to identify and examine the most vulnerable foods and processes that could be used for intentional food contamination.

To get an idea of possible vulnerable segments and areas along the farm to table food supply chain (figure 5), many documented cases of unintentional outbreaks of food borne diseases could be considered. For example, in 1985 there was an outbreak of *S. typhimurium* infection caused by contamination of pasteurized milk at a diary plant in the U.S. affecting 170,000 people (Ryan et al., 1987). The contamination was allegedly caused by unintentional mixing of contaminated milk with pasteurized milk. In September and October of 1994 *Salmonella enteritidis* gastroenteritis developed in 224,000 persons in the United States after they ate Schwan's ice cream. It was found that the outbreak was caused by contamination of pasteurized ice cream premix during transport in tanker trailers that had previously carried nonpasteurized liquid eggs containing *Salmonella enteritidis.* Consequently it was induced that food products, which did not require re-pasteurization should be transported in designated containers (Hennessy et al., 1996). Hepitatis “A” was responsible for almost half of the outbreaks of liver disease in Shanghai, China, affecting 292,301 people in 1988. It turned out that raw shellfish, such as clams, were responsible for causing outbreaks of hepatitis A (Halliday et al., 1991). The conclusion was drawn that it was necessary to enforce strict regulations related to harvesting and distribution of shellfish in order to ensure healthiness of marketed clams. In addition, it was suggested that residential effluent drainage into catching areas should be regulated. In 1996 in Sakai City, Japan, 7000 children became ill with Eschria coli 0157:H7 infection from contaminated radish sprouts served in school lunches, resulting in numerous deaths (Mermin and Griffin, 1999). Numerous outbreaks of Influenza Flu were responsible for a number of deaths and dozens of hospitalizations since 1996 in Hong Kong. During the outbreak in 1996 1.5 million chickens were killed to eliminate the source of the outbreak (CDC, 2004).

### 2.5.3 Biological Invasive Species

More than 50,000 species of animals, plants and microbes have been either accidentally or intentionally introduced into the U.S. in the past 100 years (Pinmentel, 2002). In the past 40 years the rates of biotic invasions have increased significantly due to population growth, rapid movement of people, alteration of the environment, and increased trade among nations. Some of these non-indigenous species have caused substantial economic losses in agriculture, forestry, the environment and other segments of the U.S. economy.

Alien plants, such as purple loosestrife, aquatic weeds, crop weeds, etc. are estimated to cause approximately $34,662 million in annual costs (Pinmentel, 2002). Non-indigenous mammals, birds, reptiles, amphibians, and fish cause about $40 billion in annual costs. Imported arthropods, such as crop pests, forest pests, imported fire ants, and others cause $20 billion in annual costs. Imported microbes such as plant pathogens cause $41 billion in annual costs. Non-indigenous livestock diseases are responsible for $9 billion in annual costs (Pinmentel, 2002). Generally, economic costs of biological invasions include impacts on production, price and market effects, trade, food security and nutrition, human health and the environment, and financial costs impacts (Evans, 2003).

#### 2.5.3.1 Foot and Mouth Disease

One of the most widely publicized case of unintentional agricultural contamination was the recent FMD outbreak in the UK. Between February 20th and September 30th 2001 there was a total of 2026 cases of FMD confirmed in Great Britain (Scudamore, 2002). Total losses from this outbreak were estimated to be £7.6-8.5 billion (Mangen and Barrell, 2003). FMD could be spread though air, transport vehicles, artificial insemination, milk related transmission, direct contact, and by wildlife such as birds, dogs, cats, and rodents. An additional complication with FMD is that the infected animals do not show the signs of the disease for a couple of weeks but they are contagious (Garner and Lack, 1995). This means the infected animals are spreading the disease before they are diagnosed and removed from the heard. Variations in weather, regional geography, farming practices, and farm-level variability in bio-security could all introduce spatial and temporal heterogeneity into transmission patterns. However, it is speculated that the most likely origin of the outbreak in the UK was contaminated meat products, which were used as feed for pigs (Scudamore, 2002). The most likely method of accidental introduction of FMD into the United States is from contaminated animal products, frozen semen, or animal feed imported from areas of the world, which have the disease (McCauley et al., 1979). In terms of agricultural terrorism these possible methods of FMD introduction point to vulnerable segments of agricultural sector which require increased attention in light of increased biosecurity awareness.

FMD outbreak in Great Britain spread into neighboring countries such as Netherlands, France and Ireland. It was inferred (Bouma et al. 2003) that the most likely route of infection in the Netherlands was the importation of Irish veal-calves via an FMD infected staging point in France. As a result, in Netherlands alone 26 outbreaks were detected and 260,000 animals were killed, 1800 farms were vaccinated and subsequently depopulated.

Based on the FMD outbreak in Great Britain, farms 0.5,1 and 1.5 km. away from a single farm affected by FMD have probabilities 0.26, 0.06, and 0.02 respectively of becoming infected (Ferguson et al., 2001). Farms 3-5 km away from an infected piggery have probability 0.0153 of being infected due to wind borne and local spread within 3 days of detecting clinical signs of the FMD outbreak (Sanson, 1993). Probabilities of infection spread for sheep and cattle farms are assumed to be approximately one tenth of the levels for pigs. The evolution of the epidemic depends in part on the distribution of times between the four key events: 1) infection of a farm, 2) the report of a suspected infection, 3) confirmation of disease, and 4) slaughter of the animals on the infected farms (Garner and Lack, 1995; Ferguson et al., 2001). Large farms are considered to be more susceptible to the disease. Cattle are more susceptible to the disease than sheep (McCauley et al., 1979; Ferguson et al., 2001).

### 2.5.4 Centralized Distribution Channels

In recent years, centralized production, processing and distribution of agricultural products have been increasing features of US food supply. This development has increased the risk of large outbreaks of food borne diseases (Sobel and Swerdlow, 2002; Khan et al., 2001).

Centralized production, processing and distribution of agricultural commodities present serious threats when it comes to agricultural contamination. The 1996 outbreak of *E. Coli* in Japan was shown to have occurred due to contaminated white radish sprouts, which was served to school children through the lunch program (Mermin and Griffin, 1999). Over 7,000 people where affected by the outbreak. As a result of intense public anxiety restaurants and hotels throughout Japan experienced a decrease in their businesses. Sales of fish, meat, and restaurant meals decreased by 40 to 60 percent. This case demonstrates the potential dangers of centralized food distribution. In the case of centralized food distribution channels, such as school lunches, many people tend to be affected because the same meals are served to many schools. This demonstrates the need for upgrading the food safety measures at facilities related to centralized food production, processing and distribution, especially those that are more vulnerable to intentional contamination and those with lower or outdated food safety criteria.

However, centralized food production and distribution also has certain advantages. For example, improvements in operations of a large producer might be easier instituted than simultaneous improvements in smaller producers that would lead to equivalent improvements in food safety. Raw consumption of certain foods implies the need for control measures directed at farms and other production establishments because consumers can do little to protect themselves.

### 2.5.5 International Sources of Contamination

Most countries have established food safety infrastructures, which could be adjusted or expanded to reflect higher alert for acts of food supply sabotage. However, the diversity in the food supply system makes prevention extremely difficult especially when taking into account international sources. Many developing countries have less developed food safety infrastructures and are more vulnerable to intentional food contamination. Agricultural contamination in foreign countries, intentional or unintentional, poses threats to domestic food markets due to modern global network of international trade. Food commodities that have been intentionally or unintentionally contaminated and imported to the U.S could have substantial health effects.

For example, in 1995 there was an outbreak of Salmonella detected in 17 states in the US and in Finland (Mahon et al., 1997). A total of more than 242 cases were documented out of a possible 5000-24000 cases considering underreporting. It was established that the infection among American and Finish patients was caused by consumption of contaminated alfalfa sprouts, which were produced by different growers. However, contaminated alfalfa sprouts were grown from the seed that came from a common seed shipper in the Netherlands. Hence it was concluded that seeds which were contaminated before shipment were the cause of the outbreak. To prevent future similar outbreaks the suggestion was made to enhance decontamination of seeds before shipping. This could be achieved by soaking the seeds in chlorine bleach at high concentrations.

In another example, outbreaks of *cyclosporiasis*, with 1465 cases reported by 20 states in North America in 1996, were linked to consumption of Guatemalan raspberries (Herwaldt et al.,1997). It was established that as few as five Guatemalan farms could have accounted for the 25 of the 29 events where raspberries were served and for which a single exporter could be traced.

The 1996 outbreak of E. Coli in Japan due to contaminated white radish sprout was attributed to contaminated seeds imported from the U.S. (Mermin and Griffin, 1999). In response to this outbreak the Japanise national institute of health has placed one physician at the Division of Emerging Diseases at the World Health Organization and one physician at the Epidemic Intelligence Service at the Centers for Disease Control and Prevention of the U.S. Department of Health and Human Services. The reason for those placements was to gain experience in communicable disease control and outbreak investigation.

## 2.6 Prevention

Deliberate food contamination incidents via massive disruption of food processing, storage, transportation or distribution, could seriously damage economic stability. Therefore, it is important to initiate and/or enhance preventative measures, which would provide increased security to the food supply of the economy. Clearly, food supply of a gigantic economy such as the U.S. is difficult, if not nearly impossible, to completely safeguard against any possible assault. Nevertheless, eliminating as many conceivable venues of disaster as possible is necessary to decrease the vulnerability of the economy. Along the farm to table food supply chain (Figure 5.) measures such as tracing systems and recalls, monitoring and examination of product qualities, reducing access to chemical, biological and nuclear materials, and other actions can be used to prevent agricultural and food sabotage (FSIS 2003; Khan et al., 2001).

Deliberate food contamination using chemical, biological or nuclear agents is a relatively new threat to national security. The key to preventing food adulteration is to enhance existing food safety measures, and to establish new food safety measures based on vulnerability assessments. Hence, the most vulnerable commodities and their production and supply processes need to be identified. For example, prevention measures should be enhanced at the most readily accessible agricultural and food processes, foods that are most vulnerable to undetected contamination, commodities that are most widely distributed, and the least supervised agricultural and food production areas and processes (WHO, 2003).

It is also important to increase security measures at central production, processing and distribution facilities. The control and screening of access to certain areas, chemical and biological agents, raw products, equipment, and other key factors in the food supply chain, needs to be enhanced based on the vulnerability assessment.

### 2.6.1 Agricultural Production

Ensuring the safety and security of food supply starts at the farm level of the food supply chain. Some of the areas of critical importance at this level are monitoring and control of farm animals, feed and feed ingredients, seeds, pesticides, irrigation water, and harvesting practices, such as open air drying, etc. Different agricultural production processes will require different prevention methods.

#### 2.6.1.1 Prevention of Contagious Animal Diseases

Enhanced monitoring and quality control measures might have detected contaminated meat and consequently prevented the massive FMD outbreak, which paralyzed beef farming in the UK. Enhanced monitoring and quality control measures might have also prevented an outbreak of Salmonella in the US and Finland caused by contaminated seeds exported from The Netherlands (Mahon et al., 1997). Many more areas could probably be identified. However, since analysis of all possible threats is probably impossible, emphasis could be placed on the most vulnerable points and on determining deviations from normal characteristics.

Outbreaks of farms animal diseases such as FMD have been shown to have devastating consequences (Bouma et al., 2003; Burton and Young, 1996; Ferguson, et al., 2001; MaCauley et al., 1979). Allegedly, the most likely origin of FMD outbreak in the UK was contaminated meat products, which were used as feed for pigs (Scudamore, 2002). Therefore, close feed inspection on a regular basis may be essential for prevention of an outbreak of FMD or similar diseases. In terms of designing regional mitigation policies for outbreaks of infectious diseases, such as FMD, estimates of spatial distribution, size, species composition of farms (Keiling et al., 2001), and contact rates (Nielen, et al., 1996) between farms need to be developed.

#### 2.6.1.2 Anti-microbial Livestock Drugs and Vaccination

Anti-microbial drug (antibiotic) use on farms has been surrounded by controversy since the practice began in the 1940s (Mathews at el., 2001). Anti-microbial drugs are designed to kill disease-causing microorganisms such as bacteria and fungi. However, at low levels these drugs are also used to promote livestock growth. This type of drug application raises some issues. The problem is that there are scientific uncertainties about implications of using anti-microbial drugs as growth promoters. There are different opinions within the government about the risks to public health posed by using anti-microbial drugs in farm animals. First, livestock drug residues may remain in final products and cause human illness. Second, microorganisms, such as bacteria may be developing resistance to anti-microbial drugs. In a related case, an outbreak of an anti-microbial resistant salmonellosis attributed to pasteurized milk in Illinois in 1985 affected about 170,000 to 200,000 people (Ryan et al., 1987). It was considered that since many people who drank the contaminated milk would not have become ill if they had not been exposed to anti-microbial drugs, the anti-microbial resistance of the disease may have increased the size of the outbreak. It was also considered that the use of anti-microbial drugs in dairy farms could lead to the emergence of resistant strains of bacteria. However, it is uncertain what levels of drugs are sufficient to cause drug resistance. It is also uncertain whether bacterial drug resistance would decline if low-level use of anti-microbial drugs were stopped.

Vaccines for diseases such as FMD are available. However, vaccination presents it's own set of problems. For example, the European Union (EU) is against general vaccination because it would damage its export markets. The reason is that carrying "Disease free" status is extremely important for participants in international trade. Disease free countries such as the US have strict measures against diseased imports. Standard detection tests look for antibodies against FMD as a sign of infection (McCauley et al., 1979; Mathews and Buzby, 2001; Mathews et al., 2001; www.economist.com, 2001). These are the same antibodies that vaccination produces. Therefore, vaccinated animals are excluded from trade. In addition, vaccination provides protection for only six to twelve months. Hence, repeated vaccination, which is not cheap, is required to fight the disease. In addition, while vaccinated animals may appear to be healthy, they may still be carriers of the infection. This means that vaccinated animal could transmit the virus to other, healthy animal, thus leading to more vaccination costs.

Another problem with vaccination is that most vaccines are effective only against certain strains of a given disease. This makes it difficult to protect the production from disease occurrence. For example, there are at least 7 immunologically distinct types of FMD, each with 3 to 29 different subtypes. A vaccine against one virus type does not necessarily protect against another virus type (McCauley et al., 1979). So even if it was decided to vaccinate against FMD, which target virus type and subtype should be vaccinated against first? Perhaps the answer depends on relative probabilities of occurrence, and damages. The type and subtype that is most likely to occur and most destructive should be vaccinated against first. Hence, quantities of proper vaccines to stock prior to the outbreak are investment decisions that would have to be made ex ante.

Most studies that compare various vaccination regimes to various slaughter systems as preventative and responsive strategies respectively found vaccination strategies to be economically inferior to slaughter strategies (Berentsen et al. 1992, Schoenbaum and Disney, 2003). However, Bates et al. (July 2003) found that ring vaccination would be economically more effective than slaughter strategy if it was possible to differentiate vaccinated and FMD infected animals. In a similar study Bates et al. (February 2003 a, b) find that pre-emptive slaughter of high risk herds and vaccination of all animals within a specified distance of an infected herd decrease the duration of an epidemic compared with baseline eradication strategy.

#### 2.6.1.3 Surveillance and Detection

Effective response to a food borne disease outbreak depends on timely detection of a contamination incident. Surveillance systems, including epidemiological investigations, could be used to identify the agent and contaminated food and eliminate the effected commodity from the market. The objectives, as well as the procedures, of epidemiological investigation would be similar whether the contamination was intentional or unintentional. In either case, the steps would involve identification of the causative agent as well as the manner of contamination and transmission.

Detection of an outbreak of food borne disease depends on the ability of public health officials to identify increased cases of a particular illness by observing multiple patients with a specific clinical syndrome. Laboratories and epidemiological investigations could provide vital information to be applied in surveillance systems. For example, the CDC in collaboration with the state health departments maintains a surveillance system for cases of botulism. The State Department of Health is notified when a clinician faces a botulism case and requests an antitoxin treatment. State health departments in turn conduct an investigation to detect additional patients, and identify and eradicate the contaminated food supply (Sobel and Swerdlow, 2002). PulseNet is a network of public health laboratories that generate unique DNA patterns for food borne pathogens. Detection of pathogens with identical patterns signals the possibility of an outbreak. Similarly, the salmonella outbreak detection algorithm is designed to detect increases in salmonella serotypes reported to the CDC. A state epidemiologist is alerted if the number of reported cases exceeds the expected number. However, these passive surveillance systems tend to underreport the incidents because not all ill patients seek medical care, not all clinicians test for every food borne pathogen, and not all laboratories report individual cases to health officials. For example, around 20 to 100 cases of salmonellosis are unreported for each reported case (Khan et al., 2001). FoodNet conducts active surveillance of diagnosed cases of ten enteric bacterial as well as parasitic infections and of haemolytic-uraemic syndrome.

##### 2.6.1.3.1 Farm Animal Surveillance and Detection

Most of the studies that investigate FMD mitigation options concentrate on vaccination and slaughter. Less attention has been devoted to surveillance and detection systems, which would allow for timely and more effective response measures. Although some attention has been raised towards surveillance systems (Bates et al. September 2003; Akhtar and White, 2003), no empirical investigation has been performed, to the best of my knowledge, on the merit of such policies relative to vaccination and slaughter.

One of the possible surveillance and detection systems could be to conduct periodic screening of animals. This practice would assist in avoiding massive outbreaks of infectious diseases such as FMD. Regular screening and testing of farm animals directed towards evaluating animal health could assist in preventing a successful intentional spread of FMD or similar disease. Earlier detection through periodic testing would allow for timelier implementation of response strategies such as slaughter, disposal, cleaning and disinfection. Latent period of FMD infected animal is around one week (Garner and Lack, 1995), which means that frequent testing of animals could detect FMD carriers before the clinical signs of the disease appear. Hence, frequent animal testing could decrease the time of unobstructed spread of the disease. Therefore periodic testing of animals could decrease the magnitude and associated costs of needed response actions as well as the value of lost agricultural product. Moreover, screening and testing of animals could be conducted by either a regional veterinarian or employees of cattle operations provided adequate training in testing procedures.

### 2.6.1.4 Farm Level Decision Making

Adoption of enhanced food safety measures at the farm level depends on private implications of such strategy. From the farmer's perspective, the attractiveness of the preventative measures against possible food terrorism acts depends on the impacts of such measures on profitability and risk in the short run and in the long run. Hence, the strategy will be adopted either because of profitability and associated risks, or because of imposed constraints (McCarl, 1981). Some of the issues related to farm level adoption of prevention strategies are:

1. How is farmer welfare affected by various prevention strategies? That is, what are the effects on profits and profit variation? How are the farmer's welfare dimensions, such as profitability and risk aversion, valued when it comes to choosing between strategies that have various degrees of prevention measures? Are there other dimensions of welfare affected by the strategy, and if so, to what degree?
2. Which one of the preventative strategies is most appropriate from a social welfare maximization standpoint? What are the dimensions of social welfare affected by "food terrorism and it's preventative measures? For example, what is the relative importance of having a low probability of an outbreak of a food borne disease? What is the probability level of a "food terrorism act" at which the society is willing to bare additional costs to prevent food tampering. Obviously at low probability of food contamination the society is not too concerned about it to be paying for extra costs of prevention measures. However, at some higher probability level, paying premiums for avoiding an outbreak of food borne disease becomes a reasonable move.
3. How could a food terrorism prevention policy be designed so that a socially optimal strategy is also most optimal from a farmer's perspective? Are subsidies and/or taxes going to be needed to encourage adoption of certain strategies rather than others? How effective would regulative strategies be in upgrading safety measures at farms?
4. Finally, what are the strategies that could be employed for preventing acts of food terrorism at the farm level? For example some of the options are, tamper resistant or tamper evident seeds and animal feed, increased monitoring of facilities, restricted access to vulnerable materials and areas, employee screening, animal vaccination, etc. How are these and other

options ranked in terms of importance in prevention of food terrorism incidents?

### 2.6.1.5 Prevention as a Production Factor

It has been argued that prevention practices, often in the literature referred to as damage control, differ from production inputs in a way that needs to be reflected in optimal strategy selection. First, damage control agents, such as pesticides, antibiotics and immunization, do not generally enhance productivity directly as do standard production inputs. Damage control agents are meant to facilitate prevention of negative outcomes such as pest and/or disease outbreaks, fires, frosts, etc. This characteristic of prevention options needs to be reflected in modeling of strategies for preventing possible agricultural sabotage incidents. Second, direct production inputs could interact with damage control agents and, thus may affect effectiveness of damage control. For example, fertilizer stimulates the growth of weeds, thus changing the effectiveness of herbicides. Contrary to the first point, it has been argued that damage control inputs could affect output mean as well as variance. Variance effects are, in part, determined by the interaction between damage control input and stochastic element in the abatement, or damage control, function (Saha et al.,1997).

### 2.6.1.6 Risk Considerations

At the farm level, risks of agricultural contamination are dealt with in two ways, mitigation and adaptation (Shogren, 2000). Mitigation essentially refers to actions that prevent or contribute to prevention of agricultural contamination. For example, enhancing feed inspections would reduce the chances of introducing non-indigenous species such as FMD or BSE infected livestock. Adaptation refers to activities, which will reduce the impact of a contamination incident if realized. For example, a farmer may choose to diversify a portfolio of produced commodities in order to decrease his/her risks of facing adverse impacts in case a given commodity gets contaminated. This behavior would represent adaptation to the possibility of an agricultural contamination.

Mitigation activities, such as applying sunscreen in order to reduce the risks of skin cancer, endogenously influence the probability of an adverse outcome. For example, the farmer may choose to vaccinate cattle to reduce the chances of disease occurrence. Hence, the probability of agricultural contamination is in part determined by preventative activities, which are determined endogenously. Adaptation activities, such as adjusting crop mix, on the other hand, affect the magnitude of adverse outcomes if realized. Hence, mitigation and adaptation activities affect both odds and severity of adverse outcomes such as agricultural terrorism. Therefore, economic, as well as natural science, models of risk assessment need to consider the role of prevention and adaptation strategies as antecedents of the risk of agricultural contamination.

#### 2.6.1.7 Risk Aversion and Insurance

Prevention and response actions affect not only expected returns but also the variance of returns across states of nature. Risk adverse decision makers are usually more likely to invest in prevention and response strategies, and diversify their portfolio to reduce vulnerability towards high variance of returns. As risk adverse decision makers, farmers often rely on insurance programs to decrease variability of their profits caused by agricultural sabotage, climatic conditions or other stochastic conditions. Optimum design of such programs and farmers' behavior under risk with and set of options including insurance have previously been investigated (Coble at al., 1996; Knight and Coble 1997; Makki and Somwaru, 2001). It was found that participation of farmers in crop insurance programs is influenced by such factors as level of risk, expected indemnity payments from the contract, cost of Insurance, premium subsidy (Makki and Somwaru 2001), competing risk management options (Sherrick et al., 2004) and demographic differences.

If applied to the case of agricultural terrorism similar principles would apply. Agricultural terrorism insurance, as an option to reduce vulnerability of farmer income, is likely to be adopted under similar conditions as regular crop insurance. In other words factors such as insurance costs, indemnity payments, risk premium, and effectiveness and costs of alternative mitigation options will play significant roles in insurance adoption.

#### 2.6.1.8 Preventative Slaughter

Slaughter of animals in a region not yet infected by a highly infectious disease could be considered a preventative measure. By slaughtering the animals under risk of exposure to the disease the likely number of diseased animals would be reduce, thus we would reduce the spread of the disease. Fore example, in 1997-98 outbreak of classical swine fever (*CSF*) in Netherlands preventative slaughter involved 26 farms within 1 km radius of the first two detected farms (Mangen and Burrell, 2003). Moreover preemptive slaughter in case of an outbreak allows the producers to market their animals before they are possibly infected and become unmarketable.

#### 2.6.1.9 Farmer Spillovers

Many of the preventative strategies involve secondary effects that are not usually considered in private decision making of a given farmer. When a farmer applies pesticides the benefits accrue not only to him but also to adjacent farmers (McCarl, 1981). In a similar fashion, the benefits of preventing an outbreak of a contagious disease in plants or animals to various degrees accrue to farms within certain proximity. Hence, even the farmers that would not adopt prevention strategies could benefit from prevention measures executed by neighboring farmers. This introduces a "free rider" problem of a public good, where private decision making will result in under-employment of preventative strategies (Hanley at al., 1997). Consequently, for each prevention strategy, the extent of a "spillover" effect needs to be investigated and taken into account for proper policy design purposes. Proper policy would reflect true benefits and costs, which include spillover effects of adopting preventative measures, such as vaccination.

### 2.6.2 Processing and Manufacturing Procedures

The key to preventing food sabotage is to upgrade production processes and quality control measures at central production facilities. For example, in the outbreak of antimicrobial resistant salmonellosis attributed to pasteurized milk, which affected more than 168,000 people in Illinois in 1985, one of the possible reasons of the outbreak could have been the unusual sequence of operations at the plant where the outbreak originated. Pasteurization at this plant was an early step in processing, which was followed by careful post-pasteurization handling of milk during separation, blending, and other steps to prevent contamination of the milk. However, a few millimeters of contaminated milk mixed with pasteurized milk in later stages could have caused the outbreak (Ryan et al., 1987).

There has been some advancement made in this respect. For example, recent declines in salmonellosis campylobacteriosis coincide with changes in meat and poultry slaughtering practices at processing facilities mandated by the Pathogen Reduction and Hazard Analysis and Critical Control Points (HACCP) rule of the USDA (Khan et al., 2001).

### 2.6.3 Storage and Transport

Food borne disease could clearly originate from food contamination at storage or transportation facilities. Obvious options to enhance prevention measures at these facilities are to install monitoring systems, reduce access to vulnerable areas and lethal materials, screen personnel that have access to vulnerable areas and lethal materials, and monitor sanitary compliance of storage areas and transportation means. Although there are no documented cases of deliberate contamination at storage or transportation facilities, lessons could be learned from unintentional contamination cases. For instance, the 1994 Salmonella outbreak, which developed in 224,000 persons in the United States, was traced to eating Schwan's ice cream. Contamination of Schwan's ice cream was caused by contamination of pasteurized ice cream premix, which was transported in tanker trailers that had previously carried nonpasteurized liquid eggs containing *Salmonella enteritidis*. Consequently it was concluded that food products, which did not require re-pasteurization should be transported in designated containers (Hennessy et al., 1996).

### 2.6.4 Retail Distribution and Food Service

Food sabotage at distribution outlets or food service points such as restaurants is likely to go undetected before contaminated produce reaches consumer's plates. Unlike earlier stages along the farm to table food supply chain, products sold at retail distribution points and restaurants do not go through any additional inspection or processing, other than cooking, which rarely involves testing for chemical or nuclear agents. Therefore, measures that would facilitate prevention of food adulteration should be initialized or enhanced. Relying on tamper-resistant or tamper-evident seals, which have been used for some food items and for pharmaceuticals is one way to improve food safety at distribution outlets. Monitoring and surveillance of such facilities as retail or wholesale distribution points and restaurants may help to prevent deliberate food contamination. For example, surveillance systems might have prevented intentional restaurant salad bar contamination that occurred in The Dalles, Oregon in 1984 infecting 751 people (Torok et al., 1997).

### 2.6.5 Trade Inspection

Due to the global nature of modern economy it is easy to conceive the possibility of agricultural sabotage, which could originate in remote countries and regions. In fact, there are numerous documented cases of unintentional contamination of agricultural commodities (Mermin and Griffin, 1999; Levine et al., 1996; Mahon et al., 1997; Herwaldt et al.,1997), which were manifested through international trade. Therefore, the importance of enhancing inspection of imported agricultural commodities cannot be overemphasized. Clearly, commodities that fail to meet international safety criteria should be excluded from trade.

Trade restrictions that arise due to detection of contaminated commodities are readily accepted. However, it is often difficult to determine whether a given barrier reflects a health concern or is a form of disguised protectionism. Under current trading rules nations are allowed to use trade barriers to protect human, animal and plant health, but such barriers cannot be used as disguised protectionism. Before the Uruguay Round of GATT (General Agreement on Tariffs and Trade), the U.S. did not import any cattle, sheep, swine, and some other forms of meat from countries that were not FMD free. After the Uruguay Round, imports from disease-free regions of a country could be allowed even if the disease may have occurred in other regions of the exporting country (Paarlberg and Lee, 1998).

## 2.7 Tracking

Effective mitigation of a food borne disease outbreak depends not only on detection of the outbreak, but also on identification of the sources of original contamination. Timely determination of the source of contamination can greatly facilitate rapid removal of all contaminated products along the food processing chain. Tracing systems, which allow for comprehensive market recalls, are critical in responding to food contamination, whether intentional or unintentional. This issue is especially relevant for agricultural production systems (WHO, 2002), where raw products produced on small farms are often combined to form larger shipments. With no tracing system in place it is difficult to identify the producer of a contaminated product. Therefore, it is difficult to narrow and recall only potentially contaminated products along the food supply chain.

In the case of animal diseases, such as FMD or BSE, the benefits of tracking mechanisms, such as ear tags, include limiting the spread of the disease, faster trace back of infected animals, reducing production losses due to the disease, reducing the costs of government control, reducing trade losses, and boosting consumer confidence (Disney et at., 2001). The objective of tracing systems is to find all farms linked to infected areas, and prevent any further disease dissemination from infected locations.

## 2.8 Response and Control

Response involves actions which are implemented after the event of agricultural sabotage has taken place and are intended to minimize the impact of contamination. These activities may include stopping the spread of and eradicating an outbreak of a possibly infectious contamination. Given that the agent, the carrier and the original source of contamination have been identified, it is necessary to remove all infected commodities from the reach of consumers and the public in general. This requires establishing regulations that address marketability of suspected commodities, destruction of infected commodities, containment of the disease, accesses to vital facility, etc.

For instance in response to the 2000 FMD outbreak in England, in addition to the policy of slaughtering animals on infected farms, further control measures were introduced, such as a ban on all animal movements, closure of markets, and restricted public use of footpaths across agricultural land (Ferguson et al., 2001). Generally the options to control disease transmission among animals include mass vaccination, slaughtering and decreasing mixing rate. Likewise, Jalvingh et al. (1999) categorize the control mechanisms for the spread of classical swine fever in The Netherlands in 1997-98 into diagnosis of infected farms, depopulation of infected farms, movement control, tracing, and pre-emptive slaughter.

Effectiveness of response depends on surveillance, preparedness and communication levels (WHO, 2002). The better the surveillance and communication, the more prompt is the detection of an outbreak which will lead to timelier, more effective response measures. On the other hand, better preparation levels should lead to more effective response measures such as medical treatments, identifying the sources of an outbreak, banning contaminated products, etc.

### 2.8.1 Movement Ban and Transportation

An immediate response to infectious agricultural contamination is to ban movement of contagious commodities across regions. The purpose of movement bans is obviously to stop or at least slow down the spread of infection. In case of an outbreak of a disease such as FMD it is necessary to ban movement in and out or the general area of the outbreak. For example, in the Netherlands after detecting FMD infected animals the immediate regulative response was a 72h movement ban in the whole country for all transports of livestock, poultry and conveyances for transporting these animals (Bouma et al., 2003). This strategy will reduce the mixing of animals and thus will reduce the likelihood of healthy animals getting infected by diseased animals at staging points, sale barns, and other livestock facilities. It also decreases movement in and out of infected areas, thus reducing the spread of the disease.

Transporting infected animals from one region to another is the surest way of spreading the disease. Therefore, it is vital to regulate animal movement as a response to FMD outbreak to slow down the spread of the disease. For example, During 1997-98 outbreak of classical swine fever in Netherlands all transportation was banned within a quarantine zone of 10km for at least 42 days (Mangen, and Barrell, 2003). However implementation of transportation ban necessitates depiction of animal movement system in the region. Both heterogeneity of animal movement related to specific farms and the dynamics of flow of animals between farms are to be taken into account when examining the animal transportation system (Bigras-Poulin, et al., 2004). In addition, a highly contagious disease such as FMD could be also spread by public vehicles moving from infected to uninfected regions.

### 2.8.2 Slaughter and Vaccination

In the case of a highly contagious disease such as a FMD outbreak, it is essential to stop the spread of and eradicate the disease as quickly as possible. Vaccination and slaughter have been the most common responses to highly infectious animal disease outbreaks. Ferguson et al. (2001) call for cost-benefit analysis of mass vaccination options versus slaughtering based control of infrequent outbreaks. Schoenbaum and Disney (2003) investigated the effectiveness of four slaughter and three vaccination strategies under varying conditions of herd sizes and rates of disease spread in the U.S. The slaughtering options included slaughtering only infected herds, slaughtering herds with direct contact with the infected herd in the 14 days prior to the detection of the infection, slaughtering herds within 3km distance of infected herd, and slaughtering herds with both direct and indirect contact with the infected herd. Vaccination options included no vaccination, vaccinating all herds within 10 kilometers of the infected herds after 2 herd infections were detected, and vaccinating all herds within 10 kilometers of the infected herds after 50 herd infections were detected. The choice of the best mitigation strategy depended on herd demographics and the rate of contact among herds. Generally, ring slaughter (3 km) was more costly than other slaughter strategies. Ring vaccination was more costly than controlling with slaughter alone. However, early ring vaccination decreased the duration of outbreaks.

Garner and Lack (1995) investigated the effectiveness of four control options for FMD, involving “stamping out”, where no vaccination is applied but animals in contact farms are slaughtered and destroyed (Berentsen et al., 1992), dangerous-contact slaughter, and early or late ring vaccination in three different regions of Australia. They found that if FMD is likely to spread rapidly then slaughter of dangerous contact and infected herds reduced the economic impact of the FMD outbreak. Early ring vaccination turned out to reduce the size and duration of an outbreak, but was uneconomic when compared to stamping-out alone. Keiling, et al. (2001) found that both ring slaughtering and ring vaccination are effective if implemented rigorously, although ring slaughtering is more effective. Neighborhood slaughtering is found to be more effective than neighborhood vaccination. They also argue that spatial distribution, size, and species composition of farms all influence the pattern and regional variability of outbreaks.

Morris et al. (2001) found that delaying the slaughter of animals at the infected farms beyond 24 hours would have slightly increased the size of the FMD epidemic in Great Britain in 2001. Failure to carry out pre-emptive slaughter of animals at the susceptible farms would substantially increase the size of the epidemic. Vaccination of up to three of the most outbreak dense areas, in addition to an adopted control policy, such as slaughter, would slightly decrease the number of infected farms. However, relying solely on vaccination and disregarding other control policies would significantly increase the size of an outbreak.

Although slaughtering option has been shown to be most affective in most circumstances for eliminating the disease (Schoenbaum and Disney 2003; Garner and Lack 1995; Keiling et al., 2001; Morris et al., 2001; Berentsen et al., 1992), it is possible that the farmers may choose not to slaughter their animals unless given monetary incentives in the form of compensation/subsidy. Therefore it is relevant to investigate what type of compensation will need to be provided to prompt preemptive slaughter of healthy animals in case of an FMD outbreak?

### 2.8.3 Communications

Rapid and effective response to an unintentional, and especially to an intentional massive food contamination incident, requires prompt communication between health care providers, public health officials at various levels and government agencies. Currently the CDC has a 24-hour capacity to respond to reports of food borne disease emergencies (CDC, 2003). The CDC can contact all state epidemiologists and directors of public health laboratories regarding surveillance issues and outbreaks.

Intense media coverage of food adulteration is to be expected. Accurate information is to be delivered regarding the nature of the incident, suspected and/or affected food commodities, possible measures to prevent exposure, and applicable immediate treatment actions in case of exposure.

## 2.9 Decision Support Tools

Level of preparedness is to a great extent determined by the availability of decision support tools. Such tools include procedures to detect infected agricultural segments, such as farms, protect uninfected segments from exposure to the virus, and to manage response and control strategies. Decisions made during the first couple of weeks of an outbreak are likely to be crucial in reducing the size and length of an infectious disease outbreak. Decision support tools, such as EpiMAN, developed in New Zealand for response and control of potential FMD outbreaks, could be used for detection of an outbreak, management of infected farms, movement control measures, and cleaning and disinfection measures (Morris, et al., 2002; Sanson, 1993). Decision support tools could allow the choosing of a portfolio of response and prevention actions, including examinations of the fixed costs and irreversibility dimensions of certain actions (McCarl, 2003).

## 2.10 Preparedness and Training

Preparedness plans are developed and implemented before the incident occurs. To a great extent preparedness depends on surveillance, detection tracking mechanisms. In addition, preparedness includes clear formalization and delegation of responsibilities prior to the event of bio-terrorist alert. Law enforcement and public health authorities need to have guidelines developed for the effective response to take place. For example, some of the components of preparedness are, ability of detection, linkage between relevant government agencies, training, and vulnerability assessment as discussed in the Guidelines for Establishing and Strengthening Prevention and Response Systems (WHO, 2002).

Simulated exercises organized by various governmental agencies have been used to test preparedness (Sobel and Swerdlow, 2002). The exercises allow one to assess rapidity of detection and notification, evaluate the adequacy of existing resources for doing epidemiological investigations, establish time to collect, analyze, and disseminate data, evaluate the adequacy of available medical resources, and to practice collaboration between parties involved in response activities.

### 2.11 Medical Response

Medical response is a critical component of food borne disease outbreak mitigation. Whether the contamination is intentional or unintentional, medical response steps in terms of treatment of casualties is approximately the same. Depending on the agent and number of casualties, medical personnel and supplies may need to be transported to the outbreak site.

### 2.12 Existing Prevention and Response Costs Estimates

McCauley et al. (1979), who evaluated the economic consequences of a potential outbreak of FMD in the US, assume a $0.30 cost of production per dose of vaccine in the U.S. in 1976 dollars. They also estimate by using budgeting that it would cost $152,160 to test 1 million doses of FMD vaccines. Transportation costs are assumed to be around $10 per 1,000 pounds for 1,400 miles. Storage costs were estimated to be $0.72 per hundred pounds for unloading and reloading, plus $0.52 per 100 pounds per month for refrigerated storage. They also report calculated costs of vaccination teams, costs of district offices, costs of state offices, costs of emergency programs, and costs of vaccine evaluation teams. Costs of a one-year surveillance program, conducted by replacing vaccination teams with evaluation teams, that would follow the completion of a vaccination program were estimated to be $34,197,872 for 37,895,000 livestock heads. When it comes to slaughter programs they assume that 0.5 percent of cattle, swine and sheep will be slaughtered due to infection or exposure. Costs of depopulation were estimated to be $79, $48, $27, $24, $24 per head for dairy cattle, feedlot cattle, beef heard, swine and sheep respectively. Indemnification costs were $190, $80, and $37.5 per head for cattle, swine, and sheep respectively.

Schoenbaum and Disney (2003) derived slaughter, surveillance and vaccination costs from 1998 NIMBY test exercises. Slaughter costs include costs of appraisal, euthanasia, carcass disposal and cleaning/disinfection. Surveillance costs include costs of testing per herd and costs per surveillance visit. Vaccination costs are given in terms of costs per herd. All of their estimates are broken down in terms of three herd categories, small (<100), medium (100-450), and large (>450), her sizes.

## 2.13 Prevention of and Response to Food Sabotage on International Level

Bioterrorism is of concern at both the national and international levels. Security and safety of the food supply is vital not only for the U.S. economy but also for the welfare of any other country and for the prosperity of the global economy as a whole. It has been shown that there could be a serious contagion effect present from terrorism in a multi country region (Drakos and Kutan, 2003). Therefore, there is a need for regional cooperation against terrorism by creating multinational organizations facilitate anti-terrorism measures on international level. Moreover, much like retaliation against terrorism (Dwight, 1988), response and prevention could be analyzed in a game theoretic framework, with countries as players who could free ride from public benefits of terrorism mitigation, to justify cooperative prevention and response to agricultural terrorism.

Although vulnerability of food supply varies across the countries it is clear that similar basic principals of preventing, and if necessary responding to, food supply adulteration should apply in different countries. Moreover, given the global nature of today's economies, both prevention and response measures have to be internationally coordinated. The authorities of participating countries have to fight bioterrorism in the ways that are compatible and complementary to one another. International cooperation is needed to prevent possible sabotage of exported food. There are numerous documented unintentional incidents of international food contamination. For example, the 1989 cyanide contamination of Chilean grapes exported to the U.S. and Canada (WHO, 2002), the 1995 salmonella outbreak in the US and Finland due to contaminated alfalfa sprouts seeds obtained from The Netherlands (Mahon et al. 1997), the 1996 outbreak of cyclosporiasis in the North America due to contaminated raspberries imported from Guatemala (Herwaldt et al., 1997) and many more.

International initiatives need to be developed to enhance food inspection and, if necessary, response activities to prevent and respond to food terrorism. Figure 6 shows the proposed linkages (WHO, 2002) between national and international food safety systems to facilitate detection and response to food terrorism incidents. Instituting and/or improving these linkages will allow for prompter exchange of relevant information, which will facilitate rapid removal of unsafe food from the markets. This figure illustrates how food safety-related institutions need to be interrelated not only on national but also on international levels.

Prompt response, that would minimize the damages sabotage event, is important on both national and international levels. International organizations such as WHO could provide response guidelines for particular food contamination incidents at national levels. Detailed procedures directed towards increasing counter terrorism awareness and strategies are outlined in Specific Measures for consideration by the Food Industry (WHO, 2002). At international levels WHO could be viewed as an organizational unit when it comes to communication and launching international response. As such, WHO's functions would include, but not be limited to, implementation of International Health Regulations, coordination of worldwide disease and food safety surveillance networks, coordination of international response to communicable diseases, and provision of technical assistance for national preparedness and response.

Measures to prevent international food adulteration incidents could be beyond the resources of many member countries. International cooperation is essential in order to assist many developing countries to implement and/or enhance food safety programs. Hence, international guidelines and recommendations for fighting food terrorism need to be established to increase the effectiveness of battling bioterrorism. World Health Organization (WHO, 2002) has prepared international guidelines and technical information on recommended food supply safety measures primarily intended for policy makers in national governments who are responsible for food safety issues.

## 2.14 Regulatory Background

The primary agencies involved in detection and epidemiological investigation of both intentional and unintentional food borne disease outbreaks include local and state health epidemiological departments, local and state public health laboratories, the Council of State and Territorial Epidemiologists, the Association of Public Health Laboratories, and the CDC (Sobel and Swerdlow, 2002). In addition, the US Food and Drug Administration (FDA), and the US Department of Agriculture (USDA) along with state departments of agriculture and food safety divisions have the authority to regulate food supply.

### 2.14.1 Increased Political Awareness

Intentional contamination of food/agricultural commodities is one of the most viable scenarios of terrorist attacks (Khan et al., 2001) in the United States. Dramatic economic consequences of food scares call for appropriate measures to prevent and mitigate possible food contamination events. The task force members of Council for Agricultural Science and Technology (CAST, 2004) recommend development of strategic approaches that will identify critical points within the food chain at which effective prevention and response strategies will have the greatest impact on decreasing public health hazards. This implies the need for investigations and studies of possible scenarios of intentional as well as unintentional agricultural contamination. In fact recent plan proposed by president Bush calls for significantly increased spending on homeland security research projects financed by U.S. department of Agriculture (Arnone, M., 2004). Under this plan, grants for research to protect American agriculture from terrorism and foreign diseases, such as Foot and Mouth Disease (FMD) in cattle, would increase by 275 percent, to $30-million.

### 2.14.2 Bioterrorism Act of 2002

On July 12th 2002 President Bush signed into law the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (OLPA, 2004), usually referred to as Bioterrorism Act of 2002. Title III of this document deals with protecting the safety and security of the food and drug supply in the U.S. The goal of this document is to facilitate development of crisis communication and education strategy with respect to bioterrorist threats to food supply. The document promotes strategies that "address threat assessments; technologies and procedures for securing food processing and manufacturing facilities and modes of transportation; response and notification procedures; and risk communications to the public".

Subtitle A of title III concentrates on regulating imported food supplies. Section 302 discusses measures for protection against food adulteration. The measures include increasing inspections for detecting adulteration of food, providing for research on the development of tests and sampling methodologies, assessments of the threat of intentional food adulteration, and improvements of information management systems. The remaining sections address such critical issues as debarment for repeated or serious food import violations, registration of food facilities, maintenance and inspection of food records, authority to mark articles which are refused admission into the U.S., surveillance and information grants, etc.

Subtitle C of title III elaborates on upgrading agricultural security. Several issues of critical importance are discussed.

- High priority is assigned to enhancing and expanding the capacity of the Food Safety Inspection Service to conduct activities, such as increasing inspections at international points of origin and ports of entry, developing strategies for dealing with international outbreaks of animal and plant diseases, and implementing automated record keeping system.

- Attention is also directed towards increasing security at colleges and universities, which have programs in food and agricultural sciences. Under this Act qualified universities may be awarded one-time grants of up to $50,000 to enhance security standards at their facilities.
- The subtitle also states that the Secretary of agriculture may award grants to associations of food producers for the development and implementation of educational programs to enhance biosecurity measures on farms. Under this provision individual associations are eligible to receive one-time grants of up to $100,000.
- Support for research and development is also given high importance. Close partnerships with higher education and research institutions are recognized to be critical to increase biosecurity and food safety in the U.S. Such close ties with the intelligence community promise advanced researches related to vulnerability analysis, incident response, detection and prevention technologies, as well as effective planning and training activities. For fiscal year 2002 it was authorized to allocate $190,000,000 for research, development and outreach programs related to enhancement of biosecurity measures in the U.S.
- Finally the penalties for those individuals who violate the provisions are discussed. The penalties are instituted to be commensurate with the economic and health damages caused by violations.

### 2.14.3 The Role of Food Safety and Inspection Service

The Food Safety and Inspection Service (FSIS) is a public health regulatory agency of the U.S. Department of Agriculture, which has ensured wholesomeness of meat, poultry and egg products for almost 100 years. This agency employs more than 7600 inspectors and veterinarians in more than 6000 locations such as meat, egg, and poultry plants and ports of entry (FSIS, 2003). FSIS works in cooperation with Centers for Disease Control and Prevention (CDC), the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), the Department of Defense (DOD), the Animal and Plant Health Inspection Service (APHIS) and with state and local health organizations to prevent the entry of intentionally or naturally contaminated products in the food supply.

In response to September 11, 2001, FSIS has taken numerous steps to increase the security of the U.S. food supply. The most notable action was creation of the Food

Biosecurity Action Team. This team is responsible for improving food safety and security. The tasks of this team include: 1) assessing potential vulnerabilities along the farm-to-table chain (figure 6); 2) increasing FSIS cooperation with law enforcement agencies; 3) enhancing security measures at all FSIS laboratories; 4) expanding the capacities of the agency's laboratories to test for additional food safety hazards and biological and chemical agents; 5) providing guidelines on increasing food safety and security to the industry.

FSIS has also taken on major projects and initiatives to protect America's meat, poultry and egg supply from intentional or unintentional contamination. FSIS has established the Office of Food Security and Emergency Preparedness (OFSEP), which is to prevent, and if necessary, coordinate a response to any intentional food supply contamination. In order to prevent using food as a terrorist weapon, FSIS has prepared a food security plan 2003-2007, which identifies specific goals and responsibilities related to prevention activities. FSIS has also prepared and distributed Security Guidelines for Food Processors in order to assist the plants that produce meat, egg and poultry products to improve their biosecurity procedures. Imports inspections have been intensified by adding 20 new inspectors at port cities around the nation to assist traditional FSIS import inspectors assigned to the 146 import Houses around the country. FSIS has completed food supply vulnerability, which identifies the most susceptible products, agents and sites for intentional contamination of domestically produced meat, poultry and egg products. In addition, FSIS has enhanced capacity and security of the laboratories, and began educating and training of all employees on food security issues.

## 2.15 Summary

Security of agricultural markets is a major concern in the policy-making arena especially during current elevated terrorism awareness. Even though agriculture is not usually thought of as a possible venue for terrorism, a number of documented incidents demonstrate the feasibility of such events. Collectively the documented incidents of intentional as well as unintentional agricultural contamination point out vulnerable segments along the food supply chain. Agricultural contamination could cause wide range of implications, from minor discomfort of several people to massive infections and/or disruptions of markets in several industries and trade. Recent spread of FMD in Great Britain is the most notable example of how Agricultural Contamination could cause serious economic damages in a number of industries. Both, producers and consumers bear the consequences of agricultural contamination. Precise effects depend on distribution of those effects within producers and within consumers.

The most desirable option of counter sabotage efforts is prevention. Prevention practices could be adopted at any vulnerable segment along a food supply chain. Clearly priority should be assigned to the most vulnerable segments within agricultural production, processing and manufacturing, storage and transport, retail and distribution, and trade. However, adoption of preventative measures depends on private incentives of producers, distributors, and retailers. The private incentives include consideration of both, mean and variance of net returns, which are affected by marginal costs and effectiveness of prevention strategies.

Response to agricultural sabotage and control of a spread of infectious diseases such as FMD to great extent depend on effective surveillance, detection and tracking of contaminated products. Investing in surveillance, detection and tracking systems will improve the preparedness in case agricultural terrorism incident occurs. Response and control, as well as prevention, strategies need to be developed by considering multiple scenarios and options in the decision support systems.

In order to safeguard the economy from the possible devastating effects of agricultural sabotage, decision support tools need to be developed. The points discussed in this review of related literature should provide the grounds for developing the support tools. These tools will facilitate determination of the optimal level of prevention and response measures and are the subject of further investigations.

# 3 ECONOMICS OF AGRICULTURAL TERRORISM

There are three major economic issues related to agricultural terrorism. The first involves evaluation of vulnerability of the agricultural industry to terrorism. The second pertains to formulation of economically optimal policies that could reduce vulnerability. The third involves how economic research could assist in formulating such policies.

## 3.1 Vulnerability of Agricultural Industry

As discussed in the literature review section, the vulnerability of the agricultural industry to terrorism can involve both intentional and unintentional contamination. Numerous unintentional cases have occurred and illustrate possible susceptible segments of food supply chain which could potentially be used as points of sabotage. Some of those examples are, milk contamination (Ryan et al., 1987), salmonella infection from ice cream (Hennessy et al., 1996), seafood contamination (Halliday et al., 1991), *E Coli* infection from radish sprouts (Mermin and Griffin, 1999), and animal born diseases such as Avian Influenza (CDC, 2004) FMD and BSE and introduction of other non-indigenous species which could be harmful to agricultural industry (Pinmentel, 2002). A few intentional cases of food adulteration have occurred. For example, intentional contamination of food consumed by coworkers (WHO, 2002), and intentional contamination of restaurant food (Torok et al., 1997).

The above cited cases demonstrate the diversity of vulnerable points along the food supply chain. Generally, a vulnerable point is one that is characterized by low investments in prevention and preinstalled response measures towards possible sabotage and points where such events could cause significant economic damages.

The diversity of vulnerable points indicates that the possibilities for agricultural terrorism are countless or close to it. This suggests that agricultural industry is highly vulnerable to terrorism act. The consequences of such an incident could potentially be devastating due to highly inter-regional nature of agricultural markets. The contamination in the form of infectious disease could easily spread to remote regions and cause a massive outbreak even though it may have originated in on a local basis.

## 3.2 Formulation of Economic Mitigation Policies

The fundamental economic problem related to formulation of policies to mitigate agricultural terrorism is to come up with a policy that will yield the most favorable benefit-cost ratio. In other words, the policy needs to be such that the benefits from implementing it will outweigh the costs of putting it in operation.

### 3.2.1 Conceivable Mitigation Policy Components

A counter terrorism policy in the agricultural industry could involve strategies that could be composed of multiple activities that prevent the event or allow for effective response. Below I provide an overview of actions that could be considered as components of such strategies, specifically when it comes to animal diseases.

#### 3.2.1.1 Vaccination

Farm animal diseases, can in cases be remedied by preventative vaccination. The role of and relative effectiveness of vaccination needs to be investigated in order to form a policy against agricultural terrorism in form of intentional disease spread.

Vaccines against some diseases like FMD are available, although many are not currently applied on US farms and ranches. In the case of FMD vaccination is not currently practical as one cannot differentiate between a vaccinated and an infected animal. Thus vaccinated animals are eventually destroyed. However, I discuss this as a representative of the more general preventative vaccination action.

Vaccination can be viewed as both prevention and a response measures. As an ex ante prevention measure, vaccination could be used to preclude the occurrence of a disease outbreak. Vaccines also could be manufactured and stocked for ex post use. In this sense, the decision is whether or not to vaccinate the animals or stock the vaccines prior to introduction of the disease in consideration of the probability levels of disease introduction. If vaccinated preventatively, then even if the disease is introduced into the region, there will be lessened and perhaps insignificant losses due to the introduction. If not vaccinated preventatively, then there is a risk that if the disease is introduced into the region it will cause damage, and if it widely spreads throughout the region, there may be significant losses.

As a response measure, vaccination could be used ex post to stop the spread of the disease under the scenario where infected animal(s) have been detected. Timely response by vaccinating herds within certain radius of infected herd could prevent further spread of the disease. However, if the vaccines are not available then they cannot be used ex post.

Both, prevention and response vaccination have corresponding uncertainties. As a prevention measure, it is unclear under what circumstances to start applying preventative vaccination. It is unclear when the threat of an outbreak is serious enough to justify the expenses associated with carrying out massive preventative vaccination. As an ex post response measure it is unclear how extensive vaccination should be in case of outbreak detection. In other words, the radius of vaccination or number of animals/herds sufficient to contain the outbreak needs to be established.

#### 3.2.1.2 Slaughter

Slaughtering of animals is considered to be one of the most effective response measures in terms of containing the spread of a disease such as FMD (Schoenbaum and Disney, 2003; Garner and Lack, 1995; Morris et al., 2001). Under such a strategy, animals are preemptively slaughtered when infected animals are found in the region. Slaughter in a ring around the infection points reduces the chances of direct or indirect animal contact, thus decreasing infection spread. The question under such strategy is how big the slaughtering ring should be around the epicenter of an outbreak to be sufficient to stop the infection from spreading. While the goal of slaughtering strategy is to stop the disease from spreading, it is also desired to minimize the costs of such strategy. The costs could involve slaughtering and disposal expenses in addition to lost capital in the form of culled livestock. The extent of slaughtering may depend on the characteristics of the area around the outbreak. For example, regions with high human population densities, high animal concentrations, numerous roads, etc. have more favorable environments for infection spread than do regions with lower human populations, smaller animal concentrations, and less roads. Therefore, the region with more favorable conditions for disease spread would optimally apply more intensive response measures. In case of slaughtering as a response measure, this implies slaughtering animals in a larger ring around the center of an outbreak.

#### 3.2.1.3 Movement Ban

One of the possible responses to outbreaks of highly contagious diseases such as FMD is to stop the transport of livestock in the general area of an outbreak. This strategy will reduce the mixing of healthy and sick animals at staging points, sale barns, feedlots, and other cattle facilities. This will reduce the likelihood of healthy animals making contact with infected animals. In addition, general movement bans in and out of the infection zone will reduce the likelihood of transporting the disease to neighboring regions via humans and vehicles. However, lengthy movement bans will result in economic disruption.

#### 3.2.1.4 Surveillance and Detection

A category of strategies that can be used ex ante or ex post involves surveillance and detection systems. Ex ante investment in surveillance implies initiating new or enhancing existing monitoring operations or investing in equipment that can be used post event. In case of FMD regular monitoring would allow early detection of the disease, before the symptoms even show. Early detection is essential for successful containment of the disease spread because by the time the animals show the symptoms of infection the disease may have already spread to surrounding neighborhoods. Therefore, diagnosing the infection before the signs show up could reduce the spread of the disease and decrease the outbreak response costs necessary to stop the infection spread.

One of the tasks of the broader project under which this project is being conducted is to identify possible cost effective surveillance and detection methods that fit the cattle industry in Texas. One of the possibilities is to perform some ex ante actions. These include increasing the number of regional veterinary laboratories, which would conduct frequent tests of random samples of animals in the region. However, this would entail significant expenses for buildings, supplies and employees. Another possibility is to educate and require livestock operators to conduct tests to detect FMD infection and report the results to the regional veterinary clinic. Surveillance and detection mechanisms could be applied at sale barns and other points of livestock distribution. Detection, which will allow isolation and elimination of infected animals before they are mixed into healthy herds is key to preventing and/or stopping the spread of the disease. Tracing systems could be used to improve the effectiveness of surveillance and detection procedures. Methods such as ear tags will allow tracing back any livestock animal that has entered the production chain. This will expedite the identification of outbreak origins and paths allowing isolation and elimination of all animals in direct and indirect contact.

#### 3.2.1.5 Monitoring Imports

Another option is to monitor imports of live animals, animal products, feed ingredients, and other related commodities. Currently Department of Agriculture's Plant and Animal Inspection Service are responsible for enforcing the laws that protect the U.S. from agricultural pests and diseases by conducting inspections at ports of entry. For example, under the Plant Protection Act and the Animal Health Protection Act, agriculture inspectors have the authority to conduct warrantless searches of any person or vehicle entering the United States. Inspection of imports needs to be carried out at all points of entry (Wasem et al., 2004). However, different points of entry could be characterized by different levels of possible infected animal trade. Therefore, different extents of monitoring could be and in cases is employed at different points of entry. For example, live cattle being imported from Mexico are dipped in an insecticide bath prior to entry into the United States to prevent entry of exotic ticks. At the northern border, imports of cattle and beef products currently are prohibited due to BSE (mad cow disease) restrictions (Wasem et al., 2004). Setting up more elaborate inspection practices at the points of entry where products from South America enter the region than at the points of entry where Canadian products enter the region may be argued to be appropriate.

Enhancing inspection processes at points of entry would involve hiring personnel, acquiring equipment, etc. Costs (Wasem et al., 2004) associated with implementing this strategy (McCauley et al., 1979) will need to be compared to associated marginal benefits. This essentially means figuring out the probability level of an outbreak originating from foreign imports, then determining those for which spending resources on inspection and thus preventing the entry of infected products would be justified. At lower probability levels spending on monitoring imports may be economically inefficient while at higher probabilities the spending could be economically justified.

#### 3.2.1.6 Monitoring Travel

In case of a highly contagious disease, such as FMD, the spread could originate not only from animal related products but also from other sources such as travelers from regions with endemic FMD. To prevent entry of diseases through such venues the inspection at the customs of airports and other facilities of international travel may be established and/or enhanced. Currently there is a formal voluntary procedure in place at the airport customs that identifies individuals that have visited farms in foreign countries. However, this procedure is inadequate for preventing intentional introduction of disease into the U.S. Therefore, enhancing monitoring exercises at customs could be used to reduce the chances of successful agricultural sabotage.

#### 3.2.1.7 Tracing

Response strategies such as isolating and eliminating infected animals and animals that may have been in contact with the diseased may be more effective in presence of tracing mechanisms. Timely removal of infected or suspicious animals from the market is essential for containing highly infectious diseases such as FMD. Tracing mechanisms would allow tracking individual animal units through the points of processing and transportation. This would allow authorities to halt operations at facilities where the infected animal(s) have been traced through. Tracing mechanisms would also assist in identifying the point of origin of the outbreak, which may lead to some clues about the source of the outbreak in case of agricultural terrorism event. An example of tracing mechanisms is use of an ear tagging system for cattle. However, the problem with such a system is that unless the animals are officially sold in the market they may not have tags and thus no record of past origin and movement.

#### 3.2.1.8 Recovery Activities

Recovery measures mainly entail restoring, at least partially, the lost demand and production capabilities for the commodities and production systems that are affected by agricultural terrorism event. Such activities could include additional testing of products to demonstrate product safety, education of the public regarding characteristics of the threat, upgrading equipment and procedures, land decontamination etc. To evaluate the effects of such programs on consumer demand at the time of agricultural terrorism event some form of demand analysis needs to be conducted. For productive capacity one needs to do a cost benefit analysis of potential actions.

### 3.2.2 Benefits

Economic benefits from agricultural terrorism mitigation policies correspond to avoided losses that would have occurred if the policy was not designed and activated. Hence, appraising the precise benefits of such policy is complicated since the damages are usually not known unless the event has happened before. Since agricultural terrorism has not occurred very many times, to the best of my knowledge, it is hard to talk about the extent of damages under agricultural sabotage.

In cases where some information is available on the effect of particular sabotage scenario on supply and demand of affected commodities, it would be possible to approximate the damages by looking at lost consumers' and producers' surpluses. However, as discussed in the literature review section, agricultural contamination has different effects within producers as well as within consumers. For example, producers of commodities that were not directly affected by the event may see their business activity increase or decrease depending on the type of goods and services they provide. Similarly, some consumers will completely drop consumption of affected commodities while others may continue to consume unaffected brands of the commodity.

Assuming that damages of particular agricultural terrorism incidents could somehow be approximated, through lost income for example, it is still unknown how likely the incident is to take place. Therefore, economic benefits of agricultural terrorism mitigation policy need to be evaluated in terms of expected damages of such events under the absence of a mitigation policy. However, estimating expected losses necessitates some intelligence on likelihood of agricultural terrorism event. Since such information can be rare and or imperfect, scenarios of a range of threat levels will probably be needed to evaluate and compare benefits of various mitigation policies.

### 3.2.3 Costs

Estimation of costs of mitigation policies is relatively more straightforward than estimation of benefits because most policy implementation costs are likely to be either known with certainty or can be estimated. In other words, the ex ante costs of implementing and operating the policy, regardless of whether the event occurs or not, are readily subject to estimation. However, the ex post variable costs of implementing the policy depend on the extent and severity of the event, which could be hard to predict. Nevertheless, proportional costs of responding to the event could still be approximated in some scenarios. For example, in case of FMD outbreak I can expect the approximate cost of slaughtering or vaccinating per animal.

Costs of mitigation policies are likely to consist of two parts, ex ante and ex post costs. Ex ante costs are known with certainty and are incurred regardless of whether or not the event takes place. These costs are referred to as fixed costs since they are not dependent on the use of the mitigation policy. For example, in case of FMD such costs could be associated with initiating surveillance programs that would operate whether the event occurs or not. If contamination occurs such program would be used to prevent or respond to the event. However, if the event does not occur than the program is idle.

Ex post costs are variable costs of mitigation policy depend on the state of nature. In other words, if the event occurs than certain response activities are enacted, which entail some costs. However, if the event does not occur then response activities will not be enacted and no costs will be incurred. For example, in case of FMD, responsive slaughter will take place only if the outbreak occurs. Thus, if there is no FMD outbreak, then there will be no slaughter costs, if there is an FMD outbreak than there will be slaughter costs.

It is not known whether the event is going to take place or not. Therefore, expected variable costs will have to be calculated to evaluate cost effectiveness of mitigation policy. However, event probability, which is necessary to calculate expected values, is unlikely to be known. Therefore, scenarios with a range of probability levels will need to be considered.

## 3.3 Analytic Conceptualization of the Economic Problem

Following documents like the Homeland Security RFP for agricultural biosecurity centers, I will characterize agricultural terrorism mitigation policy actions into four general categories: prevention, detection, response and recovery. Each is defined below.

Prevention corresponds to activities which facilitate the avoidance of an agricultural sabotage event. Such activities include control and surveillance at the boards of entry, preventative vaccination of animals, control of access to vulnerable points along the food supply chain, control of access to hazardous agricultural chemicals, etc.

Detection entails implementing systems which would allow for timely discovery of an event and then rapid response heading off many of the damages. This could be a crucial component under the scenarios where a highly contagious disease like FMD, which takes time to show clinical signs, is used to inflict terror. Timely detection will allow for timely response actions and will limit the spread of the disease. Detection activities can precede an event being routinely done all of the time. They can also be employed once an event has been discovered in an attempt to detect infected animals and prevent infection spread.

Response actions correspond to activities employed after the event has taken place. For example, in case of FMD, response actions could be responsive vaccination and slaughter of animals. Response actions are intended to minimize the impact of the event.

Recovery actions are undertaken after the event has taken place and correspond to measures that would allow to, at least partially, reinstate lost business. An example of this could be activation of media campaign that would convey to the consumers the message that the threat has been eliminated and the products available on the market are safe for consumption.

Figure 7 depicts the stochastic nature of the problem and shows the timeline of mitigation policy components. In stage one, there is no event but the society has the opportunity to invest and initiate prevention and detection, and to invest in response capability. These investments, earlier referred to as fixed costs, will be incurred regardless of whether the event takes place or not. In the second stage, there is a probability of the event occurring *(Pr)* and a probability of it not occurring *(1-Pr)*. Under the "no event" state of nature no response measures will be activated as no disease is detected. The "Event" state of nature implies that an outbreak has occurred somewhere. At this stage local authorities have the options to enhance detection, initiate response (by say, preemptively slaughtering animals or vaccinating), detect through detection systems initiated in the first stage, or recover by demonstrating that their products are safe. At the third stage, the local businesses have Pr` probability of being infected or directly affected requiring response and then recovery and one minus this probability of not being directly effected but still having to deal with market recovery. This probability could be argued to be depended on preventative and responsive measures that were locally and/or nationally adopted in the second stage.

The setup described above reflects a few major elements of the problem at hand.

One is irreversibility, meaning that if the event occurs and necessary investments have not been made in the first stage, these investments can no longer be made. Similarly, if had invested in the first stage and no event occurred then the investment is a fixed cost and is not reversible. Second, attributes of the response capability may be conditional on investments made in the first stage. For example, in order to have the equipment to undertake surveillance systems that might detect and help stop the spread of the disease, there would be necessary investments in the first stage so second stage possibilities are dependent on first stage activities. Third, the set up reflects the tradeoffs between investment costs and event costs in the form of damages which occur infrequently. Fourth, profits of industry under consideration depend on the state on nature. Clearly if the event occurs there will be costs associated with response measures which will decrease the profits. Finally, given all of the above, the best mitigation strategy will depend on fixed investment costs, variable costs, probabilities and severity of the potential event.

### 3.3.1 Formulation

The model proposed here is based on maximizing the utility of an economic decision maker assumed to be an all knowing benevolent dictator who can manage the entire herd who faces the possibility of agricultural terrorism act. An expected utility formulation of the decision given the opportunity to adopt prevention, response and recovery actions is given in equation (1). Notice that in this formulation I categorize detection into the ex ante prevention group.

$$V = P(d)\begin{bmatrix}\pi(s,r,\delta,a)\cdot U_{EI}(a,-K(a)-s-d) \\ +(1-\pi(s,r,\delta,a))\cdot U_{EN}(a,m-s-r-c-d-L(a,r,s,c,\delta))\end{bmatrix} \\ +(1-p(d))\cdot U_N(a,m-s-d) \tag{1}$$

$m =$ Income from regular opretaions
$a =$ Attributes of the region
$K(a) =$ Value of lost capital In case of being hit by event
$s =$ Money spent on surveillance and detection
$\mathrm{d} =$ Money spent on prevention
$r =$ Money spent on response
$c =$ Money spent on recovery
$\delta =$ Random parameter depicting severity of the event
$L(a, r, c, s, \delta) =$ Monetary losses due to the event
$P(d) =$ Probability of terrorist event
$\pi(s, r, \delta, a) =$ Probability of entity being impacted by the event
$U_{ij} =$ Utility under state of nature ij (i = E(event), N(no event),
j = I(impacted), N(not impacted)

This formulation depicts the three-stage process incorporating recourse and irreversibility. The choice variables here are *d, r, s,* and *c*.

In the first stage I have the option to adopt prevention activities, which could be beneficial in the letter stages if the event occurs. However, prevention activities can only have value and be utilized if they were employed in the first stage. Notice that investment in prevention and detection is independent of state of nature, which implies that this decision is irreversible. Response and recovery on the other hand are state dependent. Both, recovery and response expenditures, *r*, take place only if the event occurs. Clearly, if the event does not take place, than there is no need for response actions.

Response actions are independent of the third stage state of nature. In other words, response actions are assumed to be initiated as soon as the second stage state of nature is known, event or no event. However, response actions are not dependent on whether the entity gets infected or not in the third stage but the impacts of the response and infection does influence the third stage. Namely, some animals will be dead and some actions may need to be undertaken locally.

On the other hand the need for recovery activities is dependent on states of nature from all stages. That is, recovery activities could be different depending on whether they are recovering from a direct hit by the event or just from the impact of the event on the market conditions. If the entity is not directly affected by the event, then recovery corresponds to restoring consumer confidence in their products. For example this could mean demonstrating product safety through extra testing. If the entity is directly affected by the event then recovery would entail much more including rebuilding the herd and decontaminating facilities. However, for the sake of simplicity, in this formulation it is assumed that if the entity is directly hit by the event then they suffer losses in terms of its capital value (*K(a)*).

L(a,r,c,s,δ) is the monetary loss function given the event. It is assumed to be a function of attributes of the entity. For example, if the area under consideration has several big feedlots, and we are talking about the possibility of FMD outbreak, then the losses are likely to be large. The loss function is assumed to be convex in r and c implying that as we adopt more response and recovery activities we will decrease the losses. However, if too much recovery and/or response actions are adopted, losses may increase. The loss function is also a function of random disease severity parameter, δ, which could represent for example disease spread rate in case of FMD outbreak.

Notice that the utility function is assumed to be a function of site attributes (*a*), such as how big are cattle operations and whether or not there are ranching, breeding or feedlot operations in a region. It could be argued that site attributes which affect the loss function could also play a role in utility level. In the state of nature where event occurs and the entity gets hit net profits are lost capital *(k(a)),* minus surveillance expenditure *(s)*, minus prevention expenditure *(d)*. Under state of nature where the event occurs but the entity escapes the attack net profits are returns *(m)* minus surveillance *(s)*, minus response *(r)*, minus recovery *(c)*, minus prevention *(d)*, minus indirect losses *(L)*. Under no event state of nature net profits are returns *(m)* minus prevention expenses *(s)*. Denoting net profits as *Y* and assuming that marginal utility as a function of Y is indifferent of state of nature, which implicitly assumes risk neutrality with constant marginal utility of income, I can show the following by taking the first order derivatives with respect to s, r, and c.

$$\frac{\partial P}{\partial d}\left(\pi U_{EI}+(1-\pi)U_{EN}-U_N\right)=\frac{\partial U}{\partial Y} \tag{2}$$

$$P\cdot\left[\frac{\partial \pi}{\partial s}\left(U_{EI}-U_{EN}\right)-(1-\pi)\frac{\partial U}{\partial Y}\frac{\partial L}{\partial s}\right]=\frac{\partial U}{\partial Y} \tag{3}$$

$$\frac{\partial U}{\partial Y}\left(1+\frac{\partial L}{\partial r}\right)(1-\pi)=\frac{\partial \pi}{\partial r}\left(U_{EI}-U_{EN}\right) \tag{4}$$

$$P(1-\pi)\frac{\partial U}{\partial Y}\left(1+\frac{\partial L}{\partial c}\right)=0 \tag{5}$$

Using (2), (3) and (4) and denoting partial derivatives with subscripts it can be shown that

$$\frac{\pi_r(U_{EI}-U_{EN})}{\pi_s(U_{EI}-U_{EN})-(1-\pi)U_Y L_s}=P(1+L_r)(1-\pi) \tag{6}$$

$$\frac{\pi_r(U_{EI}-U_{EN})}{\pi U_{EI}+(1-\pi)U_{EN}-U_N}=P_d(1+L_r)(1-\pi) \tag{7}$$

$$\frac{P_d\left(\pi U_{EI}+(1-\pi)U_{EN}-U_N\right)}{\pi_s(U_{EI}-U_{EN})-(1-\pi)U_Y L_s}=P \tag{8}$$

Equations (6), (7) and (8) give optimality conditions for spending on employing prevention, response and detection actions. Equation (5) simply says that marginal decrease in losses as spending on recovery measures increases $\left(\partial L/\partial c \leq 0\right)$ is equal to normalized price of recovery measures at optimality.

Since I assumed risk neutrality then equations (2,3,4, and 5) can be rewritten as follows after denoting K(a) as K

$$P_d\left(-\pi K-\pi m-(1-\pi)(r+c+L)\right)-1=0 \tag{9}$$

$$P\left(\pi_s(-K-m+r+c+L)-L_s(1-\pi)\right)-1=0 \tag{10}$$

$$\pi_r(-K-m+r+c+L)-(1+L_r)(1-\pi)=0 \tag{11}$$

$$P(1-\pi)(1+L_c)=0 \tag{12}$$

Using the implicit function theorem, I can examine the comparative statics implications of parameter variations in this formulation. The effects of threat levels and severity of the event could be investigated. Using equation (9) for prevention I can show

$$\frac{dd}{d\delta}=-\frac{P_d\left(\pi_\delta\left(-K-m+r+c+L\right)-(1-\pi)L_\delta\right)}{P_{dd}\left(-\pi K-\pi m-(1-\pi)\left(r+c+L\right)\right)} \qquad (13)$$

The numerator of (13) is signed negative under the assumption that m and K are large enough. The denominator's sign is tied to the sign of $P_{dd}$. In other words the sign of (13) depends on effectiveness of prevention activities, magnitude of losses, income and money spent on surveillance, response and recovery.

$$\frac{ds}{d\delta}=-\frac{\pi_{s\delta}\left(-K-m+r+c+L\right)-L_{s\delta}(1-\pi)+L_s\pi_s}{\pi_{ss}\left(-K-m+r+c+L\right)-L_{ss}(1-\pi)+L_s\pi_s} \qquad (14)$$

Notice that the value of this expression does not depend on probability of an attack but rather on conditional probability of being affected if the attack occurs. The sign of the above expression is ambiguous and depends on the signs and relative magnitudes of its components. For example it depends on the magnitude of costs of surveillance and detection, and on the magnitude of the effect of event severity on the effectiveness of detection in terms of effects on $\pi_s$ and $L_s$.

Similar results arise for surveillance activities relative to changes in probability of event occurrence. Namely,

$$\frac{ds}{dP}=-\frac{\pi_s\left(-K-m+r+c+L\right)+L_s(1-\pi)}{P\left(\pi_{ss}\left(-K-m+r+c+L\right)_s-L_{ss}(1-\pi)+L_s\pi_s\right)} \qquad (15)$$

Using the same approach I can show that

$$\frac{dr}{d\delta}=-\frac{\pi_{r\delta}\left(-K-m+r+c+L\right)+\pi_\delta(1+L_r)+\pi_r L_\delta-(1-\pi)L_{r\delta}}{\pi_{rr}\left(-K-m+r+c+L\right)+\pi_r(1+L_r)+\pi_r L_\delta-(1-\pi)L_{rr}} \qquad (16)$$

Similar to previous results the sign of equation 16 is ambiguous. Relative magnitudes and signs of individual components determine overall sign of the equation.

The effect of probability of agricultural terrorism, on adoption of response activities is trivially zero as apparent from equation 11. By definition response activities are only adopted if the event occurs.

For recovery activities it could be shown that

$$\frac{dc}{d\delta} = \frac{P\pi_{\delta}(1+L_c) - P(1-\pi)L_{c\delta}}{P(1-\pi)L_{cc}} \tag{17}$$

From equation (12) I can see that $L_c$=-1, therefore the numerator is negative. The sign of the denominator depends on $L_{cc}$ and so does the sign of the whole expression. For recovery activities such as restoring consumer confidence through publicity $L_{cc}$ is likely to be positive. Therefore, the sign of (17) is positive implying that as severity of the event increases the optimal level of recovery activities also increases.

### 3.3.2 Inclusion of Externalities and Non-Exclusiveness

The formulation presented above assumes a single decision-making benevolent dictator that can compel all to cooperate and does not explicitly reflect public good characteristics or differential individual behavior under a choice of strategies. Specifically, strategies adopted by some entities will affect other entities in the area. For example, if one entity adopts surveillance and thus prevents the spread of the disease when detected, it will reduce the probability of a neighboring entity being affected by the event even if no screening and detection was adopted by neighboring entity and would thus lower the incentives for all individuals to cooperate. Similarly, if in case of a contamination event one entity adopts responsive slaughter it will reduce the chances that the neighboring entity will get infected. Moreover extensive slaughter, as opposed to moderate or no slaughter strategy, will have positive effect on consumer confidence. Therefore the entities that do not adopt strategies such as slaughter in case of outbreak will benefit from slaughter strategies adopted by others.

To reflect these public good characteristics equation (1) could be rewritten as

$$V = P(\mathbf{d}) \cdot \sum_i \left[ \begin{array}{l} \pi_i(\mathbf{s},\mathbf{r},\delta,a_i) \cdot U_{EIi}(a_i, -K(a_i) - s_i - d_i) \\ + (1 - \pi_i(\mathbf{s},\mathbf{r},\delta,a_i)) \cdot \\ \cdot U_{ENi}(a_i, m_i - s_i - r_i - c_i - d_i - L_i(a_i,\mathbf{r},\mathbf{s},\mathbf{c},\delta)) \end{array} \right] + (1 - p(\mathbf{d})) \cdot \sum U_{Ni}(a_i, m - s_i - d_i) \qquad (18)$$

where **d**, **s**, **r**, and **c**, are vectors composed of prevention, surveillance, response and recovery activities adopted by individual decision making entities represented by *i*.

The corresponding first order conditions with respect to $d_j$, $r_j$, $s_j$, and $c_j$, are:

$$\frac{\partial P}{\partial d_j} \sum_i \left( \pi_i U_{EIi} + (1 - \pi_i) U_{ENi} - U_{Ni} \right) = \frac{\partial U_j}{\partial Y} \qquad (19)$$

$$P(\mathbf{d}) \cdot \sum_i \left[ \frac{\partial \pi_i}{\partial s_j} (U_{EIi} - U_{EN}i) - (1 - \pi_i) \frac{\partial U_i}{\partial Y} \frac{\partial L_i}{\partial s_j} \right] = \frac{\partial U_j}{\partial Y} \qquad (20)$$

$$\sum_i \left[ \frac{\partial \pi_i}{\partial r_j} (U_{EIi} - U_{ENi}) - (1 - \pi_i) \frac{\partial U_{ENi}}{\partial I} \frac{\partial L_i}{\partial r_j} \right] = \frac{\partial U_j}{\partial Y} (1 - \pi_j) \qquad (21)$$

$$P(\mathbf{d}) \cdot \left[ \sum_i \left( -(1 - \pi_i) \frac{\partial U_i}{\partial Y} \frac{\partial L_i}{\partial c_j} \right) - (1 - \pi_j) \frac{\partial U_{ENj}}{\partial Y} \right] = 0 \qquad (22)$$

Similar to previous section, marginal utility of income ($\frac{\partial U_j}{\partial Y}$) is assumed to be constant, corresponding risk neutral preferences. As apparent from the above equations, optimality conditions under explicit consideration of positive externalities from mitigation strategies adopted by individual decision making units are different from those where externalities are not considered. Specifically, in equations 19 through 22 probabilities of infection for individual entities depend on actions carried out by other entities. Similarly losses suffered by individual uninfected businesses in case of an outbreak are affected by what type of surveillance, response and recovery strategies others adopt. Hence, counter agricultural terrorism actions implemented by each entity will affect other entities without compensation. This means that the costs of strategy implementation for a particular entity may not align with benefits brought by adoption of this strategy. Therefore, strategies that provide external benefits will be underproduced by privately optimizing agents as normally found in investigations regarding public good (Hanley et al., 1997; Myles 1997). This implies that taking positive externalities into account will improve the social efficiency of optimal combination of mitigation strategies adopted by individual decision makers. External effects of prevention, surveillance, response, and recovery actions should be a part of regional decision making as opposed to forming policy based on the total cooperation assumption under the benevolent dictator formulation used above. However, more thorough investigation of the effects of positive externalities of mitigation strategies is not the focus of this work and is held for the future investigations

## 3.4 Summary

In this chapter I discussed basic economic issues related to mitigation of potential agricultural terrorism act. The basic idea of forming optimal mitigation policy is to come up with a strategy that generates the largest benefit/cost ratio. In this discussion, particular attention was given to stochastic nature of the problem. A three-stage conceptual model was proposed and analyzed, from a perspective of a benevolent dictator decision maker, in terms of mitigation decisions considering possible states of nature.

The conceptual setup was used to formulate an analytical model which maximized expected utility/profits given the choice of prevention response and reaction options to mitigate possible sabotage event. This model was used to portray the overall picture of decision making process and to analyze the optimal conditions for adopting prevention and response strategies. Using comparative statics I analyzed the effects of threat levels and event severity on adoption of prevention and response measures. The major findings were that the effects of threat level and event severity on optimal levels of most mitigation options were ambiguous and depended on various factors such as effectiveness and characteristics of mitigation options. Response strategy was shown to be independent of threat level. Recovery strategy is positively correlated with event severity and independent of threat level. The effects found to be ambiguous in this chapter will be empirically investigated in the next chapter. The effects of positive externalities created by mitigation strategies were also recognized. However, the more in depth analysis of this issue is left for future research.

# 4 ECONOMIC DESIGN OF ANIMAL DISEASE MANAGEMENT SYSTEMS: TRADEOFFS BETWEEN DETECTION AND RESPONSE

Today as the world becomes increasingly more interrelated and the likelihood of disruptive terrorist events increases, substantial attention is being paid to formation of animal disease management systems. Such systems consist of 4 basic types of components:

Prevention systems – systems where there are actions undertaken to try to intercept disease vectors before they are introduced.

Detection systems – systems designed to screen animals to detect disease early and thus allow more rapid treatment and much lower spread than would otherwise be the case. These systems can also be coupled with prevention activities to screen imported animals before they get in contact with uninfected domestic herds. Depending on the point of view detection system could be viewed as a component of a prevention strategy because detection systems are set up prior to introduction of the disease and prevent massive outbreaks in case of disease introduction.

Response systems – systems which involve actions to stop the spread and ultimately eradicate the disease and thus avoid further economic losses.

Recovery systems – systems put in place to restore lost assets or demand shifts due to introduction of animal disease. Since these actions are typically utilized after introduction of a disease they could be classified under response systems depending on the point of view.

Collectively these systems entail a mixture of fixed and variable costs. Most of the fixed costs involve ex ante investments in prevention, detection, and response capability systems that are incurred whether or not an outbreak occurs. An economic issue that arises here entails designing the optimal mitigation system given a particular set of disease characteristics. More importantly, given the difficulty of threat assessment, I will investigate how varying characteristics of the threat influence the optimal design of a threat management system. Therefore, in this chapter I will

a) address the economic framework pertinent to mitigation activities directed towards intentional/unintentional animal disease outbreaks. In particular, I will address the interrelationship between detection, as a form of prevention, and response activities
b) set up and demonstrate a first order application of the framework in a case study setting,

c) investigate the effects of threat characteristics as well as effectiveness and costs of prevention and response options on the optimal mix of mitigation actions.

In this investigation I will do a first order empirical evaluation of a broader set of FMD management alternatives examining surveillance systems and exploring the interaction between surveillance and response strategies. Specifically, I examine in a simplified case study setting the conditions for desirability of enhanced detection systems considering various characteristics of a potential FMD outbreak, costs of program implementation, severity of the disease outbreak, and relative effectiveness of the surveillance and response strategies.

## 4.1 Background on Disease Management Research and Design

Analyzing the economic implications of animal health complications has become a prominent feature of policy-oriented research. In recent years, the issue became even more pertinent as the fears of agricultural terrorism have grown due to increased incidents of terrorism acts. From an epidemiologic point of view the goal is to prevent, stop and eradicate the disease as fast as possible or with fewest possible infection cases. From an economic point of view the objective is to minimize ex post economic losses that could be brought by a potential disease outbreak plus the cost of ex ante actions. This, in most cases, inherently implies a tradeoff between ex ante costs and the value of infection cases under an event. In this section, I discuss methodological issues associated with economically efficient animal disease mitigation strategies and empirically examine interrelationships of various mitigation options.

### 4.1.1 Detection Strategy vs. Slaughter Strategy

I will investigate ex ante – ex post tradeoffs by considering a relatively simple case that entails detection, as a form of ex ante prevention policy, and slaughter as a form of ex post response policy. Periodic testing of animals for FMD infection is chosen as a detection scheme. The study will examine the optimal number of annual herd animal tests as determined by such factors as threat levels, disease spread characteristics, response effectiveness, and costs of mitigation alternatives. A major decision in this setting is associated with ex ante investment in the detection program. Specifically, under what circumstances is it beneficial to invest in the detection program and thus intercept the disease spread in a timely manner, versus rely on response measure, which, unlike detection program, would be activated only if the outbreak occurs?

### 4.1.2 Disease Spread

The effectiveness of prevention and response strategies will greatly depend on characteristics of the disease spread. Therefore, some kind of disease spread model needs to be established in order to get a perception about key aspects of effective prevention and response. This would be best done with a detailed epidemiologic model but will be done herein using some equations from the literature.

### 4.1.3 Data Requirements

To conduct this analysis the following data need to be incorporated. The scenarios with corresponding sabotage and farm infection probabilities need to be developed. The analysis will require data that reflects the effectiveness of different prevention activities in terms of detecting the outbreak and successful responsive slaughter and vaccination. Additionally, the cost coefficients associated with different prevention and response activities need to be acquired. Resource endowments for prevention and response activities need to be recognized. Prices of agricultural commodities under different states of nature and different prevention and response strategies need to be introduced.

Since availability of all the desired data is limited, I will set up a model that is somewhat abstract and is simplified but contains the relevant elements related to agricultural terrorism using the data I can access plus some expert opinion.

### 4.1.4 Expected Results

The empirical model proposed here is expected to cover but not exactly depict reality and hence will yield results that will be suggestive of the optimal mix of prevention and response strategies. Using hypothetical but realistic event occurrence scenarios will allow evaluation of the cost effectiveness of various prevention and response strategies. The results will illustrate the relative desirability of prevention versus response strategies under different sabotage scenarios.

Particular attention and caution needs to be exercised while interpreting the results of the model. The findings will be conditional on particular scenarios analyzed and assumption employed in this research. Hypothesized sabotage scenarios as well some of the parameters assumed in this investigation are likely to have wide range of possible values. Therefore the findings should not be interpreted as numerically informative results, but rather as results indicative of possible changes in strategies.

### 4.1.5 General Economic Issues

The possibility of agricultural sabotage, such as spread of infectious animal diseases, presents several economic problems as discussed in Chapter 2. Contamination related food scares can have devastating effects on the markets of not only directly affected agricultural commodities, but also other commodity markets. In the case of infectious disease events, the tourism industry has been found to be highly vulnerable. Serious economic damages could also arise from loss of export markets. Therefore, the policy composed of prevention, detection response and recovery actions needs to be devised and instituted in order to minimize the expected losses from agricultural sabotage.

Formulation and implementation of mitigation strategies is on one hand based on the relative costs of strategy options. Clearly, it is economically efficient to adopt the mix of strategies which will minimize the mitigation costs. On the other hand, the strategy needs to be effective in prevention and/or physical removal of the disease, or other threats, from the supply chain. On the cost side, different mitigation options have different characteristics. Most prevention strategies, such as surveillance and detection systems, tracing, preventative vaccination, control of access to vulnerable points along the supply chain, involve a priory investment costs. This means that the fixed costs associated with these options will be incurred regardless of whether the outbreak occurs or not.

Clearly at low probabilities of contamination, prevention strategies with significant investment costs are less desirable than under higher probabilities. On the other hand response strategies such as ring vaccination, slaughter, disposal and disinfection, mostly rely on costs which are incurred if the contamination occurs. Response strategies will generally decrease the economic damages of contamination but will not eliminate them. Therefore, the tradeoff of choosing between prevention and response strategies is whether or not one spends money upfront and protects themselves from potentially significant economic losses due to agricultural contamination or wait and see if the event occurs in which case they rely on response strategies. In practice, it is likely that a combination of prevention and response strategies will be adopted as mitigation policy against agricultural terrorism. However, the implication from the previous chapter is that the relative reliance on the strategies will depend on such elements as threat level, costs and effectiveness of prevention and response strategies, and severity of the event.

### 4.1.6 An Analytical Framework

The model used in this case study needs to capture the stochastic elements related to the possibility of agricultural sabotage such as intentional introduction of farm animal diseases. The conceptual model in this chapter is similar to the formulation in the previous chapter but will be simplified to a two stage model. Namely a two stage discrete stochastic model with recourse (Dantzig 1955, Cocks 1968, Boisvert and McCarl 1990, Ziari 1991) will be used. The model in this chapter is based on the decisions of the region under a benevolent dictator instead of on decisions of individual members of the region. I will also drop the third stage of the decision making process as recovery is not really going to be considered.

Figure 1 illustrates the stages and related events and activities for the case study. In stage one there is no agricultural contamination in the region. At this stage farmers have the options to invest in surveillance and detection of animals, or do nothing. In stage two there is a possibility of infectious disease outbreak in the region. If there is an outbreak in the region then the farmers can respond by increasing or initiating vaccination, slaughtering uninfected cattle, or doing nothing. At this stage farmers get compensated for slaughtering. In case of a disease outbreak the severity of it in part will depend on the length of time that the outbreak is allowed to spread uninterrupted. Surveillance and detection systems could allow timely recognition and intervention to stop the spread. Hence, more extensive surveillance systems such as periodic testing of animals will lessen or halt uninterrupted spread of the disease. As response measures various slaughter and vaccination strategies could allow reduction of economic losses by removing susceptible units before infection. Under the scenario where there is no outbreak in the region the farm operations continue as usual. However, decisions made in the first stage will affect the profits, which consist of net revenues from animals vaccinated in the first stage and of revenues from not vaccinated animals.

### 4.1.7 Empirical Approach

Stochastic programming is a widely accepted tool to address uncertainties related to objective function coefficients, input-output coefficients and right hand sides of the constraints (Dantzig 1955, Cocks 1968, Boisvert and McCarl 1990, Ziari 1991). Two major categories of stochastic programming are stochastic programming without recourse and stochastic programming with recourse. Stochastic programming without recourse assumes that the decision maker plans now and discovers the results of the decision later. These type of models do not provide adoptive solutions. In other words, solutions received from such models are based on unconditional expected values. On the other hand, stochastic programming with recourse allows some of the decisions to be modified at later stages of a process. In other words, some decisions are made ex ante, followed by a stochastically determined state of nature, after which the decision maker is allowed to adjust the previous decisions (depending on context) and/or make new decisions depending on the realized state of nature. Discrete stochastic programming with recourse considers sequential nature of resource endowments and allows for earlier decisions and their consequences to affect later decisions. In order to proceed with discrete stochastic programming, decision making stages need to be defined and ex ante information is needed about discrete probability distribution of stochastic coefficients and resource endowments across the stages.

### 4.1.8 General Framework

To examine the relationship between prevention, in the form of detection, and response measures I adopt the approach of minimizing the expected costs of possible agricultural sabotage and its mitigation. Considered costs include the outbreak induced value of lost agricultural product and corresponding lost income, as well as costs of prevention and response actions.

$$L = C_d D + P[H(G(S, D, R)) + C_r R]$$

Where, L is the costs of prevention and response strategies, plus losses from potential terrorist event. $C_d$ is costs of detection D, while $C_r$ is costs of response R. P is the probability of an outbreak. S is the severity of an outbreak such as spread rate of a disease. H(G) is a monetary damage function in the event of an outbreak. G(S,D,R) is a physical damage function. For example G could represent number of infected cows in case of an outbreak.

Taking first order derivatives will give:

$$C_d + P\frac{\partial H}{\partial G}\frac{\partial G}{\partial D} = 0$$

$$P\left(\frac{\partial H}{\partial G}\frac{\partial G}{\partial R} + C\right) = 0$$

which implies that

$$\frac{\partial G/\partial R}{\partial G/\partial D} = \frac{PC_r}{C_d}$$

Hence, at the optimum marginal rate of substitution between prevention and response activities will equal to the ratio of expected marginal costs of response strategy and marginal costs of detection strategy. This implies that optimal combination of prevention and response strategies directly depends on the event likelihood, or threat level.

## 4.2 Scope of the Case Study

The empirical work done in this study will be based on a possibility of a Foot and Mouth Disease (FMD) outbreak in Texas where cattle farming comprises a significant portion of the agricultural industry. Key features of FMD are that it is highly contagious and its outbreak could lead to significant economic losses. Therefore, intentional introduction of FMD could be viewed as one of the possible venues of agricultural terrorism. Moreover, investigation of FMD mitigation options is further justified by the possibility of unintentional FMD outbreak in today's globally integrated markets,

In 2002, Texas cattle operations amounted to roughly 14 percent of the total U.S. cattle operations (NASS, 2002). Cattle are found on more than 150,000 Texas farms and ranches. Sales of cattle and calves comprise the largest portion of state's agricultural cash receipts. Examining the repercussions of market sabotage, as well as the options for prevention, detection and response in a region such as Texas is vital for assuring stability of regional as well as national markets for meat products. Additionally, examining prevention, detection and response strategies on a local basis rather than a national level may prove to be more efficient in terms of understanding the regional economic issues and developing effective economic components of decision support tools. Nevertheless, basic features of the economic approaches in this study are expected to be applicable in broader settings. Therefore, generalization and utilization of this decision support system in other regions will not present serious complications.

The study is conducted from the perspective of minimizing combined farmer losses due to possible FMD outbreak in Texas. In 2003, Texas farms carried 13,600,000 head of cattle.  At an average price of $600 per head this amounts to $8,160,000.00 of statewide cattle value.

### 4.2.1 FMD Mitigation

Economic analysis of prevention and response strategies directed toward Foot and Mouth Disease (FMD) have been the topics of numerous studies (Bates et al. July 2003; Bates et al. September 2003; Bates et al, July 2001; Garner and Lack, 1995; Schoenbaum and Disney, 2003; Berentsen et al., 1992; McCauley et al. 1979; Ferguson et al., 2001).  All of these studies mainly concentrate on vaccination and slaughter as the sole prevention and response FMD mitigation policies.  Most of the studies found slaughter policies to be superior to vaccination.

Much less attention has been devoted to surveillance and detection systems, relative to that devoted to vaccination and slaughter, which would allow for timely and more effective response measures.  Although the importance of surveillance systems has been emphasized (Bates et al. September 2003; Akhtar and White 2003), no empirical investigation has been performed, to the best of my knowledge, on the merit of such policies relative to prevention, response, and recovery strategies such as vaccination and slaughter.

#### 4.2.1.1 Surveillance

Current US programs to detect and prevent FMD rely on the recognition and reporting of clinical signs by a producer, animal care taker, meat inspector or veterinarian (Bates et al. September 2003).  Reliance on such an approach has two major problems.  First, detection based on visual observation of clinical signs implies that the disease could have been present and possibly spreading before the realization of its presence.  Second, clinical signs of FMD are indistinguishable from the signs of other diseases (Bates et al. February, 2003 a, b).  Therefore, more reliable methods for detection of FMD may be appropriate.

Periodic screening systems could be viewed as a preventative or early detection policy and could assist in avoiding disease outbreaks or limiting the scope of outbreaks.

Regular screening (Fox and Hennessy, 1999) and testing of farm animals directed towards evaluating animal health would allow for early detection of possible disease outbreaks. As a result, earlier detection would allow for earlier implementation of response strategies such as slaughter, disposal, cleaning and disinfection. In case of FMD, the latent period of infected animal is around one week (Garner and Lack, 1995).

It is possible that periodic testing of animals could detect FMD carriers before clinical signs appear. This means that frequent animal testing could decrease the time of unobstructed spread of the disease, thus decreasing the magnitude and associated costs of needed response actions as well as the value of the lost agricultural products and subsequent effects on future production. Screening and testing of animals could be conducted by either a regional veterinarian or employees of cattle operations provided adequate training in testing procedures.

#### 4.2.1.2 Response Activities

Response actions to outbreak of FMD are mainly vaccination and slaughtering. Both vaccination and slaughter could be administered either based on various radiuses values around infected areas or based on animal contact. Numerous studies have been reported regarding optimal response strategy (Bates et al. July 2003, Berentsen et al., 1992; Ferguson et al., 2001; Garner and Lack, 1995; Schoenbaum and Disney, 2003;). Most of the studies found that slaughter policies were more beneficial than vaccinations strategies. The main reason for this is that currently vaccinated animals can not be differentiated from FMD infected animals. Therefore, vaccinated animals are excluded from trade. This means that although vaccination will contribute to slowing down the spread of the disease, vaccinated animals will ultimately have to be slaughtered in order to regain the FMD free status for trade purposes. Hence direct slaughter instead of vaccination followed by slaughter could be less expensive. On the other hand, mass slaughter could require significant efforts. However, it would not be unreasonable to assume that there are enough resources to carry out slaughter policy. For example Schoenbaum and Disney (2003) found that under such conditions slaughter of herds in direct contact with infected herds is the most effective strategy.

#### 4.2.1.3 Model Formulation

To investigate the relationship between surveillance and response mechanisms, I adopt a cost minimization approach similar to the one described above. Total costs include expenses on surveillance and detection, costs of response strategies, and economic damages from potential outbreak. Surveillance and detection costs encompass fixed costs of installing testing facilities and equipment along with the variable costs of administering tests that are incurred regardless of outbreak occurrence. Response costs include costs associated with vaccination and slaughter including loss of cattle market values due to vaccination and slaughter. Economic damages from potential outbreak include cattle values lost due to infection and earnings lost per infected cattle. This can be expressed mathematically as follows. Suppose an outbreak has probability P of occurrence, then total cost equals

$$L(N,R) = Y \times FTC + N \times VTC + P \times \left[V \times H(R) \times D(t) + CR \times R\right] \qquad (23)$$

where L(N,R) is losses associated with prevention, response and occurrence of potential FMD outbreak. N is a number of tests performed annually on cattle in the region. R represents response activities in the state of nature where outbreak occurs. Y is a binary variable representing investment in surveillance system. Y=1 corresponds to the decision of investing in testing and screening facilities, while Y=0 corresponds to no investment in testing and screening systems. Clearly, Y=0 implies that N=0. CR costs of response activities, FTC is fixed testing costs while VTC is variable testing costs. The response effectiveness function, H(R), represents the proportion of animals lost in case of an outbreak under various levels of response actions (R). D(t) is the disease spread function expressed in terms of days that the disease is allowed to spread before detection.

The response effectiveness function, H(R), is hypothesized to be convex meaning that as the society employs more response actions, such as slaughtering, the damages from FMD outbreak will decrease. However, too much of the response actions could increase the damages. Therefore, I assumed a convex quadratic form for the damage function (Figure 11).

$$H(R) = \left(a_1 + a_2R + a_3R^2\right) \tag{24}$$

The disease spread function D(t) represents the number of herds infected on any given day *t* after the initial infection in the region. *t* is assumed to be a function of number of animal screenings conducted in a region per year. This implies that D(t(N)) is a decreasing function of the number of screenings N (Fox and Hennessy, 1999). In other words, increased number of screenings per year will decrease the time period for the disease to spread uninterrupted and therefore will decrease the potential number of infected herds. I investigate two forms of disease spread, exponential and Reed-Frost (Carpenter et al. 2004).

When, D(t) is assumed to have an exponential form as discussed in Anderson and May, 1991 the number of infected herds is assumed to be increasing exponentially over time after initial introduction of the disease (Figure 9, Figure 10).

$$D(t) = e^{\beta t} = e^{\beta \frac{365}{N+1}} \tag{25}$$

By plugging (24) and (25) into (23) and manipulating first order conditions I can show that optimal number of screening per year is

$$N = \left( \frac{P * CR * 365\beta(a_1 + a_2R + a_3R^2)}{(a_2 + 2a_3R)(VTC - \lambda)} \right)^{1/2} - 1$$

where λ is a lagrange multiplier for the constraint reflecting investment in surveillance system when N>1. It could be inferred from this equation that N is an increasing function of probability of disease outbreak, disease spread rate, and costs of response, and a decreasing function of VTC provided that VTC>λ.

The second functional form of spread of animals such as FMD was based on the Reed-Frost equation (Carpenter et al. 2004).

$$\hat{D}_{t'} = \left[ TN - \sum_{t=0}^{t=t^*-1} \hat{D}_t \right] \left[ 1 - q^{CI} \right] \tag{26}$$

Since TN is total number of herds in the area and $\hat{D}_t$ is number of infected animals in day *t*, therefore $\left[ TN - \sum_{t=0}^{t=t^*-1} \hat{D}_t \right]$ is number of susceptible herds at time period t*. q is the probability of avoiding the adequate contact, necessary to transmit the disease. 1-q is the probability of making an adequate contact and is equal to $^{k}\!/_{TN-1}$’ where $k$ is number of adequate contacts a herd makes in time period t. $k$ was assumed to have slow, 0.15, and fast 0.4 rates according to Schoenbaum and Disney, 2003. CI is cumulative number of infectious herds in any time period during the outbreak. Number of infectious herds is calculated using $CI = \sum_{\mu}^{7} \hat{D}_{t^*-\mu}$ to reflect the fact that FMD spreads for at least 7 days before showing clinical signs of infection at which point the diseased herds are assumed to be diagnosed and destroyed. $\hat{D}_{t'}$ is number of infected herds in each of the time periods during the outbreak. Therefore, the total number of infected herds at the time of screening (t*) will be given by $D_{t^*} = \sum_{t=0}^{t=t^*} \hat{D}_{t'}$ . This representation allows me to reflect the fact that in the early stages of FMD outbreak the disease will be spreading at the increasing rate. However, as the number of infected herds increases, number of susceptible herds will decrease. Therefore, at some point of FMD outbreak, number of infected herds will increase at a decreasing rate. Figure 13 shows the spread of the disease under fast spread scenario.

#### 4.2.1.4 Simple Inventory Problem

This problem could also be viewed as a simple inventory problem (Buffa, 1973). In other words the decision on the number of annual tests to be made prior to realization of state of nature could be viewed as similar to the problem of optimal order size for a business. Cost minimizing order size depends on per order costs and costs of maintaining the inventory. Corresponding situation in this context is depicted in figure 8, where *a* is total costs of surveillance and detection program, *b* is expected damages of an outbreak, and *c* is the sum of *a* and *b*. In our case cost minimizing number of annual tests is affected by testing costs and associated expected damage costs in case of an outbreak. This graph illustrates cost minimizing number of annual tests for a given probability of an agricultural sabotage, or an outbreak of FMD.

### 4.3 Empirical Specification for FMD Case

In equations (23) and (24) R represents the level of response actions. For empirical analysis this variable was normalized to1. Schoenbaum and Disney (2003) estimate that the most effective response action against FMD outbreak in the US is slaughter of herds with clinical signs and herds in direct contact with the diagnosed herds. This strategy according to their study leads to 17% reduction in number of slaughtered animals as compared to the strategy of slaughtering only the diagnosed herds. In this analysis, I assume that the damage function is minimized at R=1, corresponding to the most effective response scenario according to Schoenbaum and Disney. At R=1 the number of slaughtered animals is reduced by 17%. Therefore, if at R=0 the proportion of lost animals is 1, corresponding to losses under no response actions, than at R=1 the proportion of losses is 0.83 (Figure 11). Based on this information, the response effectiveness function used in this analysis was $H(R)=1-0.34R+0.17R^2$.

The product of disease spread D(t) and response effectiveness function H(R) is multiplied by the average loss value per infected herd (V). This value was calculated as follows:

$$V = C \times NH + \left( CV + \frac{GI}{TN} \right) \times NH \qquad (27)$$

where, C is the costs of slaughter, disposal, cleaning and disinfection and was assumed to be $69 per head (Bates et al, February 2003 a). NH is average number of cattle heads per herd in Texas, which was found to be around 50 (Ernie Davis, Personal Communication, August 2004). CV is an average market value per cattle head reported to be $610.00. GI is gross income for Texas cattle and calves operations reported to be $6,829,800,000 in 2001 (Texas Department of Agriculture, 2001). TN is number of cattle heads in Texas reported to be approximately 13,700,000 in 2001. Thus, the value used for V was $58,876.

The costs of testing include costs of surveillance per herd and costs of surveillance per visit corresponding to fixed and variable costs of screening and testing system. Fixed testing costs (FTC) are estimated to be $42,915,000, which was calculated by multiplying per herd testing costs ($150) for operations of less than 100 animal heads (Schoenbaum and Disney, 2003) and the number of cattle operations in TX (286,100). The investment made in form of fixed costs is made in the first stage prior to the realization of the state of nature and is independent of the number of screenings employed. Hence Y=1 corresponds to the decision of investing in testing and screening facilities, while Y=0 corresponds to no investment in testing and screening systems. Variable testing costs (VTC) are assumed to be $50 per visit per herd (Schoenbaum and Disney, 2003), under the scenario where an outside expertise is required to conduct the screenings at each farm. Since N represents number of screenings in a region such as Texas, VTC represent variable costs that correspond to single testing of all the farms in the whole region. Hence, for the whole Texas the costs per visit would be 50*286100=$14,305,000.

Cost of response (CR) corresponds to costs, which include expenses for appraisal ($300 per herd), euthanasia ($5.5 per head), and carcass disposal ($12 per head) (Schoenbaum and Disney, 2003). Thus costs of response were calculated to be $1175 per herd. Optimal number of herds slaughtered under response strategy in Schoenbaum and Disney (2003) was 37 herds. Therefore costs or response strategy corresponding to R=1 are assumed to be 37*1175=$43475. CR could also include costs of vaccination, the estimates of which range from $6 to $8.61 per head (McCuley et al. 1979; Bates et al. February 2003 a, Schoenbaum and Disney, 2003). However, I rely on Schoenbaum and Disney's results, which show that the most effective response strategy did not involve vaccination. I exclude it from response measures and assume that loss minimizing response activity corresponds to slaughter of infected herds and herds with direct contacts with the diagnosed infected animals. This analysis essentially corresponds to the scenario under which vaccinated animals are ultimately slaughtered to avoid trade restrictions. However, this may not be necessary after development of a vaccine which could be differentiated from FMD infection. The model presented here could be adapted to such scenario.

### 4.3.1 Parameterization of Disease Spread

For the exponential spread specification under no prevention or response actions other than slaughter of only infected herds with clinical signs, I used fast (0.4) and slow (0.15) levels of disease spread based on direct and indirect daily contact rates per herd (Schoenbaum and Disney, 2003; Bates et al., 2001) to calculate appropriate disease spread coefficient ($\beta$). Considering that the herd will spread the disease for approximately seven days before showing the clinical signs of disease at which point the herd is slaughtered and disposed of, I simulated daily numbers of infected herds *(D)* for the two levels of disease spread. In other words, I start out with one infected herd and using slow and fast contact rates I simulated daily total number of infected herds *(D).* Using calculated data I regressed *ln(D)* on number of disease spread days to arrive at the estimates of $\beta$, which were statistically significant and equal 0.026 and 0.208 for slow and fast spread respectively. Time of disease spread is represented in terms of length of periods between regional screenings of animals. The less the number of screenings the longer the time intervals between the screenings, which would allow for more disease spread. On the other hand, the more the number of screenings, the less the time intervals between the screenings. Hence, there will be less opportunity for the disease to spread uninterrupted. Functionally, time intervals between the animals tests are represented by 365/(N+1), where N is the number of tests per year conducted in a given region, such as Texas. N+1 represents the fact that even if there is no animal screening adopted in a region the disease will be detected from clinical signs. However, if there is no animal testing system set up in the region, then the disease will not be detected at any site before clinical sings appear and will spread significantly.

Because of difficulties getting numerical solutions using the Reed-Frost formulation directly it was decided to approximate the disease spread using a logistic functional form (28). The Reed-Frost formulation was used to simulate daily spread of FMD under slow and fast rates of spread. Using equation (26) I simulated daily number of total infected herds since initial infection. TN was 286100, *k* was 0.15 and 0.4 for slow and fast spreads respectively.

$$D(t) = \frac{TN}{1 + \beta_1 e^{\beta_2 t}} \tag{28}$$

For fast disease spread, the logistic function gave an almost perfect fit to the Reed-Frost formulation with an $R^2$ equal to 0.99, $\beta_1$=512040, $\beta_2$=-0.319 (Figure 13). For slow disease spread I got $\beta_1$=14554.2, $\beta_2$=-0.012, $R^2$=0.97 (Figure 12). Letting t=(365/N+1), as in the case of exponential spread, and plugging (28) into (23) the optimal values for N were derived under various scenarios for Reed-Frost disease spread approximated by logistic function.

## 4.4 Model Experimentation

The model described above was constructed with a capability to conduct sensitivity analysis. I varied a number of the parameters to evaluate the effects of changes in situation characteristics on the optimal number of annual screenings. Specifically, to evaluate the effects of threat characteristics I varied the likelihood of disease outbreak and the spread rate of the disease. Probability of outbreak was varied from 0.001 to 0.9. In addition, I evaluated the sensitivity of optimal number of animal testings as it is influenced by the costs of the testing activity. This was accomplished by decreasing the variable testing costs by tenfold and hundredfold consecutively. I also evaluated the implication of alterations in the effectiveness of the response strategy. Two levels of response effectiveness were examined. One implied a 17 percent decrease in animal losses due to response actions compared to no response actions (Schoenbaum and Disney, 2003). The other implied a 30 percent decrease in animal losses due to more effective response actions. I also considered the possibility that prevention activities could provide ancillary benefits by identifying for example other animal health problems. Specifically, I decreased per herd fixed costs associated with instituting the surveillance systems. The motivation behind this is that investments made in detection systems could bring other benefits that are not related to FMD detection. Therefore those benefits could be used to offset some of the fixed investment costs. Hence, I ran cases where I reduced fixed costs by $50 per herd. Finally I investigated dependency of animal testing on post event recovery actions. This was accomplished running a case where I decreased the losses of income per FMD infected animal by 30%.

## 4.5 Results

The goal of this work was to evaluate the effects of various conditions on the optimality of adopting ex ante versus ex post schemes to fight the possible spread of FMD. The tradeoff was examined by varying the probability of events, disease spread rates, costs of surveillance and detection activities, effectiveness of response activities, and ancillary benefits of surveillance and detection activities. The following sections summarize the results of my experiments.

### 4.5.1 Higher Threats

The first experiment done involved raising the probability of an event to see how the optimal mix of activities varied. The hypothesis is the higher the event probability the more likely that ex ante prevention investments are to be made. The probability was varied from 0.001 to 0.9.

Both, exponential spread and Reed Frost spread formulations indicated that in case of a slow spread of FMD, detection actions were not economically desirable until the probability of outbreak was at least at high as 0.6 (Figure 14, Figure 16). However, in case of fast spread then the optimal number of tests varied from 5 to 22 under exponential spread model, and from 0 to 29 under RF spread model (Figure 15, Figure 17). Overall, under both FMD spread formulations, increasing the probability of an outbreak increased the use of surveillance systems.

However, in the scenarios where surveillance systems are most expensive and response actions are more effective than in other scenarios, even extremely high probabilities of an outbreak did not trigger investment in detection systems. This was the case for slow spread scenarios with full variable costs of detection and increased response effectiveness from 0.17 to 0.3. Thus, I can conclude that investment in surveillance and detection systems is contingent on the context of the disease case. Factors such as threat level, relative costs and effectiveness of alternative mitigation options play a determining role.

### 4.5.2 More Effective Response

The second experiment involved enhancement of response effectiveness. The hypothesis is that more effective response activities will increases reliance on response actions and decreases reliance on testing and screening. To test this hypothesis and evaluate the magnitude of this effect I increased the effectiveness of response actions from 0.17 to 0.3. The results indicate that increasing response effectiveness to 0.3 has a slight effect on the use of animal health testing. In all cases, increasing response effectiveness either increases the event probability at which detection systems ought to be in place or decreases the number of annual animal health tests. For example, in slow spread scenarios (Figure 14, Figure 16), for exponential as well as RF models, with tenfold decreased variable costs of testing, the event probability at which investment in detection systems is made increases from 0.6 to 0.8 due to increasing the effectives of response. In fast spread scenarios, for both, exponential and RF spread models, increasing the effectiveness of response decreases the number of animal tests by one or two annually (Figure 15, Figure 17).

### 4.5.3 Cheaper Surveillance

As expected, decreasing the variable costs of testing and screening increases the worth of investing in such systems. Specifically, if variable testing costs were decreased hundredfold, then the number of annual tests in case of slow disease spread goes from 0 to 6 under RF formulation (Figure 16). Similar results arose for the exponential spread model (Figure 14). In the case of fast disease spread, the results are more illustrative. Both exponential spread and RF spread formulations show noticeable differences in the number of annual tests (Figure 15, Figure 17). When variable costs are decreased 100 fold, corresponding to the scenario where testing is cheaply performed by farm employees, the number of annual tests increases from 13 to 23 at 0.2 probability of outbreak occurrence under RF formulation. Similarly, under exponential spread formulation testing increases from 8 to 15 tests per year at 0.2 probability of outbreak occurrence.

### 4.5.4 Event Severity or Speed of Disease Spread

Next the effect of speed of disease spread was examined. The hypothesis was that the higher the disease spread rate the more the optimal strategy would rely on detection systems. Such results occur under both the exponential (Figure 14 and 15) and RF (Figure 16 and 17) formulations of disease spread. Testing and screening becomes considerably more advantageous for fast spread than for slow spread. In case of slow spreading disease, investment in detection systems is triggered only at high levels of outbreak likelihood. However, in case of fast spreading disease investment in detection systems is made even under low levels of outbreak likelihood.

### 4.5.5 Ancillary Benefits

It was considered that there was a possibility of ancillary benefits emerging from investing in surveillance systems for detection of FMD in terms of other animal health and management activities. To examine this I ran the scenarios with the fixed costs of testing decreased by $50 per herd. It was found that for fast spread scenarios, under both exponential and RF specification, such ancillary benefits associated with ex ante investment did not affect the number of annual animal tests. This was a trivial result because number of tests is not affected by fixed costs. Fixed costs are independent of number of tests.

What is affected by fixed costs is whether or not there will be surveillance program in place at all. Under slow spread scenarios lowering fixed costs affected the outbreak probability at which it was optimal to start investing in surveillance systems. For example, under both, exponential and RF, spreads with minimal variable costs and response activity with 17 percent effectiveness, the probability at which it became advantageous to invest in surveillance programs decreased from 0.6 to 0.4. Similar results were obtained in scenarios with increased response effectiveness and increased variable costs of testing.

### 4.5.6 Herd Size

Optimal number of annual animal tests was hypothesized to be affected by the average herd size. Therefore, I changed the current average herd size of 50 to 400. The result indicated that with larger average herd size surveillance and detection systems become more advantageous than with smaller herd sizes. For example, with fast spread and minimal variable testing costs the optimal number of animal tests reached 39 per year. This result was expected due to the effect of fixed costs of detection systems per herd. The larger the herd size the less the average fixed costs per test. Therefore, large herd size will decrease average costs per test. This effect is known as economies of scale.

### 4.5.7 Recovery Actions

Animal surveillance intensity depends on the level of response as well as recovery activities. Recovery activities, identified as the ones that are directed towards restoring consumer confidence, decrease the losses per infected animal by restoring back some of the lost demand. To evaluate this effect, I decreased lost gross income per infected animal by 30%. Since the results for slow disease spread gave a low number of animal tests, the results are presented for fast spreads in graphs 10 and 11. In both of the exponential and RF spread formulation cases the number of tests decreased only slightly under such a recovery benefit. Along the probability spectrum the number of tests decreased only by 1, if any, under both formulations. This implies that cattle value losses avoided by detection are large enough to justify use of detection and surveillance even under substantial recovery program.

### 4.5.8 Economic Consequences

Economic consequences of potential agricultural sabotage, in the form of FMD outbreak, and various mitigation strategies were calculated in terms of expected financial losses in the cattle industry. Specifically, losses consisted of two parts, cattle values per head and average revenue per head. The results are depicted in Figure 20 through Figure 29.

The two formulations of disease spread gave similar results. Losses varied from around \$60,000 to around \$280,000,000 depending on probability of attack, spread rate, and mitigation strategy. Under slow spreads (Figure 20 and 22) economic losses mainly depended on response effectiveness until certain level of outbreak probability was reached (around 0.6) because surveillance and detection was not found to be advantageous for lower probabilities. Hence, the six curves of monetary losses collided into two depending on the effectiveness levels chosen in this work. After probability of outbreak reached 0.6 surveillance and detection activities started to became advantageous under reduced costs of testing. Hence the curves branched out depending the costs of surveillance and detection.

The exponential and RF spread formulations gave similar results for the fast spread cases (Graphs 20 and 22). Under fast spread scenarios, the economic losses are significantly higher than under slow spread. Moreover, surveillance and testing was adopted even for lower levels of probabilities of sabotage. The losses mainly varied according to costs of surveillance and detection programs. Three levels of variable costs were considered in this work. Hence, three main patterns of monetary losses stand out. Increasing effectiveness of response activities has a minor effect on decreasing the losses.

Figures 24 through 27 show expected losses as a percentage of total monetary worth of regional Texas cattle industry. The worth of cattle industry was supposed to consist of monetary values of live animals and annual revenues generated by those animals. Financial losses from a potential FMD outbreak reached almost 2% of total cattle industry's economic worth under extremely high probabilities of outbreak when surveillance and detection systems were adopted. Figures 28 through 31 show proportions of cattle industry's financial worth lost when no surveillance and detection strategies were considered. Response actions, consisting of slaughtering only contact herds, were the only mitigation policy behind these graphs. Losses under these scenarios were significantly higher under fast spread in both exponential and RF spread formulations. Comparing figure 24 through 27 to graphs 28 through 31 reveals that surveillance and detection programs will reduce the expected costs of potential agricultural sabotage in the form of FMD outbreak.

## 4.6 Conclusions

I investigated the relationship between disease/treatment characteristics and the optimal allocation of effort between prevention and response in the face of possible agricultural sabotage. A conceptual model was developed that trades off ex ante fixed costs of surveillance system and ex-post response costs considering stochastic event frequency where outbreaks only occur with a given probability. Damages considered here include loss of cattle values and loss of gross income.

As a prevention strategy I considered periodic testing and screening of cattle as means to detect potential infection before the appearance of clinical signs. This strategy is adopted prior to realization of any outbreak and thus introduces cost that are incurred regardless of whether or not an outbreak occurs.

The empirical part of the analysis was done using data on the case of Foot and Mouth disease. The investigation considered optimal allocation and design of the total disease management system in the face of varying threat levels and threat management cost scenarios. Testing and screening involves both, fixed and variable costs. As a responsive measure I adopted slaughter of herds in direct contacts as defined in Schoenbaum and Disney (2003).

The model used in this paper is based on minimizing probabilistic weighted costs of potential FMD outbreak and its ex ante prevention. The results suggest that the optimal combination of preventative and responsive strategies depends on such factors as disease spread rate, strategy effectiveness, level of FMD threat, and costs of strategies. I find that effort in ex ante surveillance increases with threat probability, cost reductions in surveillance, with disease spread rate, lower degree of effectiveness in response, and average herd size.

Overall, the higher the threat the more advantageous it is to invest in preventative policies. Although preventative and responsive measures do not necessarily preclude one-another, they are substitutes to a certain degree. In terms of strategies adopted here, this substitution could be explained by the fact that as more animal testing is performed the latent period of infected animals is reduced. Therefore, fewer herds are infected by sick herds, which means less herds will have to be slaughtered due to direct contacts with infected herds. On the other hand, at lower probabilities of event occurrence, surveillance investment costs are higher than expected costs of FMD outbreak with optimal response strategy. Therefore, as testing frequency decreases at lower probabilities of an attack, the level of responsive measures increases in case of an attack. This is depicted in Figure 32, which shows the relationship between response and surveillance at various degrees of event probability under fast RF spread and minimal variable costs of testing.

These results need to be interpreted with care as outcomes depend on the functional formulation of the disease spread and on the parameters assumed in the model. I analyzed two possible functional forms for the disease spread and although the general results compatible, the exact numerical results differ. Moreover, since the exact rate of disease spread is not known, I analyzed the model under slow and fast rates based on data from Disney (2003) and Bates et al., (2001). It is possible that the actual rate of the disease spread is substantially different from those assumed in this study. In such case the numerical results will differ but general conclusion regarding the relationship between prevention and response activities will stay the same.

The damages considered in this investigation include the lost value of slaughtered cattle and associated gross income. Losses from trade bans, decreased tourism, consumer scare and other consequences of FMD outbreak are not considered in this study. Hence, losses considered here are likely to be lower than actual losses. Therefore, preventive strategies may be even more advantageous than reported in this study. Moreover, periodic testing and screening of farm animals has other benefits in addition to detection of FMD virus. Regular animal testing could also help to detect other infectious or noninfectious diseases and monitor general animal health. Testing could also facilitate keeping inventory of farm animals in the region, which could be of benefit to researchers and policy makers. These benefits are hard to quantify monetarily, therefore they were excluded from this study.

This paper provided a preliminary analysis of the relationship between ex ante cattle screening and ex post responsive slaughter of cattle in case of FMD outbreak in a region such as Texas. Even though the results of this chapter are contingent on the assumptions made regarding the spread of FMD and the simplifications made regarding the damages of outbreak and benefits of mitigation strategies, the results shed some light on broad disease management approaches.

# 5 ANALYTICAL FRAMEWORK FOR FUTURE MODEL

## 5.1 Introduction

In this chapter I develop and demonstrate an enhanced theoretical approach to be used for evaluation of strategies. The framework proposed here goes beyond those in the earlier chapters in that it relies on an epidemiologic model to be available in the future in the context of Texas A&M National Center for Foreign Animal and Zoonotic Disease Defense.

The demonstration work done in this chapter will expand on earlier chapters to simultaneously incorporate prevention, detection and response options to FMD outbreaks. Specifically, the model will include spread of the disease under various mitigation strategies. Epidemiologic effects of numerous mitigation strategies will explicitly be incorporated to have more detailed input into economic model than that used in the previous chapter. A major difference from previous chapter is that here I will consider decision making on a more localized basis as opposed to considering the whole region as a following a single strategy. This will allow adoption of different mitigation strategies in different sub-regions. In addition, disaggregating the region also allows incorporation of differences in disease spread due to transportation. Therefore, it will be possible to incorporate animal movement bans as a possible component of responsive agricultural terrorism mitigation strategy.

The optimal mix of prevention and control/repair strategies is heavily affected by the stochastic characteristics of the issue and this choice can be influenced by attitudes towards risk. The approach developed here will also incorporate risk attitudes into decision making process. Risk aversion has been shown to be a significant factor in determining a portfolio of strategies which affect variance of returns (Brink and McCarl, 1978). Incorporation of risk aversion may alter decisions where for example, highly risk averse decision makers may be found to be more likely to invest in prevention strategies at lower probabilities of an event than would less risk averse decision makers.

## 5.2 Epidemiologic Model

An epidemiologic model is needed to parameterize the effects of a set of possible mitigation strategies that will involve prevention, detection, response and recovery measures for input into the economic model. Previously I used equations from epidemiologists to form a very simple epidemiologic model. However, more complex models exist (Bates et al., 2001; Bates et al., February 2003 a; Schoenbaum and Disney, 2003) and will soon become available. Such an epidemiologic model can be used to get estimates of physical damages under event characteristics under specified mitigation strategies. That information in turn will be integrated with data on costs, market effects and probabilities and integrated into an economc systems model of the character of the models discussed above.

As mentioned above, several prevention and response strategies would be desirable to be included in this model. These include but are not limited to increasing expenditures on and efficiency of international trade inspection; tightening the control of animal feed and medical supplements; upgrading guidelines for production processes and quality control measures at central manufacturing as well as storage and transportation facilities, removing all affected branches of food supply chain identified by enhanced tracing systems. These options, and their combinations, need to be simultaneously considered in order to come up with a set of best strategies against agricultural contamination. As shown in previous chapters, the optimal mix of strategies depends on such factors as threat level, event severity, relative costs and effectiveness of strategies.

Use of an epidemiologic model in an integrated epidemiologic and economic analysis will allow consideration of the optimal combination of mitigation strategies on a localized level.

## 5.3 Risk Considerations

It has previous been shown that the decision makers are concerned not only with the maximization of returns but also with variability of returns. Risk averse decision makers wish to minimize variance of returns and prefer stability. On the other hand, risk loving decision makers would prefer greater return variance with wider spread between possible high and low returns. It is desirable to formulate the model that will incorporate not only random variables but also the decision maker's attitude towards risk. In other words, the model portraying the choice of instituting prevention, detection and response strategies against agricultural terrorism must include the probability distribution of unknown variables and the farmer's risk attitude. However, before discussing the stochastic models it is necessary to provide a brief discussion of theoretical concepts of decision making under uncertainty.

### 5.3.1 Expected Utility

The most widely used conceptual approach explaining economic behavior under risk involves expected utility maximization. However, it has been argued that the expected utility models do not always correctly represent behavior under risk (Machina, 1994). Specifically, linearity of the expected utility function with respect to probabilities has been questioned. Nevertheless, this approach provides a practical means for evaluating strategies associated with risky outcomes. Specifically, this approach assumes that the decision makers choose among risky strategies according to the income and risk preferences reflected in his/her utility function. Therefore, while recognizing the limitations of expected utility models, I rely on this approach to evaluate various strategies to battle possible agricultural terrorism acts.

Expected utility models could be explained as follows. Suppose the utility function under uncertainty is *U(w)* where *w* represents wealth. Under multiple states of nature the expected utility function could be represented as a linear sum of utility of outcomes and their associated probabilities

$$U(w) = p_1 U(w_1) + p_2 U(w_2) + p_3 U(w_3) \ldots = \sum_{i=1}^{n} p_i U(w_i)$$

This utility function, known as the von Neumann-Morgenstern (VNM) utility function, satisfies the axioms posed by economic theory for choice under uncertainty.

Namely, it satisfies completeness, transitivity, continuity, monotonicity, substitution, and reduction to simple gambles (Jehle and Reny, 2001). Employing expected utility theory will allow taking into account preferences towards risk.

### 5.3.2 Risk Aversion

An expected utility function can depict risk averse, risk loving or risk neutral preferences. Assuming the utility function is continuous and twice differentiable with respect to wealth, Pratt (1964) showed that the properties of the utility function will indicate risk attitudes. A positive first derivative $U_1(w)>0$ implies that utility is strictly increasing in wealth, exhibiting non satiation, where $U_1$ is the marginal utility of w. A negative second derivative, $U_2(w)<0$, implies that the individual is risk averse. A positive second derivative, $U_2(w)>0$, implies that a decision maker is a risk taker. If $U_2(w)=0$, the individual is indifferent toward risk.

In terms of this study, risk preferences are relevant because the decision on what type of prevention and response measures to adopt depends on attitudes towards variability of payoffs. The farming community has been known to have risk averse preferences (Brink and McCarl, 1978). Therefore, the utility function is presumed to be concave, with a second derivative describing the extent of risk aversion, which will determine which strategy will be adopted against agricultural sabotage. It is likely that the more risk averse the community the more preventative strategies will be adopted.

From a producer's point the goal is to maximize the utility of profits given the possibility of agricultural terrorism. Farmers have certain prevention and response options the can employ that would reduce the losses from possible FMD outbreaks. It is critical to recognize at this stage that the farmers are primarily risk averse implying that they prefer stable lower income to a higher more variable income with possible high and low payoffs. The premium paid to reduce the risks is the costs of prevention and response activities implemented to decrease farmers' vulnerability towards FMD outbreaks. The magnitude of the premium that they are willing to pay in order to reduce the risk depends on probability levels of an outbreak and on risk aversion levels of the farmers. One of the objectives here is to demonstrate the effects of risk aversion levels on the optimal counter terrorism strategy.

### 5.3.3 Certainty Equivalence and Risk Premium

For a given gambling decision over wealth, such as adopting or not adopting preventative or response actions, certainty equivalent (CE) is the amount of wealth that makes the decision maker indifferent between taking a gamble and accepting CE (Jehle and Reny, 2001). Mathematically, $U(g) \equiv U(CE)$, where g is a given gamble. Hence, the lower the certainty equivalent the more risk averse is the decision maker.

The monetary value of the difference between CE and the utility of the gamble is called the risk premium. Essentially the risk premium is an amount of wealth necessary to make the decision maker indifferent between taking a gamble and accepting deterministic level of wealth. The risk premium could also be thought of as a difference between the decision maker's certainty equivalent and the expected value of the gamble. Mathematically (Jehle and Reny, 2001), risk premium is an amount of wealth, P, such that $U(g) \equiv U(E(g) - P)$.

In terms of analyzing agricultural terrorism, the risk premium corresponds to the expenses related to prevention and response strategies. The more prevention strategies are adopted the less vulnerable is the industry to fluctuations in profits and welfare due to agricultural terrorism acts. Based on the above discussion, optimal prevention related expenses will equal to the difference between certainty equivalence and expected returns, plus possible governmental assistance payments

### 5.3.4 Arrow-Pratt Coefficient

As mentioned above, the shape of the utility function determines the nature of decision maker's risk preferences. The more concave the utility function, the more risk averse the decision maker, and the more convex the utility function the more risk loving the decision maker. Hence, the second derivative, which indicates the rate of change in utility as a response to change in wealth, of the utility function gives me an idea about the risk preferences. However, the second derivative alone can not uniquely measure risk preferences because utility function is unique up to a positive linear transformation. That is, if, for example, I multiply the utility function by 2 the behavior of the decision maker does not change. But risk aversion measured by second derivative would change. In order to have a unique measure of decision maker's attitude towards risk I could divide the second derivative by the first. This measure is called Arrow-Pratt measure of risk aversion.

$$R(w) = -\frac{U''(w)}{U'(w)}$$

Since the utility function is increasing in wealth the first derivative will be positive. The second derivative can be positive or negative depending on risk attitude. If second derivative is positive than Arrow-Pratt coefficient is negative corresponding to risk loving decision making. If second derivative is negative then the Arrow-Pratt coefficient is positive corresponding to risk averse decision making. Zero second derivative would indicate linear utility function which implies risk neutral decision making.

In the context of this study risk aversion coefficient (RAC) plays a significant role because the decision on which prevention and response activities to adopt will depend on the risk averseness of decision maker. Assuming the decision maker is risk averse I know that Arrow-Pratt coefficient will be positive. However, the question is how risk averse is the decision maker, hence what is the magnitude of Arrow-Pratt coefficient. There are a few ways to select a risk aversion coefficient for modeling purposes (McCarl and Bessler, 1989). However, in this study I rely on examining implications of varying the magnitude of risk aversion coefficient on optimal strategy selection. As a result of such analysis I will get a relationship between mean returns and variance of returns along the spectrum of risk aversion coefficients and corresponding optimal prevention and response strategy combinations.

### 5.3.5 E-V Formulation

Under constant absolute risk aversion (CARA) and normality of random variable expected utility maximization is equivalent to the Expected value variance (E-V) formulation (Degroot, 1970). The E-V framework will be used herein to address the risk aversion issue related to agricultural terrorism. This method allows derivation of optimal decision strategy under multiple states of nature. In addition, it could easily incorporate decision making with recourse. A three stage model will be developed from a standard form of maximizing mean returns while minimizing variability of returns shown below

$$\begin{array}{lll} MAX & \overline{C}X - RAP \times X'SX & \\ S.T. & AX & \leq b \\ & X & \geq 0 \end{array}$$

where $\overline{C}$ is expected return per decision x over all states of nature. X is a vector of decision variables. S is a variance-covariance matrix of returns per decision over all states of nature. RAP is the Arrow-Pratt risk aversion parameter.

Under such a formulation, the optimal decision will depend on not only net returns under each decision, but also on variability of net returns and degree of decision makers risk aversion. The greater the RAP coefficient the greater the emphasis placed on decreasing the variability of returns. On the other hand, the smaller the RAP coefficient the greater the emphasis placed on maximizing expected returns and less emphasis on decreasing variability of return over states of nature.

## 5.4 Mitigation Options Relevant in This Model

There are numerous measures that could be implemented against outbreaks of FMD. These include but are not limited to: various levels of vaccination, slaughter, detection/surveillance, tracing, movement bans, and import monitoring. Various combinations of these actions could comprise a mitigation strategy. Here I provide an overview of those strategies although empirical demonstration will be based on vaccination, slaughter, and detection.

Both, preventative and responsive vaccination could be incorporated into my analysis. However, at this point exact effectiveness of either preventative or responsive vaccination is unknown. These issues need to be investigated with the extensive epidemiologic level data and are not pursued in this work. Here I assume that the necessary estimates will become available in the future and develop a framework that will utilize this information.

As in the case of vaccination, effectiveness of various slaughter options need to be investigated on epidemiologic level to provide the economic model with the estimates necessary to evaluate relative economic worth of various slaughter options. Again, in this investigation I will assume that such information will become available in the future and develop a framework that relies on this information.

In order to investigate effects of a transportation ban as a response measure in case of an outbreak, cattle transportation routes need to be known. At this time such information is not available. However, I hope that in the near future this information will become available and I will be able to incorporate this aspect into my framework.

Effectiveness of surveillance and detection systems is currently uncertain. For the purposes of this work I assume that surveillance systems would lead to a 100% prevention of FMD outbreak. I recognize that this assumption is rather restrictive. However, I proceed with this assumption with an understanding that this assumption is likely to be adjusted in the future as more information becomes available on the effectiveness of surveillance systems.

Although monitoring imports is not accounted for in the model proposed here in its current form, it could be incorporated in the future as one of the components of some of FMD mitigation strategies.

Monitoring travel is not currently a part of the model proposed in this study but could be incorporated in the future. One way to do this is to let import and travel monitoring affect probability of FMD introduction from outside of U.S. In other words such programs could be modeled to have a decreasing effect on the probability of FMD outbreak in the U.S.

Tracing systems are technically not a part of my model in its current form. However, if information on effectiveness and costs of tracing systems was available the model could be adjusted to reflect consideration of tracing systems in mitigating possible FMD outbreaks

### 5.4.1 Consumer Effects

Agricultural terrorism act will have a substantial effect on consumer demand. In several observable cases the demand for goods and services related to the commodities affected by disease outbreaks has decreased significantly. For example, under a highly infectious animal disease outbreak, such as an outbreak of FMD, the demand for meat products and related commodities has been observed to decrease in spite of the fact that FMD does not affect humans. In terms of this research, decreased demand implies that the price for agricultural commodities related to contaminated commodities will decrease. Falling prices and demand will impact agricultural producers. Therefore, consumer effects need to be accounted for when considering various prevention and/or response strategies. The conditions, including consumer effects, which may favor prevention of outbreaks over response to outbreaks, need to be investigated. The major task in this sense is to arrive at specific quantitative implication of agricultural terrorism on consumer behavior.

From producer's point of view this means estimating the effects of the event on equilibrium price of the commodity. If the price for commodity is likely to decrease drastically it may be more advantageous to invest in preventive strategies in order to avoid mass food scares. However, if the effect on price is not likely to be significant than cheaper response strategy may prove to be economically more attractive.

## 5.5 Ex Ante Investment

Both, prevention and response activities may require some fixed costs. For example, in order to be able to vaccinate, either preventatively or responsively, the investments may need to be made to ensure availability of vaccines, medical supplies, and practitioners. A better example of this would be a veterinary laboratory, which could be used for either preventative measures or for response actions. As a prevention measure a veterinary laboratory could be used to conduct and record testing for the FMD before it occurs. As a response measure to a reported FMD case(s) in the vicinity, the lab could be used to identify animals which are infected but do not yet show the signs of infection. As a result, effectiveness of response measures could be improved from more timely actions. But such benefits are not realized unless the laboratory is built. Similarly, it may be necessary to invest in some storage facility for vaccines to be used either preventatively or responsively.

Surveillance and detection is another example for an ex ante investment. The investment made in surveillance and detection could be utilized either for a prevention measure or a response action. As a prevention measure, surveillance and detection systems could be used to monitor the farms prior to a possible outbreak. As a response measure it could be used to intensify monitoring of individual farms or other units if there is an outbreak in the region. Weather surveillance and detection is used preventatively or responsively, the system and equipment for surveillance and detection needs to be set up prior to realization of outbreak or no outbreak. This implies fixed investments plus variable operating costs. The fixed investment could be employed at different levels of intensity depending on the probability of outbreak and variable costs of operating the system.

In the model proposed in this work I will use surveillance and detection as an example of counter agricultural terrorism measure that requires ex ante investment. Other measures, such as vaccination, that may show to require ex ante investment will be reflected in the actual model.

## 5.6 Model Description

The model proposed in this chapter is based on a two stage framework depicted in Figure 1. Except in this case I have more than two states of nature. For illustrative purposes I chose to have ten states of nature depending on severity of FMD outbreak.

Each state of nature has an associated probability of occurrence. In the first stage the decision could be made to invest in surveillance and detection systems. If implemented, then surveillance systems could detect the outbreak if it occurs and consequently facilitate faster control of disease spread. Regardless of whether an outbreak does or does not occur then the investment is a sunk cost. In stage two there either is an outbreak or there is no outbreak. Therefore the decisions made at this stage are state dependent, which reflects the nature of stochastic programming with recourse.

The two stage nature of this framework could easily be adapted to the three stage model above. At this point the formulation is kept as a two stage model because it is currently unclear what type of epidemiologic results will be received from epidemiologic model. The three stage model is in part based on recovery actions. At this point this is not an item of focus and requires market based data. Therefore, for now the framework is two stage.

### 5.6.1 States of Nature

For the purpose of illustration I assume ten states of nature, which vary according to severity of possible agricultural terrorist event. State of nature one corresponds to situation where there is no agricultural terrorism event and business continues as usual. The second state of nature corresponds to a situation where there is a minor outbreak of FMD. Under third state of nature the outbreak is more intense. The event gets more severe for fourth and the most severe in the fifth and subsequent states of nature. Clearly the situation with no event is the most likely state of nature.

### 5.6.2 Grids and Cattle Operations

The region under investigation is subdivided into *n* grid cells. Each grid has specific attributes, such as the number of roads, vet clinics, population, wildlife density, farm operations, etc. which affect the vulnerability of the grid towards FMD infection. The number of cattle operations in a cell is thought to be most important characteristic of a grid cell in terms of vulnerability towards FMD. Different strategies could be adopted in each of the grid cells depending on their characteristics. For example, a grid cell with high animal density is likely to adopt a more proactive strategy than a cell grid with low animal density. At this point I use ten cells in the model. All ten cells are assumed to have 100 cows.

### 5.6.3 Strategies

Numerous measures and their combinations could be considered for mitigating possible agricultural terrorism event such as intentional FMD spread. What types of measures will be considered in an epidemiologist model is not exactly clear. However, from existing literature I was able to identify several options for preventing and responding to FMD outbreaks. I keep those options in mind to construct preliminary set of strategies to combat possible FMD outbreak. Specifically I consider a set of strategies which could involve various combinations of surveillance and detection, vaccination, slaughter, etc.

For the purpose of illustration consider a set of 5 strategies. These strategies differ from one another based on their consequences. Specifically under various states of nature, different strategies will result in different numbers of vaccinated, slaughtered, infected, and normal cows. Normal cows are presumed to be cows which are not infected and not vaccinated. Vaccinated cows are divided into cows that are vaccinated preventatively in the fist stage and cows that are vaccinated responsively in the second stage.

Strategy one is to do nothing. Therefore under state of nature 1 nothing happens and all of the animals are in their usual healthy conditions. In the second state of nature there is an outbreak and half of animals in this particular grid are infected. In states of nature four and three more of them are infected and in state of nature five all of them are infected.

The second strategy calls for preventative vaccination of all animals. Therefore in all states of nature all cows show up as vaccinated in the first stage.

The third strategy is state dependent. Specifically, it calls for no action if there is no outbreak and it calls for vaccinating 50 animals in a cell if the outbreak occurs. As the severity of outbreaks worsens over states of nature, more unvaccinated animals get infected.

The fourth strategy is both state dependent and state independent. Under this strategy 10 animals are vaccinated preventatively no matter what happens. These could be the cows under higher risk of being infected if FMD occurs. For example, cows that are being transported or cows that are located near transportation points. In the second stage, if there is no outbreak, than no further action is taken. However, if there is an outbreak 20 animals are slaughtered as a response. Again, as the severity of an outbreak worsens the number of infected animals increased.

Strategy five is assumed to be based on complete surveillance and detection. In other words, in the first stage an investment is made in surveillance systems, as a result of which any outbreak is assumed to be immediately detected and effectively stopped. This assumption is rather restrictive and could be relaxed as needed.

These strategies are applied in all grid cells. However, different strategies may be applied in different cells based on their characteristics. Clearly the outcomes of the strategies are different for different grid cells under corresponding states of nature.

The strategies proposed here are presented for illustrative purposes only. I recognize that actual strategies employed later involve more considerations than mentioned here. Actual strategies may also include more measures than assumed here. However, the composition of strategies is not the interest of this work. The main interest is the effect of a wide set of strategies. Therefore I concentrate on constructing an economic model that could take the outcomes of those strategies and evaluate their economic worth.

## 5.7 Formulation

The proposed model has the following structure:

$$MAX \quad \sum_{g}\left[Mean_{g} - RAP\left(\sum_{s}\left(d^{+}_{s,g}\right)^{2} + \left(d^{-}_{s,g}\right)^{2}\right)\right]$$

$$S.T.$$

$$Mean_{g} \leq \sum_{s} \Pr_{s} \cdot RET_{s,g} \qquad \forall g$$

$$RET_{s,g} = \sum_{x}\sum_{cc}\left[C_{s,x,ac,g} \cdot STRG_{x,g}\left(REV_{ac} - COST_{ac}\right)\right] - \sum_{x} INVCOST_{x} \cdot STRG_{x,g} \quad \forall g,s$$

$$\sum_{x} STRG_{x,g} = 1 \qquad \forall g$$

$$RET_{s,g} - Meang_{g} + d^{-}_{s,g} - d^{+}_{s,g} = 0 \qquad \forall g,s$$

Where:

| | |
|---|---|
| $s$ | Corresponds to states of nature under attack and no attack |
| $g$ | Denotes grids |
| $x$ | A set of considered strategies |
| cc | Cattle categories under various states of nature and strategies |
| $RET_{s,g}$ | Returns under various states of nature for each grid |
| $Pr_{s}$ | Probability of state of nature s |
| $REV_{ac}$ | Revenues per animal under each category |
| $COST_{ac}$ | Costs associated with cattle categories due to strategies |
| $INVCOST_{x}$ | Investment costs associated with strategy x |
| $STRG_{x,g}$ | Binary variables that represent adoption of strategy x in grid g |
| $C_{s,x,ac,g}$ | Number of cows in eah grid under each state of nature and strategy by cattle categories |
| $Mean$ | Corresponds to average returns |
| $d^{\pm}_{s,g}$ | Positive and negative deviations from average returns over various states of nature. |
| $RAP$ | Arrow-Pratt risk aversion parameter. |

In this formulation the mean is calculated over all states of nature and corresponding deviations are squared and summed to come up with a variance of returns under the various states of nature. Returns ($RET_{s,g}$) are calculated for each of the states of nature in each grid with a particular prevention and response strategy. Under no outbreak, and therefore no farm infection, the returns are a function of existing prices and a function of prevention strategies adopted in the first stage. Under the remaining nine states of nature, where some level of FMD is present, the profits are a function of prevention and response actions. Returns ($RET_{s,g}$) in each state of nature are affected by the costs of adopted strategies. Costs include those of slaughter, disposal, disinfection, vaccination in either stage, and investment costs made in the first stage. At this time the only strategy that involves investment in the first stage, and thus is not dependent on state of nature is surveillance and detection. Other strategies could also be adjusted to reflect at least partial state independence.

Notice that the probability of FMD outbreak (Pr) in the region is exogenous. This essentially corresponds to the assumption that prevention strategies do not alter the probability of agricultural terrorism through FMD spread. This assumption is realistic because it is practically impossible to eliminate every possible venue of FMD spread. Therefore, if terrorists decided to spread FMD they will find a way to do so. However, the bandwidth of an attack could be reduced by adopting certain prevention and response strategies. In this case bandwidth corresponds to the extent of the spread of the disease. As such I can represent the spread of FMD as the probability of the grids being infected. In order to decrease the bandwidth, or reduce the probability of surrounding grids being infected, I could adopt certain prevention and response strategies. However, due to uncertain nature of epidemiologic effectiveness of decreasing the probability of grid infection under various circumstances I treat probability of grid infection as exogenous.

### 5.8 Results Discussion

In its current form the model suggests primarily relying on surveillance and detection systems to interrupt the spread of FMD. This corresponds to about 24 tests per year per herd, in this case assumed to be equivalent to a grid. Chapter 4 results for fast spread suggested 12 annual tests. However, in the previous chapter response activities were also adopted, whereas in this model the strategy to do surveillance and screening was constructed to be exclusive. It would be possible to construct the strategies to include both surveillance and response actions.

Effects of various levels of RAC where investigated under the following probability distribution for the occurrence of the states of nature, state one 0.9999, state two 0.00001, state three 0.00001, state four 0.00004, state five 0.00004. RAC was varied from 0 to 1. As a response the optimal strategy choice went from a combination of third and fourth strategies to adoption of fifth strategy in all grid cells. The corresponding EV frontier, which shows the relationship between mean returns and variance, is shown on Figure 33.

Increasing the probability of FMD outbreak produced similar results. Specifically I increased the probability of the four FMD involving states of nature tenfold, relative to the previous case. Depending on the value of RAC the adopted strategies switched from combinations of third and fourth strategy to completely adopting fifth strategy. The corresponding EV frontier is given in Figure 34.

## Conclusions

In this chapter I outlined a framework that will be used in conjunction with the epidemiologic model to be developed at the Veterinary school of Texas A&M University to evaluate various FMD mitigation strategies. The proposed framework could be used to evaluate economic attractiveness of various strategies to battle possible agricultural terrorism, such as the intentional spread of FMD. It is argued here that risk aversion of decision makers will play a significant role in determining the optimal combination of anti-terrorism measures to be adopted.

Using hypothetical numeric values I investigated how the optimal mix of disease management strategies is affected by risk aversion levels. It is apparent that higher risk aversion will result in adopting preventative measures such as surveillance and screening rather than responsive slaughter or vaccination. It was also observed that at higher event probabilities preventative measures were favored over responsive measures. Although, this result is consistent with the results of chapter 4, caution needs to be exercised while interpreting these results due to the epidemiologic assumptions used. It will be more appropriate to interpret the results of the model after more realistic estimates of epidemiologic model are used.

# 6 CONCLUDING COMMENTS

In the wake of raised awareness of threats to national security, agricultural terrorism is considered as an action that could disrupt social, economic and political stability (Veneman, 2002). Several cases of unintentional and some intentional cases involving contamination of agricultural product have been observed and have caused various degrees of economic damages brought by agricultural contamination. In the animal disease arena, recent outbreaks of BSE and FMD have been observed and reveal significant associated economic losses especially in the UK events. Therefore, investigation of options to mitigate possible animal disease outbreaks whether through deliberate agricultural terrorism or accidental introduction was deemed to be in order and was done in this dissertation.

To carry out this investigation, a conceptual framework for economic analysis of animal disease outbreak management strategies was developed. Four broad classes of possible outbreak related management activities were considered: (1) ex ante prevention, (2) ex ante and some ex post detection activities (3) ex post response disease management and (4) ex post recovery activities. Emphasis was placed on the differences between ex ante and ex post strategies for minimizing the economic losses from potential outbreaks. Specifically, economic tradeoffs were considered between the fixed, event independent costs of ex ante actions versus the probabilistic ex post costs encountered only when an outbreak occurs.

Comparative statics and empirical analysis were done to examine the sensitivity of the use of ex post versus ex ante actions given changes in the probability of event occurrence, disease spread rate, and relative costs. The comparative statics results showed that the optimal combination of strategies to mitigate possible agricultural contamination depends on a number of factors. In particular investments in ex ante activities rise with increases in the (a) probability of events, (b) disease spread rates, (c) magnitude of costs of an outbreak, (d) relative costs and ineffectiveness of available response strategies, (e) severity of contamination, and (f) ineffectiveness of recovery actions.

Using the analytical framework individual decision maker behavior was also examined. In that setting, it was shown that under localized decision making, individually optimal levels of surveillance, prevention, response, and recovery actions adopted at each site are affected by external benefits that these actions create. In other words, it was recognized that surveillance and response actions of one individual could affect the likelihood of another individual being infected. Similarly, recovery actions adopted by one individual could affect magnitude of losses suffered by another uninfected individual if there is a disease outbreak. Therefore, it was recommended that externality issues, brought by adoption of mitigation strategies, be included into analysis. However, these issues are left out from the empirical investigation carried out in this dissertation. These aspects of agricultural terrorism mitigation could be topics of future research.

The conceptual approach was used in an empirical, relatively simplified, case study analysis regarding foot and mouth disease outbreaks in Texas. An empirical version of the model was used to evaluate the economic attractiveness of surveillance/detection, as a form of prevention, relative to response actions represented by slaughtering of herds with direct contact with those diagnosed as infected. The number of ex ante annual animal health tests was used as a variable describing level of intensity of ex ante activity. In terms of optimal combination of ex ante and ex post mitigation activities, it was observed that although ex post activities were always used in case of an outbreak, there was some level of substitutability between ex ante and ex post mitigation activities. It was shown numerically that, for fast spread of disease, number of annual animal health tests increased while level of ex post response activity decreased as probability of an outbreak increased. The results indicate that utilization of ex ante strategies depends on a number of factors. Specifically, the amount of ex ante activity in terms of the frequency of ex ante animal tests increases as the

- probability of outbreak increases
- severity of the potential outbreak increases in the form of the number of

animals lost, the value of the animals or the rapidity of disease spread

- the cost of ex ante activities becomes lower
- the effectiveness of the response activities falls or the costs of response activities rise
- recovery activities that help restore consumer demand to pre event levels become less effective or more costly
- ancillary, non outbreak, related benefits of ext ante animal tests increases.

A key point of interest in this study was to investigate the relationship between the decision to invest in surveillance and detection infrastructure and the probability of agricultural terrorism at which this decision is optimal. It was found that for fast rate of disease spread it was optimal to invest in surveillance and detection even for very low probabilities of event occurrence. Even though intensity of optimal surveillance and detection depends on various factors, the decision to invest in this strategy was optimal across all scenarios for fast spread of the disease. This was true under both, exponential and RF, formulations of disease spread. However, while ex ante investment in surveillance was optimal for all fast spread scenarios, it was not necessarily so for slow spread scenarios. Under slow spread of the disease, investment in surveillance and detection was not optimal until probability of an outbreak was as high as around 0.6. This implies that optimality of ex ante investment depends on disease spread rate and event probability.

Finally, a richer economic modeling framework was developed that is designed to be used in conjunction with an epidemiologic model to evaluate various combinations of strategies to mitigate the consequences of disease outbreaks. This model is based on the assumption that an epidemiologic model can be used to simulate the herd consequences of various ex ante and ex post prevention, detection, response and some subset of the recovery options providing data that can be integrated into the economic model. In turn the linked models can be used to do an integrated epidemiologic and economic evaluation. Specifically, an epidemiologic model could provide estimates of the proportion of the cattle herd that is either

- healthy,
- infected,
- vaccinated, or
- slaughtered

under a wide selection of strategies for managing animal disease.

This framework, unlike the one used in the empirical case study analysis, disaggregates the region under investigation into multiple independent decision making units, who choose mitigation strategies appropriate for their particular circumstances. For example, this framework will allow relying on prevention and detection in the areas with high animal density, while relying on response and recovery in the areas with fewer cattle operations. This framework will also let us incorporate the effects of external benefits generated by adoption of mitigation strategies by individual sites. For example, as estimates become available, we will be able to incorporate the fact that surveillance of animals adopted by one site will affect the probability of infection of a neighboring site. In addition it will be possible to explicitly include the effects of livestock transportation on disease spread and on economic losses from a potential disease outbreak. Hence, it will be possible to include mitigation strategies such as transportation bans.

This final conceptual framework is also expanded so it incorporates decision makers risk preferences and an empirical trial indicates that the optimal combination of strategies will depend not only on ex ante costs, and expected losses from potential outbreaks, but also on degree of variability of losses and the degree of risk aversion.

The results herein need to be interpreted with care. Strong assumptions were made regarding functional forms of disease spread, rate of disease spread, effectiveness and use of response strategies, regional cooperative behavior, and costs of strategy implementation. These assumptions limit the robustness of the results. Therefore, the results are intended to be interpreted as preliminary descriptions of relative desirability of ex ante fixed cost investments and ex post response actions.

Future research should improve on the assumptions made in this study. Specifically use of the final conceptual model with its link to an epidemiologic model would permit incorporation of more accurate and epidemiologically sound disease spread characteristics and in turn would provide more reliable results than those given in this study. Additionally, sensitivity of demand towards livestock disease outbreak is an important omitted factor in this work. Thus research on the market consequences of livestock disease outbreak is needed and would provide better economic input for future studies of the type carried out herein. Furthermore, the effectiveness of a broader spectrum of prevention, detection, response and recovery activities needs to be investigated. Future research should also take into account individual non cooperative behavior, externalities, and the public good characteristics of counter agricultural terrorism measures.

# REFERENCES

Akhtar S. and F. White, “Animal Disease Surveillance: Prospects for Development in Pakistan”, *Scientific and Technical Review International Office of Epizootics.* 22(3)(2003):977-987.

Arnone, M., “Bush’s Plan Would Triple Money for Agricultural Research Against Terrorism.” The Chronicle of Higher Education. February 3, 2004.

Atkinson N. *The Impact of BSE on the UK Economy*. Argentine Scientific Advisory Committee on Bovine Spongiform Encephalopathy (3rd. Meeting) August 9-11, 1999. [Online]. Available at http://www.iica.org.ar/Bse/14-%20Atkinson.html, Accessed 12/12/2003.

Bates, W. T., T. E. Carpenter, M. C. Thurmond, “Benefit-Cost Analysis of Vaccination and Preemptive Slaughter as a Means or Eradicating Foot-and-mouth Disease”, *American Journal of Veterinary Research*, 64(July, 2003):805-12.

Bates T. W., M.C. Thurmond, and T.E. Carpenter, “Description of an Epidemic Simulation Model for use in Evaluating Strategies to Control an Outbreak of Foot-and-Mouth Disease” *American Journal of Veterinary Research*. 64(February 2003 a):195-204

Bates, W. T., M. C. Thurmond, and T.E. Carpenter, “Results of Epidemic Simulation Modeling to Evaluate Strategies to Control an Outbreak of Foot-and-Mouth Disease”, *American Journal of Veterinary Research*, 64(February 2003 b):205-10.

Bates T. W., M. C. Thurmond, and T.E. Carpenter, “Direct and Indirect Contact Rates Among Beef, Dairy, Goat, Sheep, and Swine Herds in the Three California Counties, with Reference to Control of Potential Foot-and-Mouth Disease Transmission”, *American Journal of Veterinary Research*. 62(July 2001):1121-29.

Bates, T.W., M.C. Thurmond, S.K. Hietala, K.S. Venkatesvaran, T.M Wilson, B.W. Colston Jr., J.E. Trebes, and F. P Milanovich, "Surveillance for Detection of Foot-and-Mouth Disease." Commentary in *Journal of the American Veterinary Medical Association*, 223(September 2003):609-14.

Berentsen, P.B.M., A.A Dijkuizen, and A.J. Oskam. "A Dynamic Model for Cost-Benefit Analysis of Foot-and Mouth Disease Control Strategies." *Preventive Veterinary Medicine.* 12 (March, 1992):229-243.

Bigras-Poulin, M., A. Thompson, M. Chriel, S. Mortensen, and M. Greiner, "Network Analysis of the Danish Cattle and Swine Industry Trade Patterns as an Evaluation of Risk Potential for Disease Spread: The heterogeneity Issue." Meeting Proceedings, *Society for Veterinary Epidemiology and Preventative Medicine,* Martigny Switzerland, (March, 2004):189-199.

Boisvert, R., and B. McCarl, "Agricultural Risk Modeling Using Mathematical Programming" Southern Cooperative Series Bulletin No. 356. Cornell University, New York. July 1990

Bouma A., A.R.W. Elbers, A. Dekker, A. de Koeijer, C. Bartels, P. Vellema, P. van der Wal, E.M.A. van Rooij, F.H. Pluimers, and M.C.M de Jong, "The Foot-and-Mouth Disease Epidemic in the Netherlands in 2001". *Preventive Veterinary Medicine*. 57(March 2003): 155-166.

Brink, L., and B. McCarl, "The Tradeoff between Expected Return and Risk among Cornbelt Farmers," *American Journal of Agricultural Economics*, 60(May, 1978):259-263.

Buffa, E. S., *Modern Production Management,* Fourth Edition, New York, John Wiley and Sons, Inc., U.S.A. 1973

Bureau of Economic Analysis (BEA), Gross Domestic Product by Industry Accounts, 2004, [On-line], Available on line:

http://www.bea.gov/bea/industry/gpotables/gpo_action.cfm?anon=97390&table_id=2927&format_type=0. Last accesses on 10/05/04

Burton M. and T. Young. "The Impact of BSE on the Demand for Beef and other Meats in Great Britain." *Applied Economics*, 28(June, 1996):687-693

Carpenter, T.E., Thurmond, C.M., and T. Bates, "A Simulation Model of Intraherd Transmission of Foot and Mouth Disease with Reference to Disease Spread Before and After Clinical Signs". *Journal of Veterinary Diagnostic Investigation.* 16(January, 2004):11-16.

Centers for Disease Control (CDC), "Food borne Illnesses," Division of Bacterial and Mycotic Diseases, (2003) [Online]. Available at: http://www.cdc.gov/ncidod/dbmd/diseaseinfo/foodborneinfections.htm. Accessed on 07/28/03

Centers for Disease Control (CDC). Basic Information about Avian Influenza (Bird Flu), (January, 2004). [Online]. Available at: http://www.cdc.gov/flu/avian/facts.htm Accessed 08/23/2004

Coble, K.H., T.O. Knight, R.D. Pope and J.R. Williams. "Modeling Farm-Level Crop Insurance Demand with Panel Data." American Journal of Agricultural Economics 78(1996):439-47.

Cocks, K.D., "Discrete Stochastic Programming." *Management Science,* 15(1968):72-79

Council for Agricultural Science and Technology (CAST), "Intervention Strategies for the Microbiological Safety of Foods of Animal Origin", Issue Paper number 25, January, 2004,

Dantzig, G. "Linear Programming Under Uncertainty", *Management Science*, 1(1955):197-206

Davis, E., Personal Communication, Department of Agricultural Economics, Texas A&M University, August 2004.

DeGroot, M.H. “Optimal Statistical Decisions,” chapter 7, New York, Mcgraw-Hill College, 1970

Department for Environment Food and Rural Affairs (DEFRA), “Farm Incomes in the U.K. 2001/2002”. Impact of Foot and Mouth Disease on U.K. Agriculture. Available on line at: http://statistics.defra.gov.uk/esg/publications/fiuk/2002/ Last Accessed 11/17/04.

Disney W.T., J.W. Green, K.W. Forsythe, J.F. Wiemers, and S. Weber. “Benefit-Cost Analysis of Animal Identification for Disease Prevention and Control.” *Scientific and Technical Review International Office of Epizootics*. 20(August 2001):385-405.

Drakos, K., and A. Kutan, “Regional Effects of Terrorism on Tourism: Evidence from Three Meditorenian Countries,” *Journal of Conflict Resolution*, 47(2003):621-641.

Dwight L., “Free Riding and Paid Riding in the Fight Against Terrorism”, *The American Economic Review*, 78(May, 1988):22-26.

Economist, The. Foot, Mouth and Public Policies. From the Economist Global Agenda. Apr 4th, 2001 [online] available at: http://www.economist.com/agenda/printerfriendly.cfm?story_id=560922 , Accessed 07/28/03.

Enders, W. and T. Sandler, “The Effectiveness of Antiterrorism Policies: A Vector-Autoregression-Intervention Analysis,” A*merican Political Science Review*, 87(December 1993):829-844.

Enders, W., T. Sandler, and J. Cauley. “UN Conventions, Technology and Retaliation in the Fight against Terrorism: An Econometric Evaluation”, *Terrorism and Political Violence*, 2(1990):83-105.

Evans E. A. “Economic Dimensions of Invasive Species.” *Choices*. Second Quarter, (June, 2003). [Online]. Available at: http://www.choicesmagazine.org/current/2003-2-02.htm , accessed on 07/28/03.

Ferguson N. M., C.A. Donnelly, and R. M. Anderson, “The Foot-and-Mouth Epidemic in Great Britain: Pattern of Spread and Impact of Interventions.” *Science*. 292 (May, 2001):1155-1160.

Food Safety and Inspection Service, “Protecting America’s Meet, Poultry and Egg Products” A Report to the Secretary on the Food Security Initiatives of the Food Safety and Inspection Service. U.S. Department of Agriculture, Washington D.C. January, 2003.

Fox, J.A., and D. A. Hennessy, “Cost-Effective Hazard Control in Food Handling”. *American Journal of Agricultural Economics*. 81(May 1999):359:372.

Food Safety and Inspection Service (FSIS), “Protecting America’s Meat, Poultry and Egg Products.” United States Department of Agriculture. A Report to the Secretary on the Food Security Initiatives of the Food Safety and Inspection Service. Washington, DC 01/31/2003

Garner M. G., and M. B. Lack., “An Evaluation of Alternative Control Strategies for Foot-and-Mouth Disease in Australia: A Regional Approach.” *Preventative Veterinary Medicine*. 23(May, 1995):9-23.

Halliday M. L., L. Kang, T. Zhou, M. Hu, Q. Pan, T. Fu, Y. Huang, and S. Hu, “An Epidemic of Hepatitis A Attributable to the Investigation of Ra Clams in Shanghai, China.” *Journal of Infectious Diseases.* 164(November, 1991): 852-9.

Hanley, N., J.F. Shorgen, and B. White, *Environmental Economics: In theory and Practice.* New York, Oxford University Press, 1997.

Heal G, and H. Kunreuther, “Interdependent Security: A general Model”, Presented at CREATE (Center for Risk and Economic Analysis of Terrorism Events), Economics Symposium (www.usc.edu/create). University of Southern California, Los Angeles, August 20-21,2004.

Hennessy T.W., C.W. Hedberg, L. Slutsker, K.E. White, J. M. Besser-Wiek, M. E. Moen, J. Feldman, W. W. Coleman, L. M. Edmonson, K. L. McDonald, M. T. Osterholm, and Investigation Team, "A National Outbreak of Salmonella Enteritides Infections from Ice Cream." *New England Journal of Medicine*. (May, 1996), 334:1281-6.

Henson S., and M. Mazzocchi. "Impact of Bovine Spongiform Encephalopathy on Agribusiness in the United Kingdom: Results of an Event Study of Equity Prices." *American Journal of Agricultural Economics*. 84 (May 2002):370-386.

Herwaldt B. L., M. Ackers, and Cyclospora Working Group. "An Outbreak in 1996 of Cyclosporiasis Associated with Imported Raspberries." *The New England Journal of Medicine.* 336(May, 1997):1548-56.

Jalvingh A.W., M. Nielen, H. Maurice, A. J. Stegeman, A. R.W. Elbers, and A.A. Dijkhuizen. "Spatial and Stochastic Simulation to Evaluate the Impact of Events and Control Measures on the 1997-1998 Classical Swine Fever Epidemic in The Netherlands." *Preventative Veterinary Medicine.* 42(December, 1999):271-295.

Jehle, G. A., and P. J. Reny, "Advanced Microeconomic Theory." Second Edition. The Addison_Wesley series in economics. U.S.A 2001

Keiling M. J., M. E. J. Woolhouse, D. J. Shaw, L. Mattews, M. Chase-Topping, D. T. Haydon, S. J. Cornell, J. Kappey, J. Wilesmith, and B. T. Grenfell, "Dynamics of the 2001 UK Foot and Mouth Epidemic: Stochastic Dispersal in Heterogeneous Landscape." *Science.* 294 (October, 2001):813-817.

Khan A. S.L., D. L. Swerdlow, and D. D. Juranek. "Precautions against Biological and Chemical Terrorism Directed at Food and Water Supplies." *Public Health Reports.* 116 (Jan.-Feb. 2001):3-14.

Knight, T.O. and K.H. Coble. “Survey of U.S. Multiple Crop Insurance Literature Since 198.” *Review of Agricultural Economics*, 19(1997):128-56.

Levine W. C., R. W. Bennett, Y. Choi, K. J. Henning, J. R. Rager, K. A. Hendricks, D. P. Hopkins, R. A. Gunn, and P. M. Griffin. “Staphylococcal Food Poisoning Caused by Imported Canned Mushrooms.” *The Journal of Infectious Diseases*. 173(May, 1996): 1263-1267.

Loyd, T., S. McCorriston, C.W. Morgan, and A.J. Rayner, “The Impact of Food Scares on Price Adjustments in the UK Beef Market.” *Agricultural Economics,* 25 (September, 2001):347-357.

Machina, M. J., Review of: Generalized Expected Utility Theory: The Rank Dependent Model (Norwell, Mass.: Kluwer Academic). *Journal of Economic Literature* 32(September, 1994):1237-38.

Mahon B. E., A. Ponka, W. N. Hall, K. Komatsu, S. E. Dietrich, A. Siitonen, G. Cage, P.S. Haues, M. A. Lambert-Fair, N. H. Bean, P. M. Griffin, and L. Slutsker “An International Outbreak of Salmonella Infections Caused by Alfalfa Sprouts grown from Contaminated Seeds.” *The Journal of Infectious Diseases*. 175(April, 1997):876-82.

Makki, S.S. and A. Somwaru. “Farmers’ Perception in Crop Insurance Markets: Creating the Right Incentives.” *American Journal of Agricultural Economics* 83(2001):662-67.

Mangen, M-J. J., and A.M. Burrell, “Who Gains, Who Losses? Welfare Effects of Classical Swine Fever Epidemics in The Netherlands.” *European Review of Agricultural Economics*, 30(June, 2003):125-154.

Mathews K. H. Jr., and J. Buzby. “Dissecting the Challenges of Mad Cow and Foot and Mouth Disease.” Agricultural Outlook. Economic Research Service USDA. August, 2001

Mathews K. H. Jr., J. C. Buzby, L. R. Tollefson, and D. A. Dargatz. “Livestock Drugs: More Questions Than Answers?” Agricultural Outlook. Economist Research Service. September, 2001.

McCarl B. “Economics of Integrated Pest Management. An interpretive Review of Literature.” Special Report 636. Agricultural Experiment Station. Oregon State University. August, 1981.

McCarl, B.A. “Linked Bio-economic Risk Assessment of Invasive Species Policy and Programs.” Research Funding Proposal, to USDA PREISM. 2003.

McCarl, B.A., and D.A. Bessler, "Estimating an Upper Bound on the Pratt Risk Aversion Coefficient When the Utility Function is Unknown," *Australian Journal of Agricultural Economics*, 33, 56-63,1989.

McCauley E. H., A.A. Nasser, J. C. Jr. New, W.B. Sundquist, and W. M. Miller. “A Study of Potential Economic Impact of Foot and Mouth Disease in the United States.” Pp.242. University of Minnesota. St. Paul Minnesota, 55108. May 1979.

Mead P. S., L. Slutsker, V. Dietx, L.F. McCaig, J. S. Bresee, C. Shapiro, P. M. Griffin, and R. V. Tauxe. “Food Related Illness and Death in the United States.” *Emerging Infectious Diseases,* 5(Sep.-Oct. 1999):607-625.

Mermin J. H., and P. M. Griffin. “Invited Commentary: Public Health in Crisis: Outbreaks of Escherichia Coli O157:H7 Infections In Japan.” *American Journal of Epidemiology.* 150(October, 1999):797-803.

Morris R.S., R.L. Sanson, M.W. Stern, M. Stevenson, and J. W. Wilesmith. “Decision-support Tools for Foot and Mouth Disease Control.” *Scientific and Technical Review International Office of Epizootics.* 21(December, 2002):557-567.

Morris R.S., J.W. Wilesmith, M.W. Stern, R.L. Sanson, and M.A. Stevenson. “Predictive Spatial Modeling of Alternative Control Strategies for the Foot-and

Mouth Disease Epidemic in Great Britain, 2001." *The Veterinary Record.* 149(August, 2001):137-144.

Myles, G. D., *Public Economics*, Cambridge, Cambridge University Press, 1997

Nayga, R. M. "Sociodemographic Influences on Consumer Concern for Food Safety: The Case of Irradiation, Antibiotics, Hormones, and Pesticides". *Review of Agricultural Economics*, 18(September, 1996):467-475.

Nayga, R. M., Aiew, W., Nichols, J., "Information Effects on Consumers' Willingness to Purchase Irradiated Food Products", *Review of Agricultural Economics,* 26(Forthcoming, 2004).

National Agricultural Statistics Service (NASS), Quick Stats: Agricultural Statistics Data Base, United States Department of Agriculture, 2001, available on-line at: http://www.nass.usda.gov/QuickStats/ , Last Accessed 11/16/2004.

Nielen, M., A. W. Jalvingh, H.S. Horst, A.A. Dijkhuizen, H. Maurice, B.H. Schut, L.A. van Wuijckhuise, , and M.F. de Jong, "Quantification of Contacts Between Dutch Farms to Assess the Potential Risk of Foot-and-Mouth Disease Spread." *Preventive Veterinary Medicine.* 28(September, 1996):143-158.

Office of Legislative Policy and Analysis (OLPA), Public Health Security and Bioterrorism Preparedness and Response Act of 2002. Public Law 107-188. 107th Congress, June 12, 2002. [On-line], Available at: http://olpa.od.nih.gov/legislation/107/publiclaws/publichealthsecurity.asp Lat5s Accessed 11/22/04.

Paarlberg, P. L., and J.G. Lee, "Import Restrictions in the Presence of a Health Risk: An Illustration Using FMD." *American Journal of Agricultural Economics.* 80 (February, 1998):175-183.

Paarlberg, P. L., J. G. Lee, and A. H. Seitzinger, "Measuring Welfare Effects of an FMD Outbreak in the United States." *Journal of Agricultural and Applied Economics,* 35 (April, 2003):53-65.

Piggott, N.E., and T. March, "Does Food Safety Information Impact U.S. Meat Demand?" *American Journal of Agricultural Economics*. 86(May 2004):154-174, 2004.

Pinmentel D. "Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species." Boca Raton, FL. CRC Press LLC, 2002.

Pinmentel D., L. Lach, R. Zuniga, Morrison D., "Environmental and Economic Costs of Nonindigenous Species in the United States." *BioSciences.* 50 (January, 2000):53-65.

Pratt, J.W. "Risk Aversion in the Small and in the Large," *Econometrica*, 32(January 1964):326-36

Ryan C. A., M. K. Nickels, N. T. Hergrett-Bean, M. E. Potter, T. Endo, L. Mayer, C. W. Langkop, C. Gibson, R. C. McCdonald, R. T. Kenny, N. D. Puhr, P. J. McDonnell, R. J. Martin, M L. Cohen, and P. A. Blake. "Massive Outbreak of Antimicrobial-Resistant Salmonellosis Traced to Pasteurized Milk." *Journal of American Medical Association*. 258 (December, 1987):3269-3274.

Saha, A., C. R. Shumway, and A. Havenner, "The Economics and Econometrics of Damage Control." *American Journal of Agricultural Economics.* 79(August 1997):773-785.

Sandler, T. and D.G. M. Acre, "Terrorism & Game Theory," *Simulation and Gaming* 34(2003):319-337.

Sanson, R. "The Development of a Decision Support System for an Animal Disease Emergency." Unpublished Ph.D. Dissertation, Massey University, New Zealand. 1993 .

Schoenbaum M. A., and W. T. Disney. " Modeling Alternative Mitigation Strategies for a Hypothetical Outbreak of Foot-and-Mouth Disease in the United States." *Preventative Veterinary Medicine*, 58(April, 2003):25-52.

Scudamore J. M. “Origin of the UK Foot and Mouth Disease Epidemic 2001.” Department for Environment, Food and Rural Affairs. UK. June 2002. [Online] Available at: http://www.defra.gov.uk/corporate/inquiries/lessons/fmdorigins.pdf Last accessed 10/29/03.

Sherrick B.J., P.J. Barry, P.N. Ellinger, and G.D. Schnitkey. “Factors Influencing Farmers’ Crop Insurance Decisions.” *American Journal of Agricultural Economics.* 86(2004):103-114.

Shogren, J. “Risk-Reduction Strategies Against the `Explosive Invader',” In Perrings, C., M. Willliamson, and S. Dalmazzone eds., The Economics of Biological Invasions, pp. 56-69. Northampton, MA: Edward Elgar, 2000.

Smith A. P., J. A. Young, and J. Gibson. “How Now, Mad-Cow? Consumer Confidence and Source Credibility During the 1996 BSE Scare.” *European Journal of Marketing*. 33 (November-December, 1998):1107-1122.

Smith M. E., E. O. Raveswaay, and S. R. Thompson. “Sales Loss Determination in Food Contamination Incidents: An Application to Milk Bans in Hawaii.” *American Journal of Agricultural Economics.* 70 (August, 1988,):513-20.

Sobel J., Khan A. S., Swerdlow D. L. “Threat of a Biological Terrorist Attack on the US Food Supply: The CDC Perspective.” *The Lancet.* 359(March, 2002):874-880.

Texas Department of Agriculture, “2001 Texas Agricultural Statistics”, Texas Agricultural Statistics Sevice, 2001

Thompson, D., P. Muriel, D. Russell, P Osborne, A Bromley, M Rowland, S Creigh-Tyte, and C Brown, “Economic Costs of Foot and Mouth Disease Outbreak in United Kingdom in 2001.” Department for Environmental, Food and Rural Affairs, UK. 2003. [On-line] Available at: http://www.defra.gov.uk/corporate/inquiries/lessons/fmdeconcostrev.pdf Last Accessed 10/06/04.

Torok, T. J., R. V. Tauxe, R. P. Wise, J. R. Livengood, R. Sokolov, S. Mauvais, K. A. Birkness, M. R. Skeels, J. M. Horan, and L. R. Foster. "A Large Community Outbreak of Salmonellosis Caused by Intentional Contamination of Restaurant Salad Bars." *Journal of American Medical Association*. 278 (August, 1997):389-395.

United Kingdom Department of Environment, Food and Rural Affairs (DEFRA), "Farm Income in the United Kingdom 2001/2002," Chapter 6, 2002. [On-line] Available at: http://statistics.defra.gov.uk/esg/publications/fiuk/2002/ , Last Accessed on 10/06/2004.

Veneman, Ann M. Testimony Before the Subcommittee on Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Committee on Appropriations, U.S. House of Representatives February 13, 2002. [On-line] Available at: http://www.usda.gov/news/special/ctc27.htm, Last Accessed 10/05/04.

Wasem, R.E., J. Lake, L. Saghetti, J Monke, S. Vina, "Border Security: Inspection Practices, Policies and Issues," CRS Report for Congress. Congressional Research Service, the Library of Congress. May 26, 2004

World Health Organization (WHO), Terrorist Threats to Food: Guidance for Establishing and Strengthening Prevention and Response Systems. Food Safety Issues. Food Safety Department. Geneva, Switzerland, 2002.

Ziari H, "The Economic Feasibility of Run-off Impoundments for Supplemental Irrigation in Blacklands Region of Texas." Unpublished Ph.D. Dissertation. Texas A&M University, College Station, Texas, May 1991

## APPENDIX

## Figures

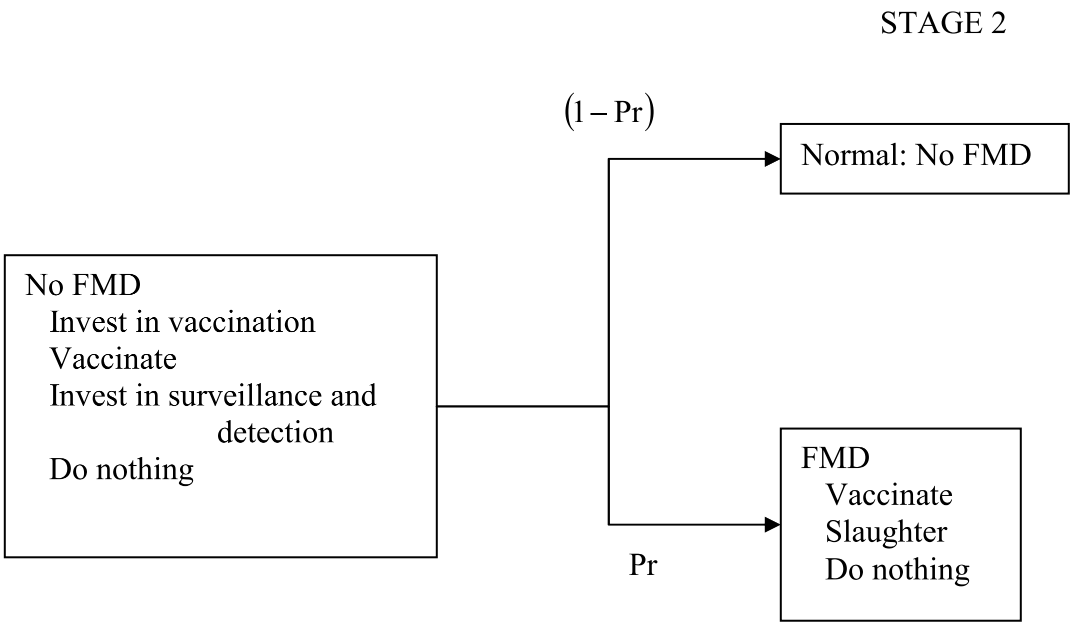


**Figure 1. Stages of decision support tool**

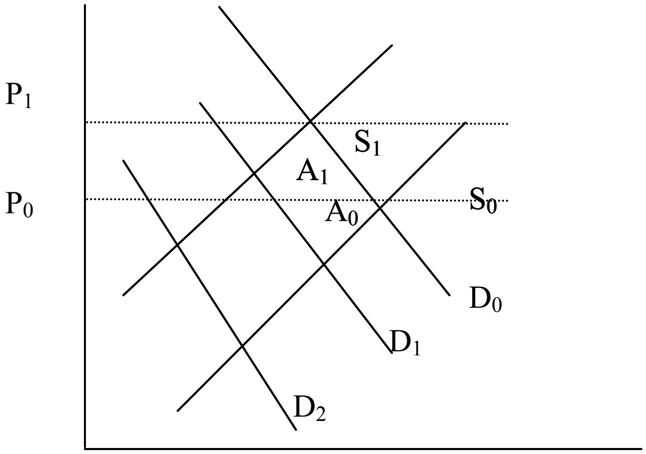


**Figure 2. Aggregate producer surplus**

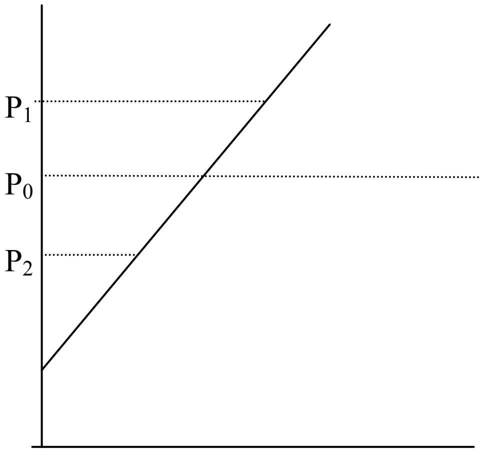


Figure 3a. Unaffected producers.

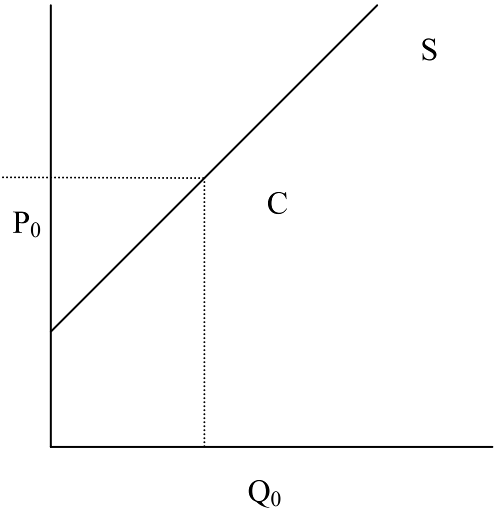


Figure 3b. Banned producers.

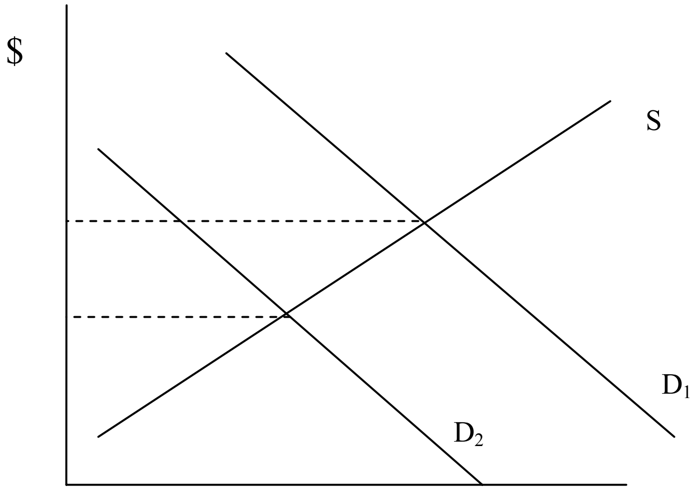
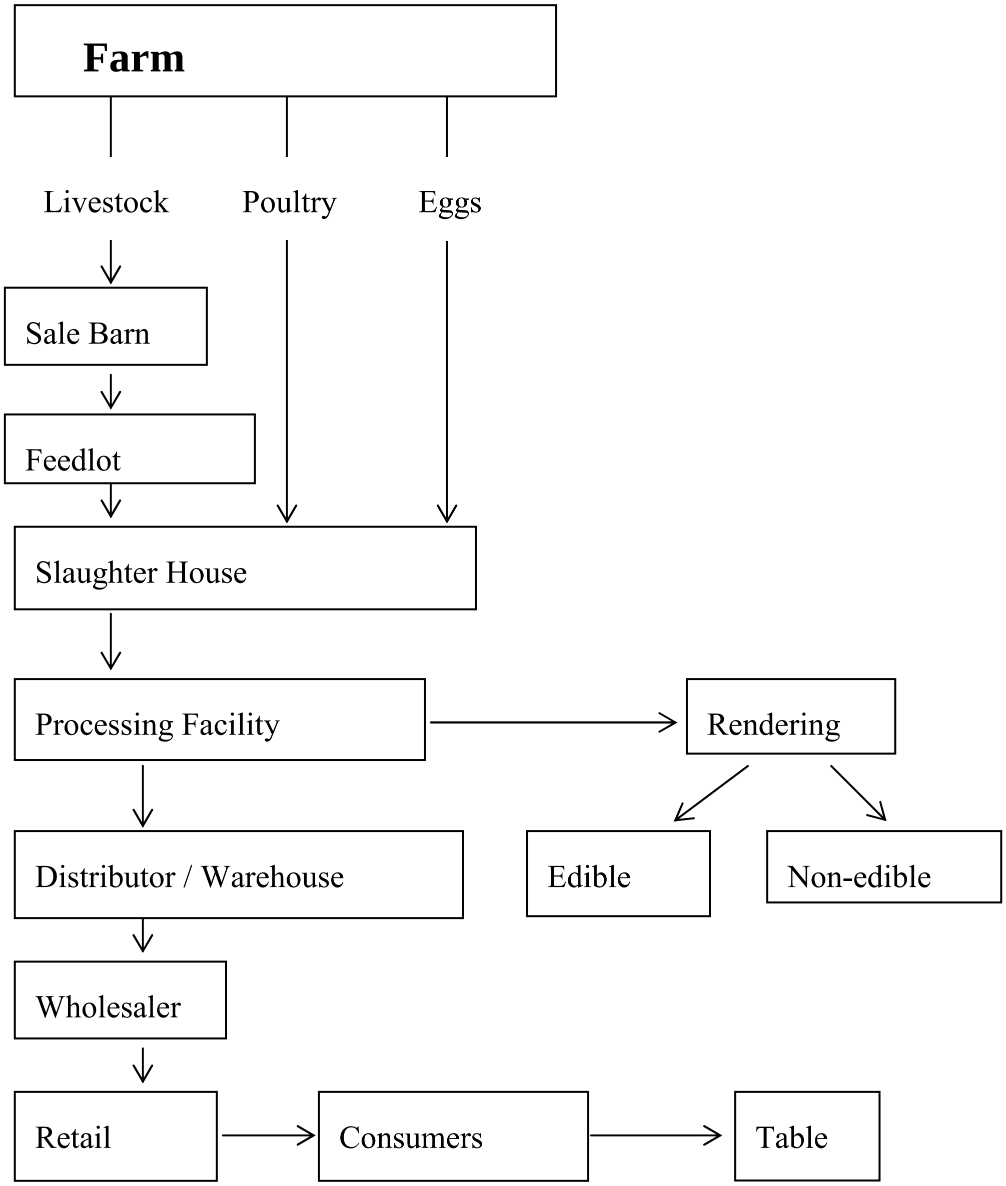


Figure 4. Effect of food scare



Source: FSIS 2003

**Figure 5. The food process: farm-to-table**

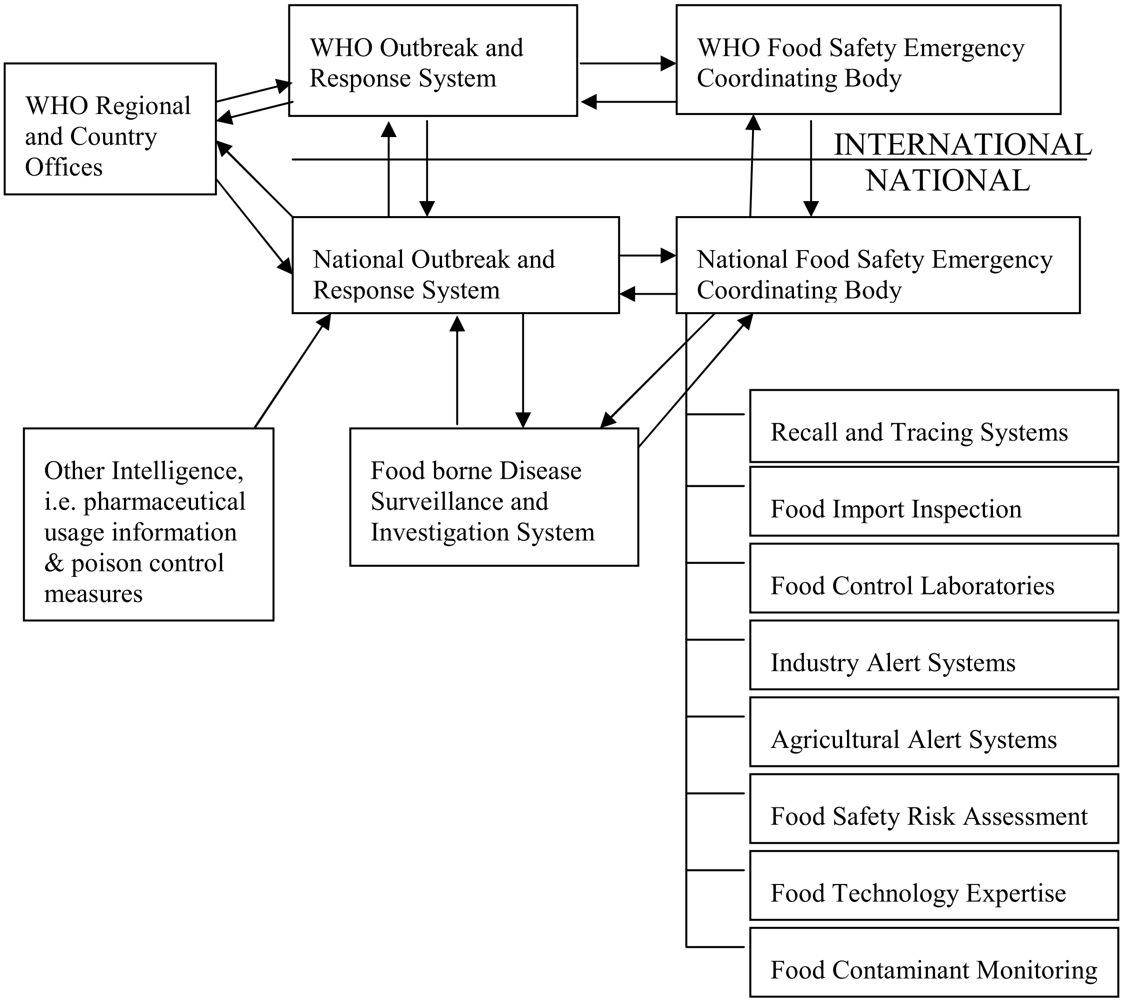


**Figure 6. Proposed linkages between existing national alert and response systems and food safety systems (World Health Organization (WHO) 2002)**

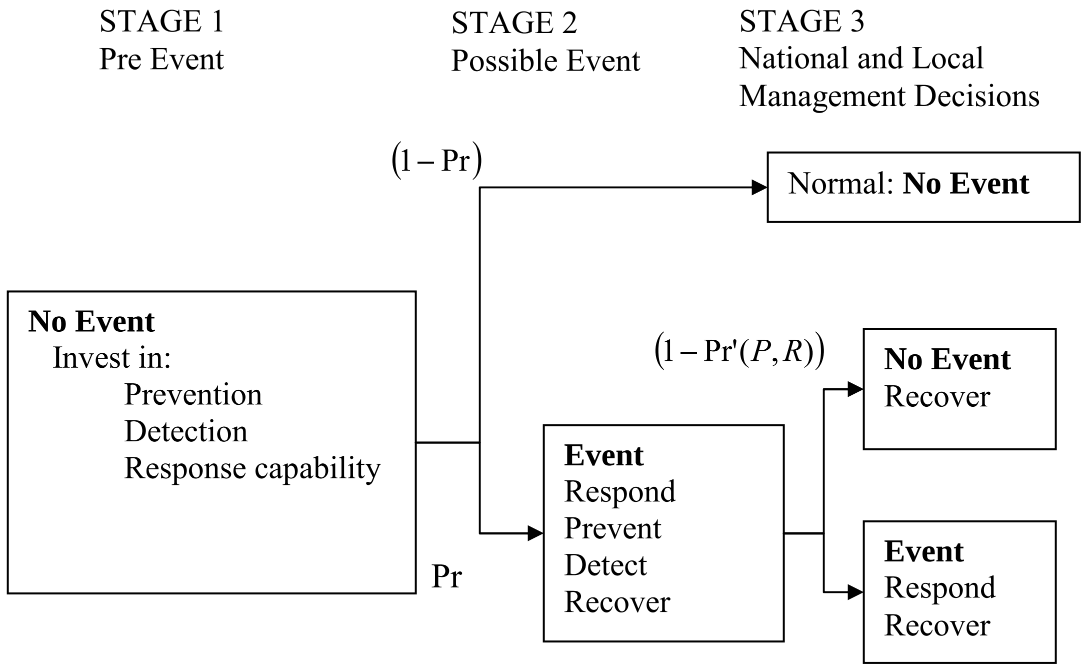


**Figure 7. Stages in localized decision making**

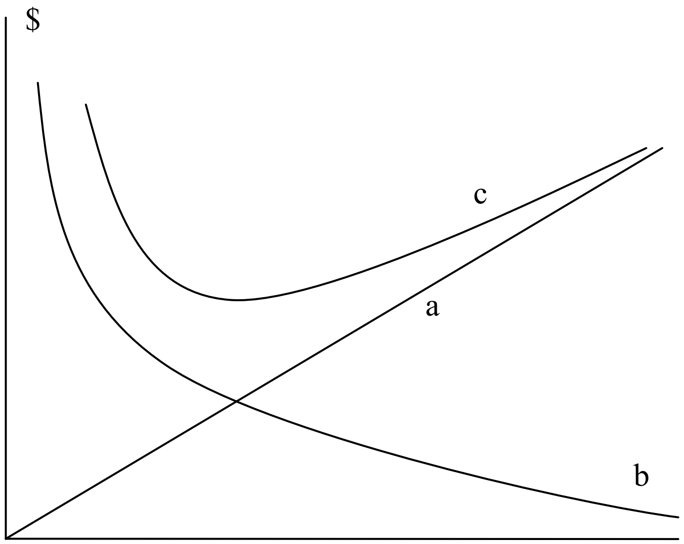


**Figure 8. Optimal number of tests**

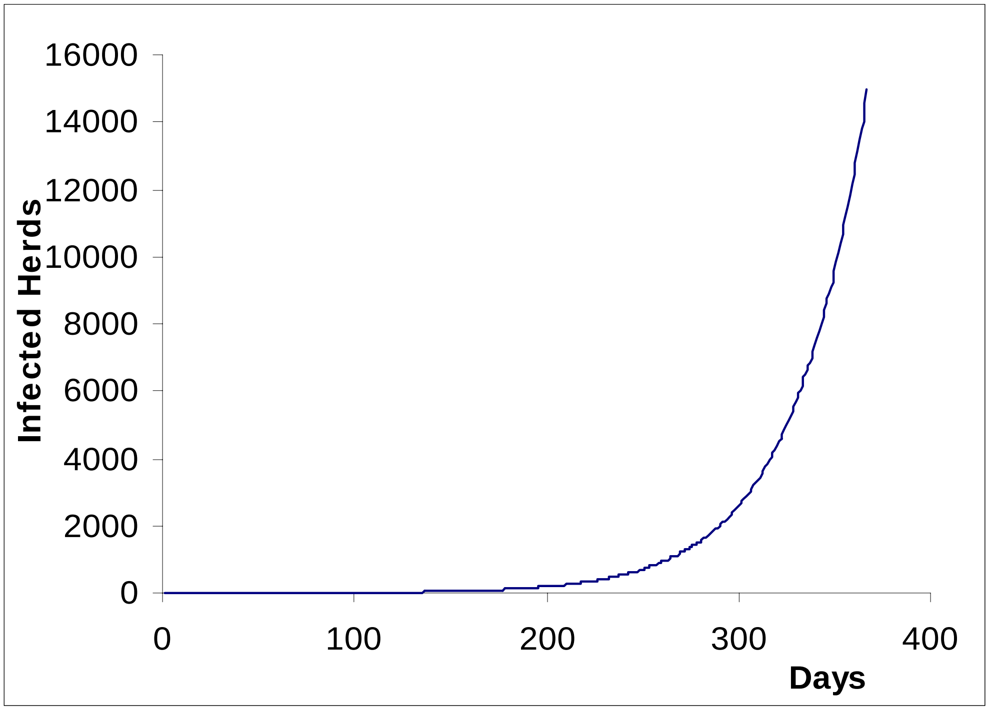


Figure 9. FMD spread under exponential formulation for slow spread

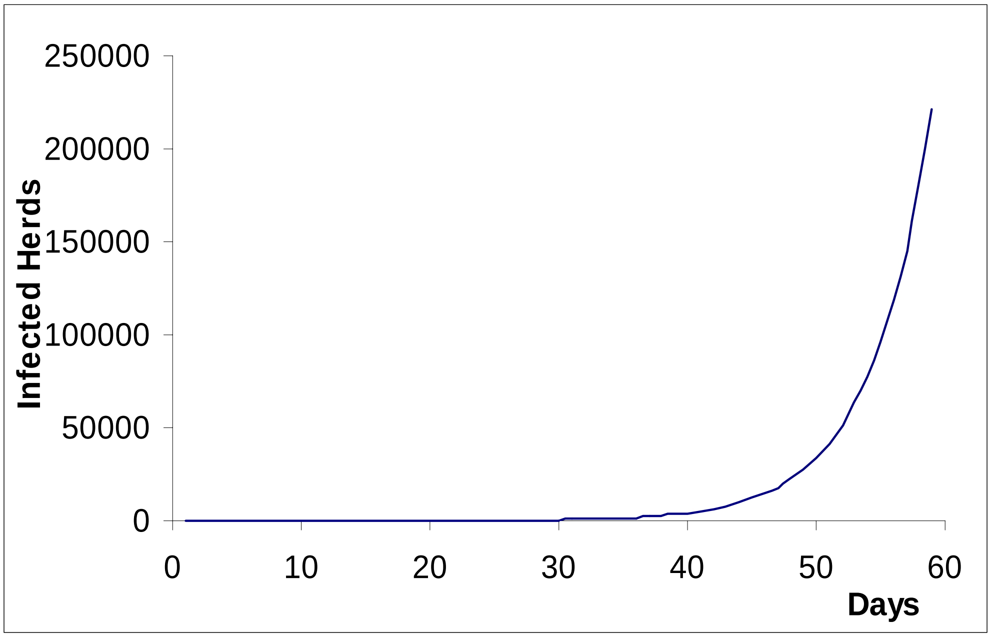


Figure 10. FMD spread under exponential formulation for fast spread

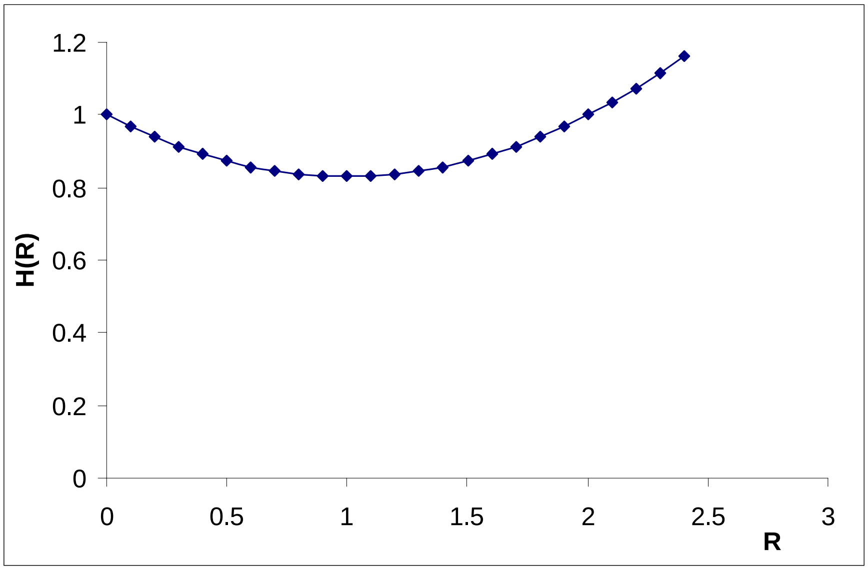


Figure 11. Effectiveness of response strategy

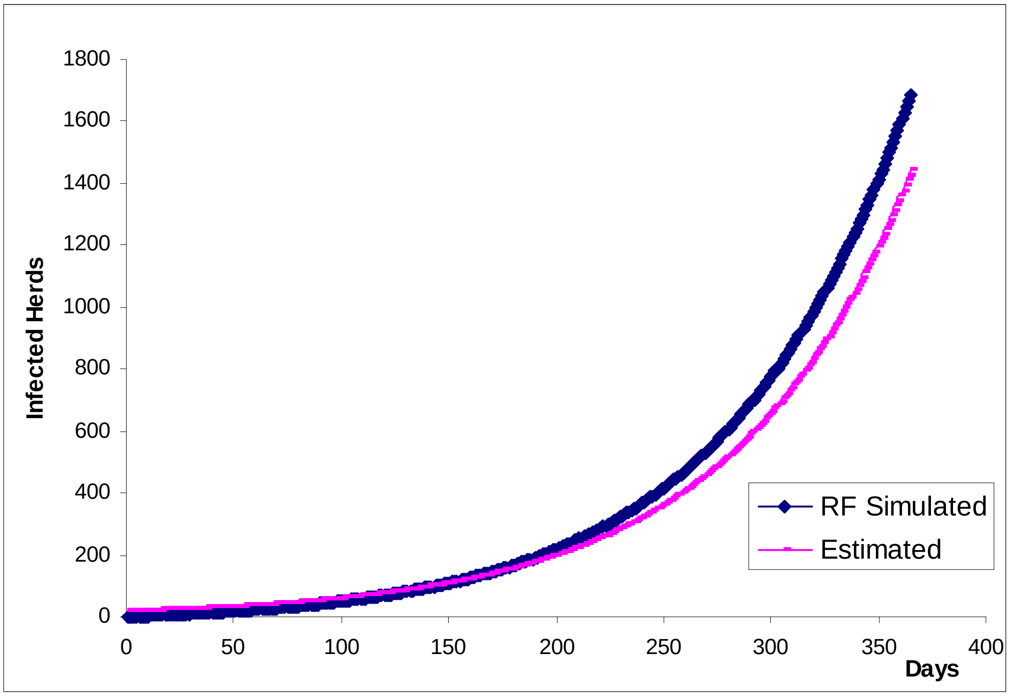


Figure 12. Spread under reed frost formulation and logistic estimation for slow spread

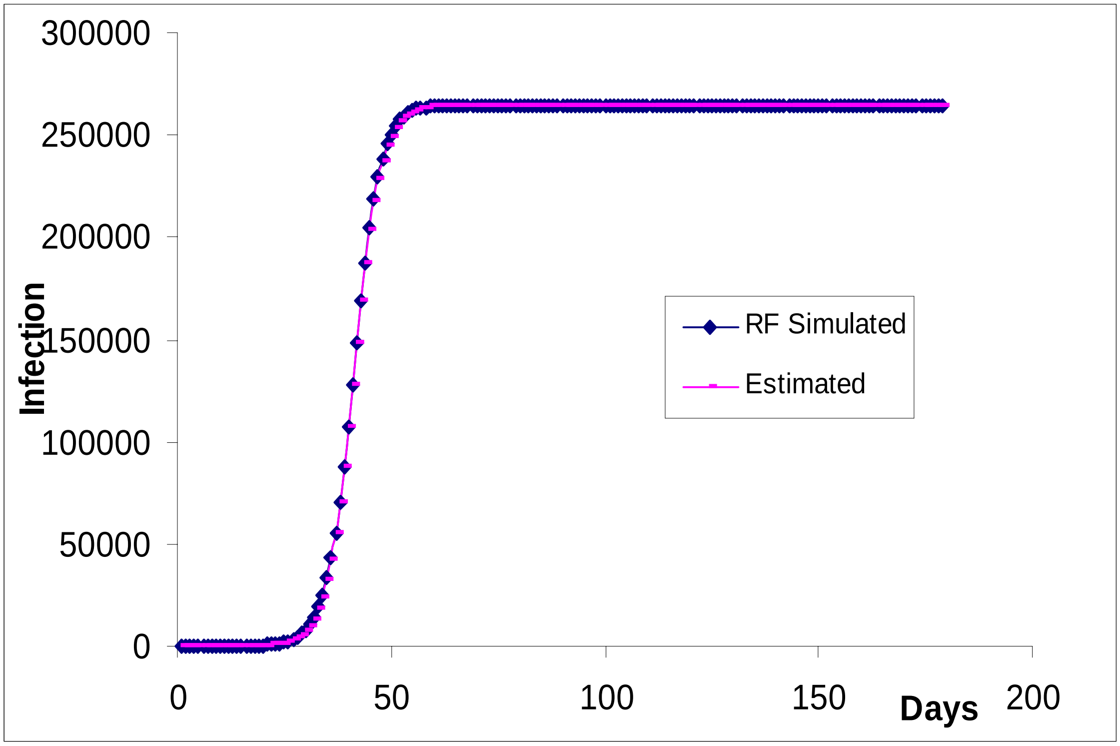
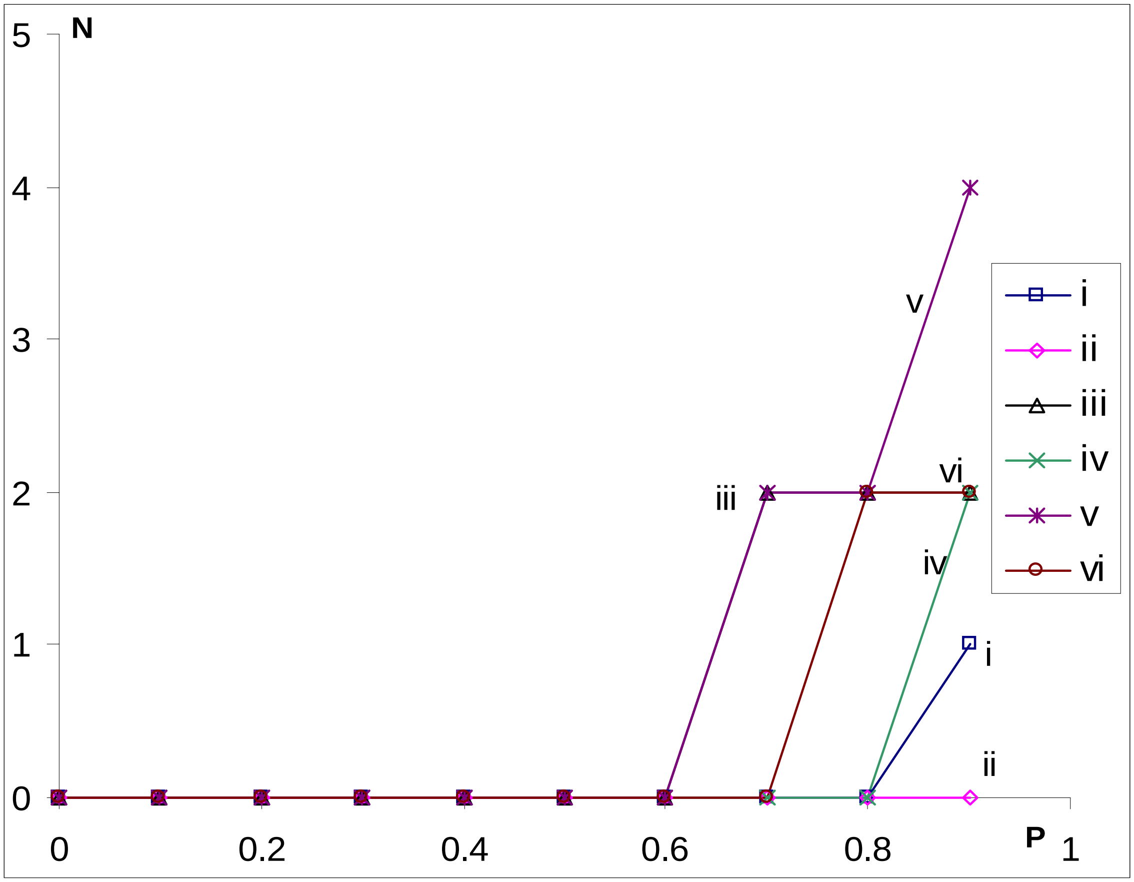
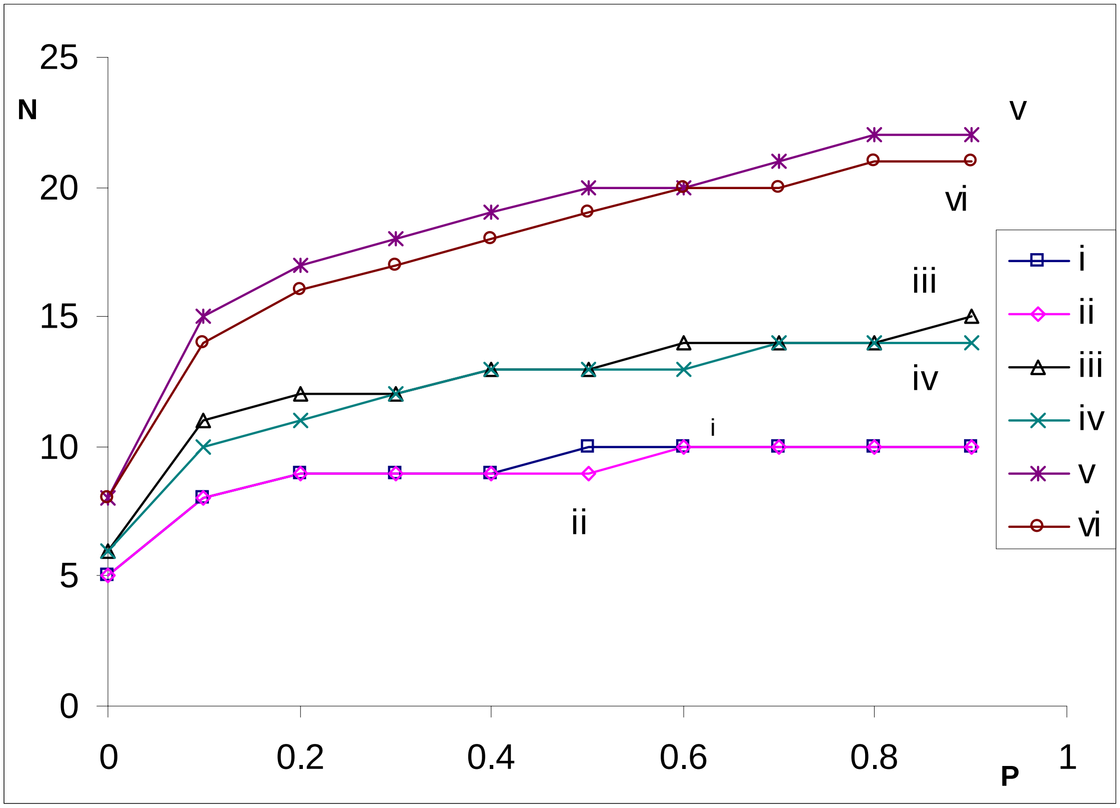


**Figure 13. Spread under reed frost formulation and logistic estimation for fast spread**



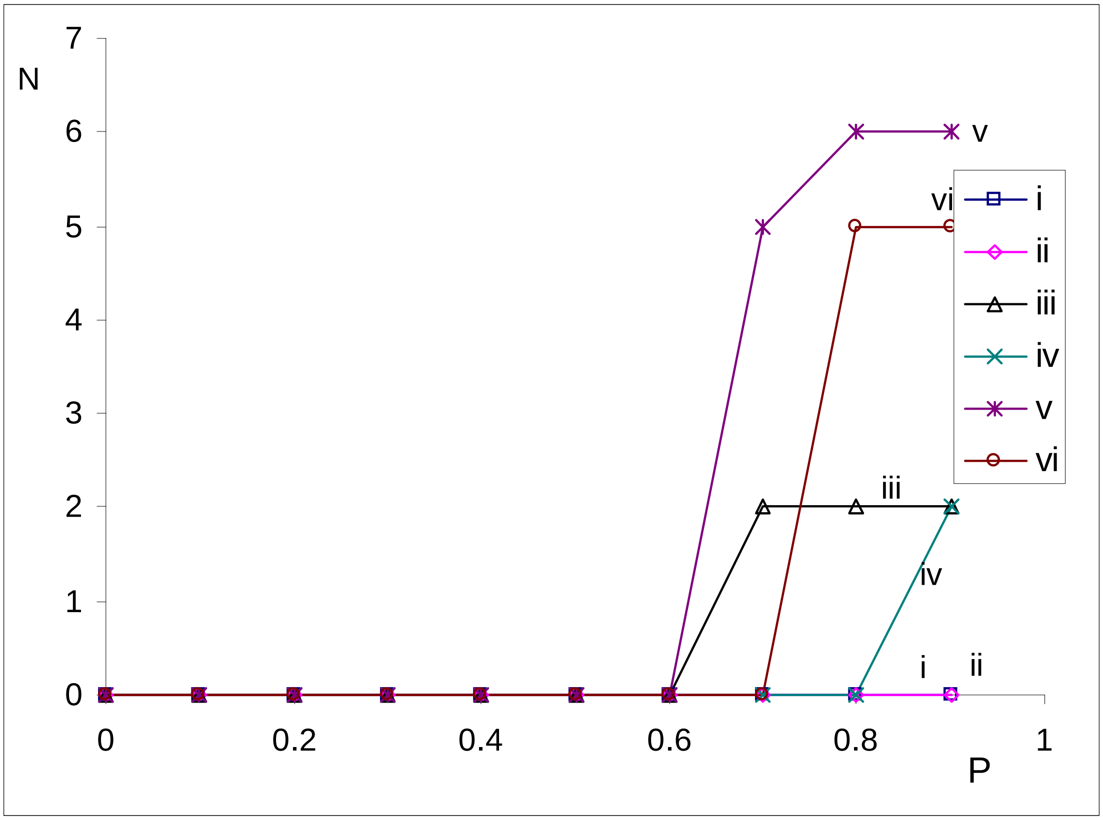
i – Full variable costs (VC), Response Effectiveness (RE) = 0.17
ii – VC, RE=0.3
iii – 0.1VC, RE=0.17
iv – 0.1VC, RE=0.3
v – 0.01VC, RE=0.17
vi – 0.01VC, RE=0.3

**Figure 14. Number of annual tests under slow exponential spread scenarios**



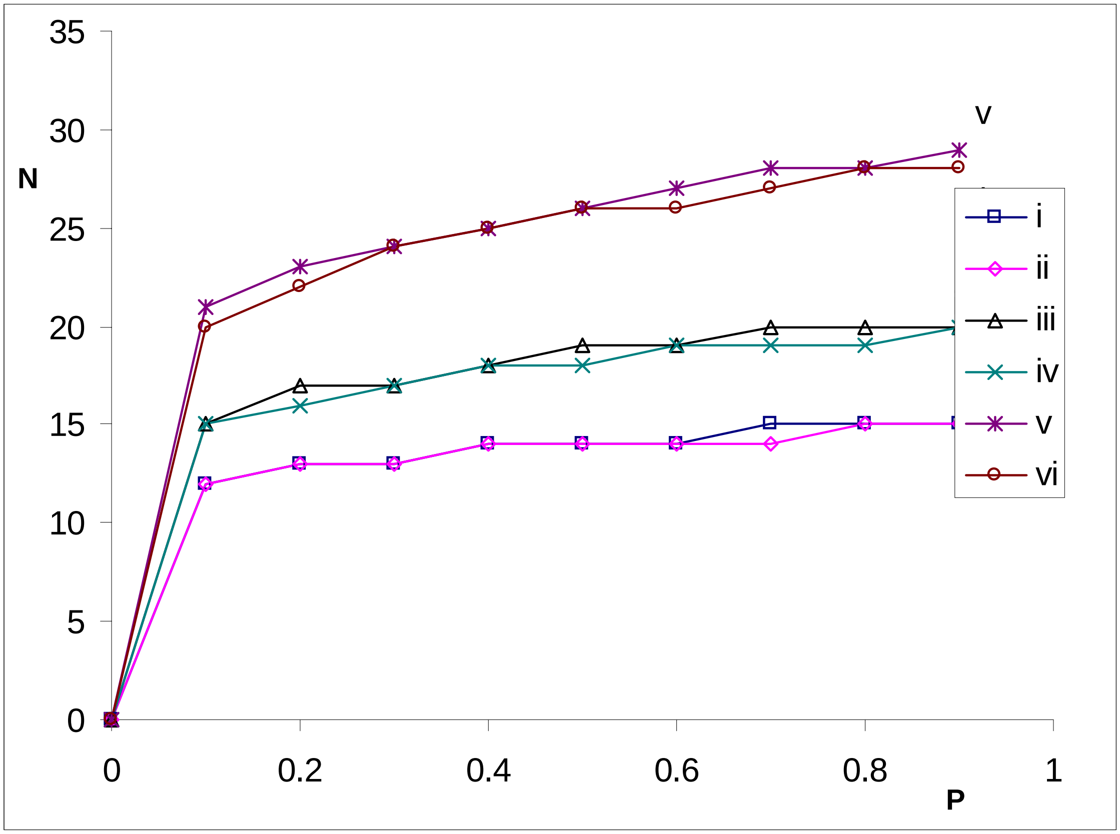
i – Full variable Costs (VC), Response Effectiveness (RE)=0.17
ii – VC, RE =0.3
iii – 0.1VC, RE=0.17
iv – 0.1VC, RE=0.3
v – 0.01VC, RE=0.17
vi – 0.01VC, RE=0.3

**Figure 15. Number of annual tests under fast exponential spread scenarios**



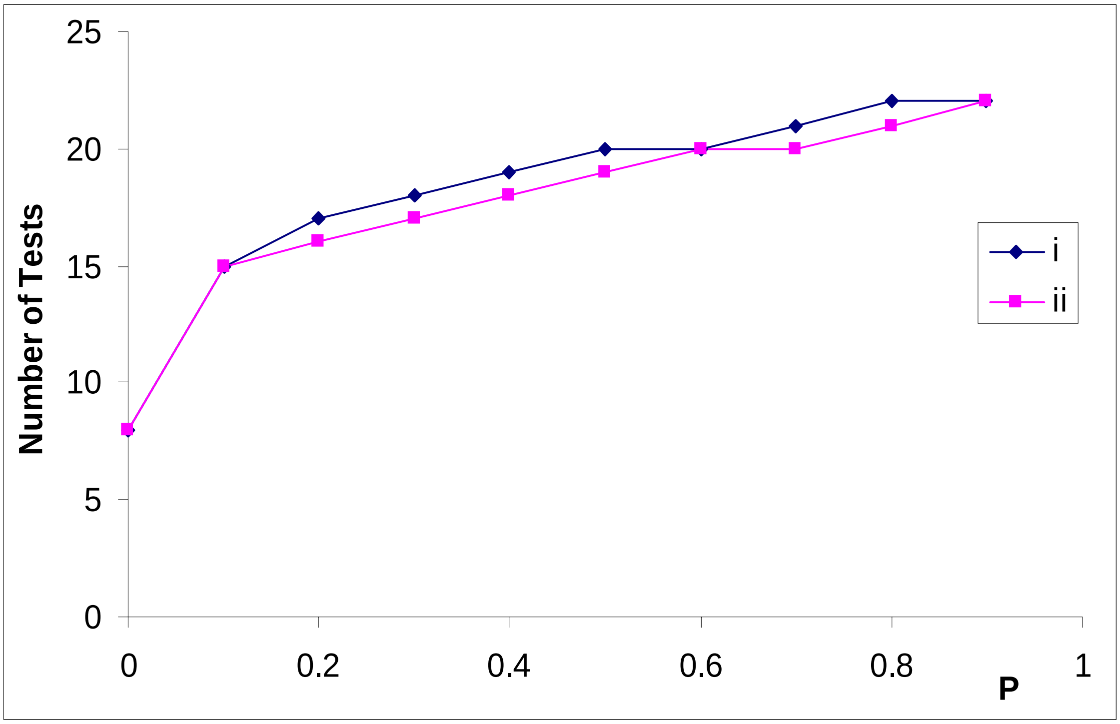
i – Full Variable Costs (VC), Response Effectiveness (RE) = 0.17
ii – VC, RE=0.3
iii – 0.1VC, RE=0.17
iv – 0.1VC, RE=0.3
v – 0.01VC, RE=0.17
vi – 0.01VC, RE=0.3

**Figure 16. Number of annual tests under slow spread under RF formulation**



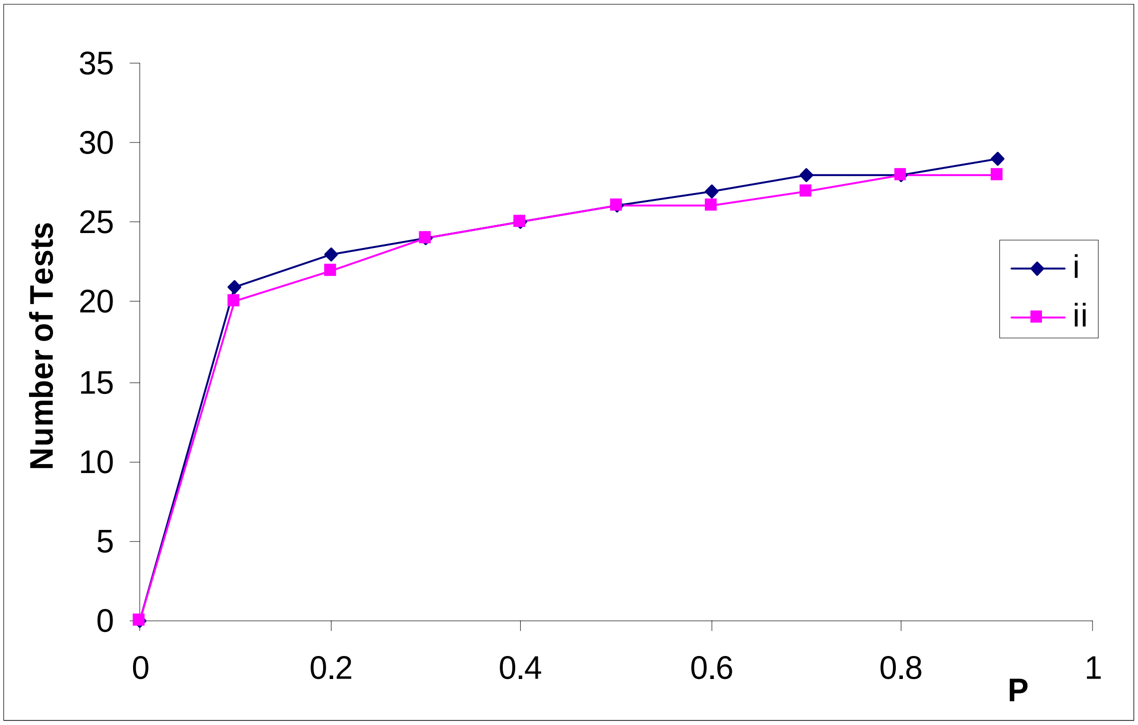
i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 17. Number of annual tests under fast spread under RF formulation**



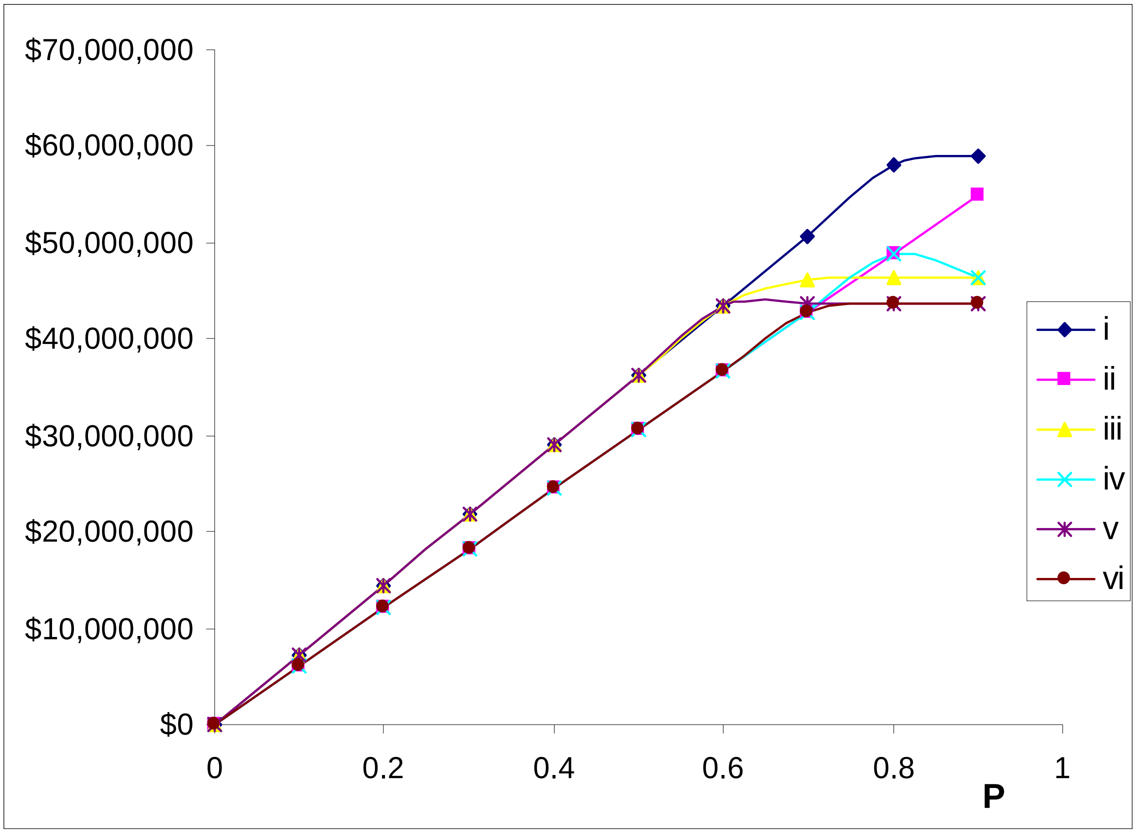
i – Without recovery program
ii – With recovery program

**Figure 18. Number of tests with recovery program in place under fast exponential spread**



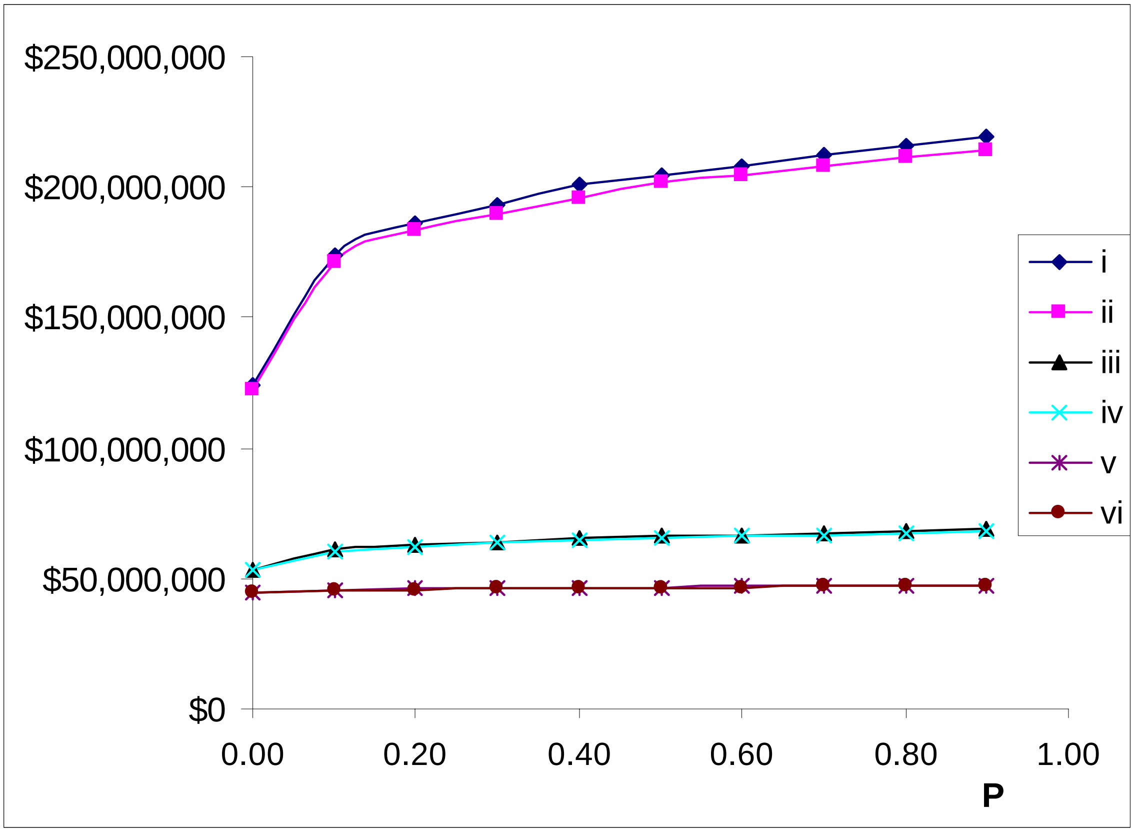
i – Without recovery program
ii – With recovery program

**Figure 19. Number of tests with recovery program in place under fast RF spread**



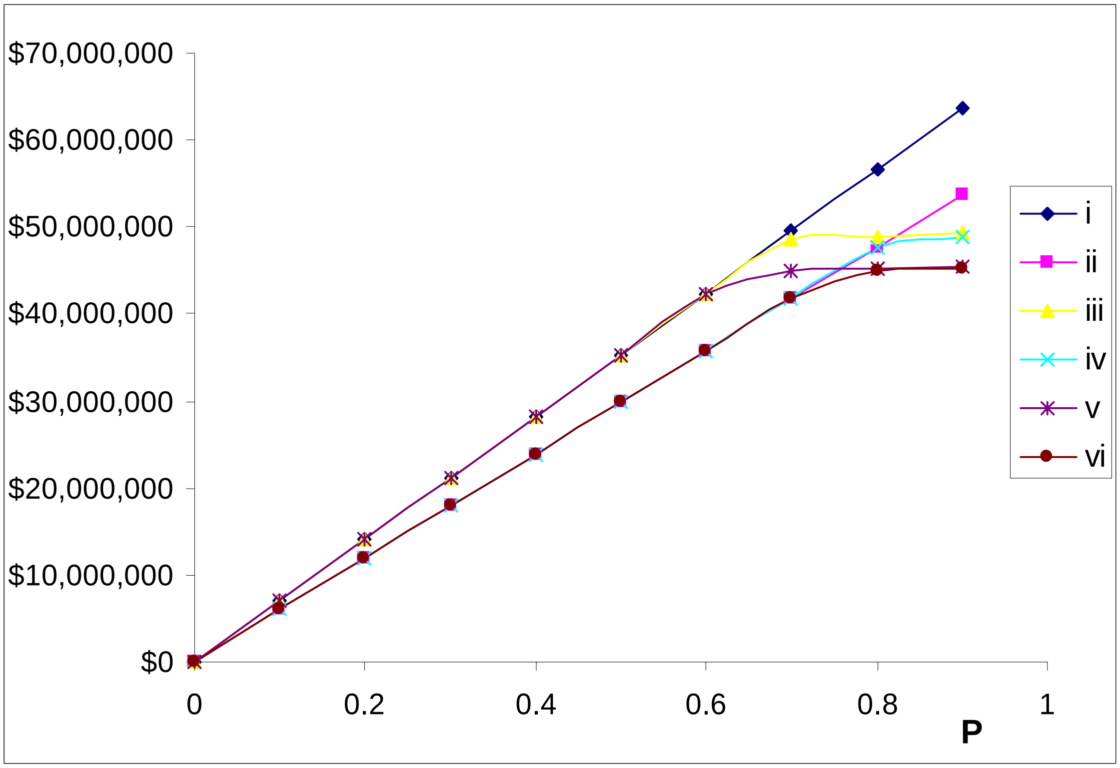
i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 20. Economic losses under slow exponential spread**



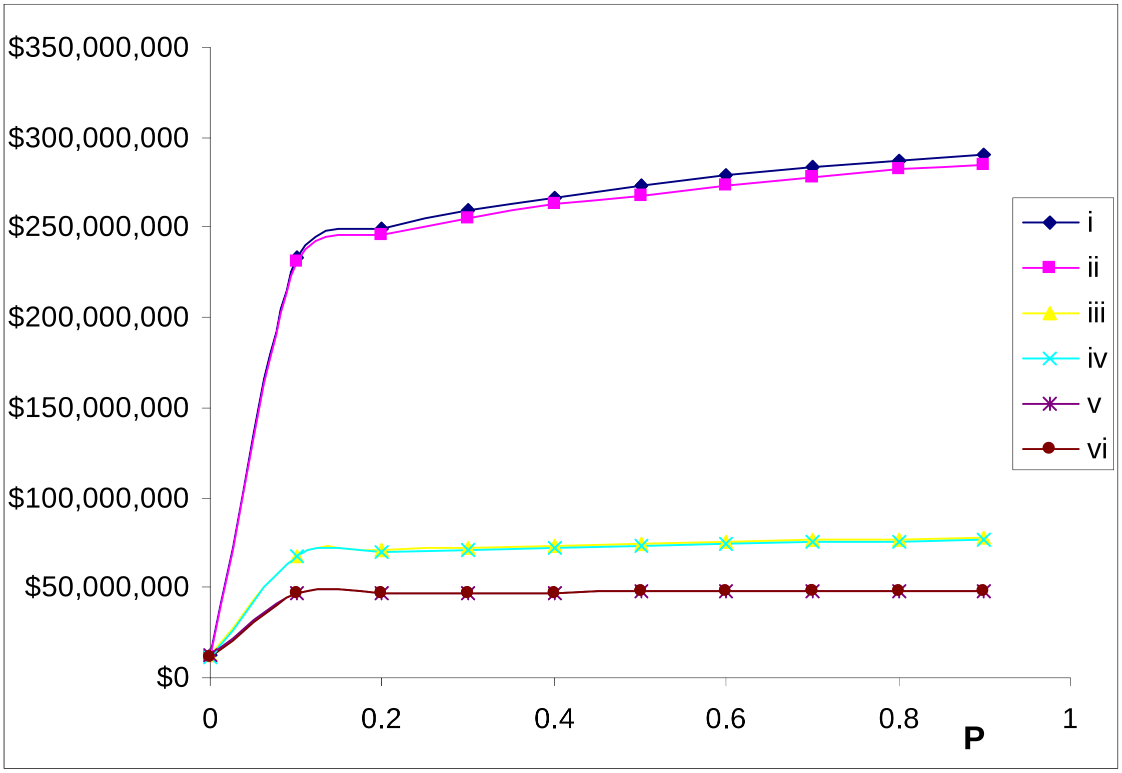
i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 21. Economic losses under fast exponential spread**



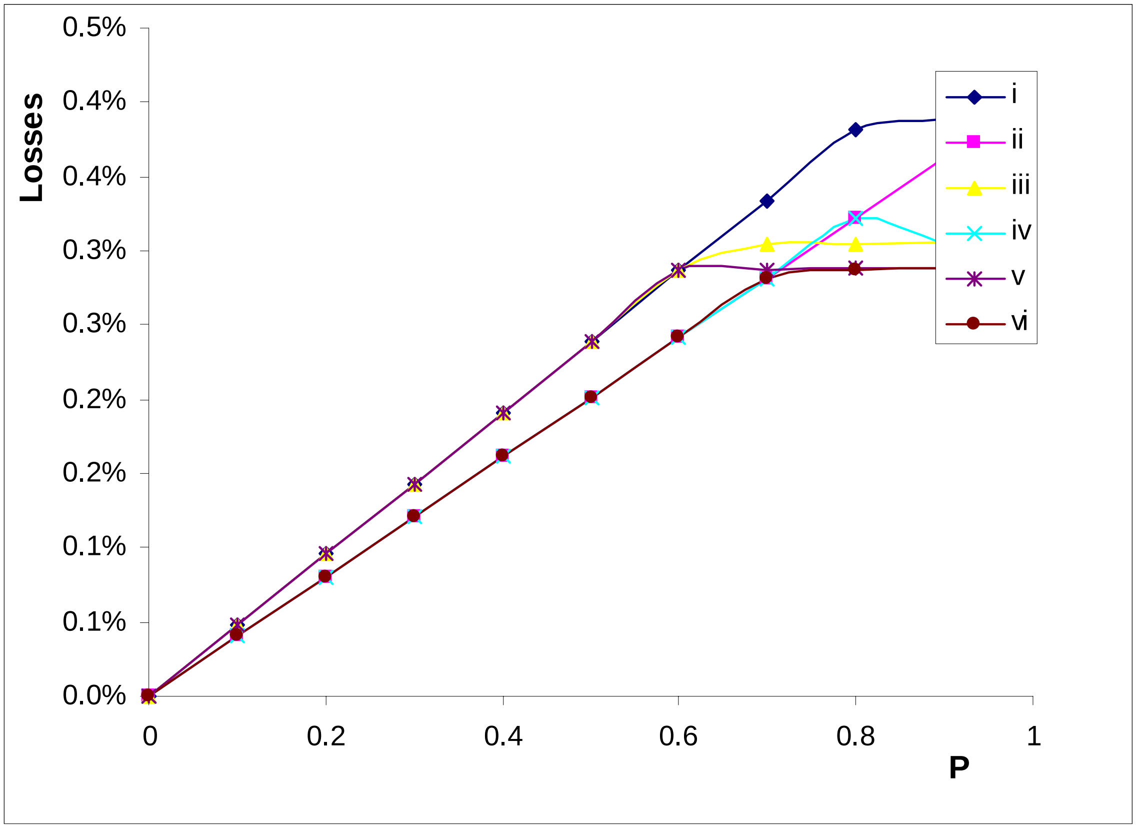
i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 22. Economic losses under slow RF spread**



i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 23 Economic losses under fast RF spread**



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iv – 0.1VTC, RE=0.3
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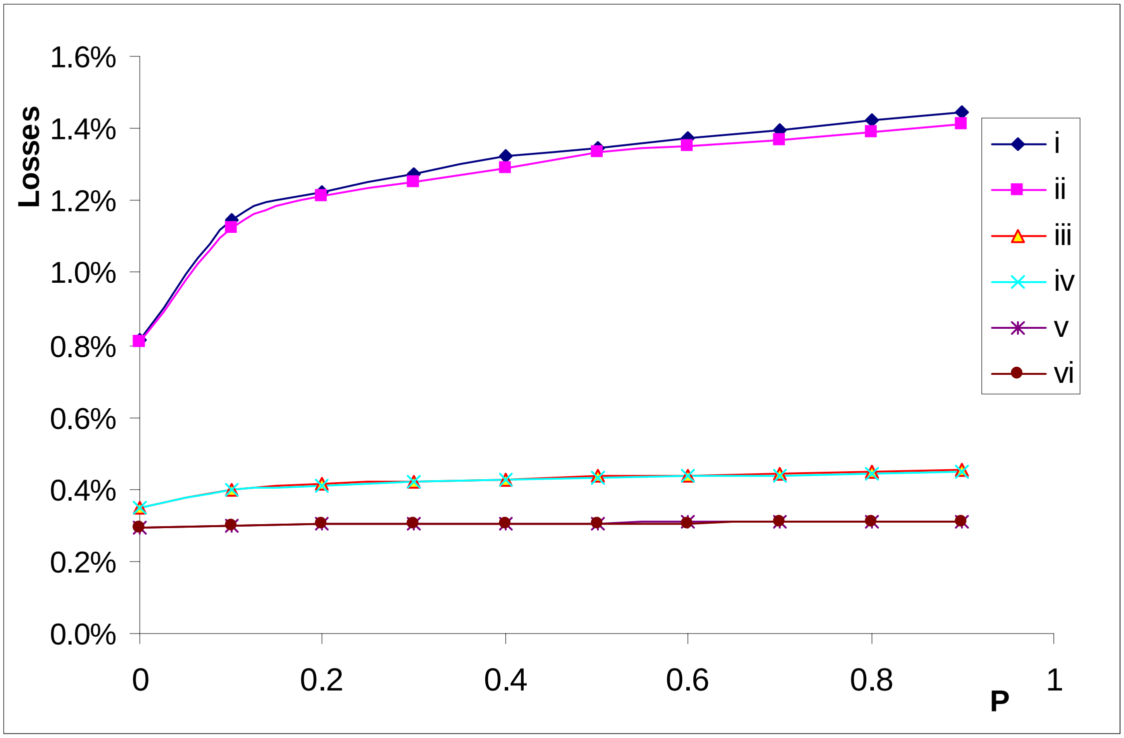
vi – 0.01VTC, RE=0.3

**Figure 24 Proportion of cattle industry's monetary value lost under slow exponential spread**



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iv – 0.1VTC, RE=0.3
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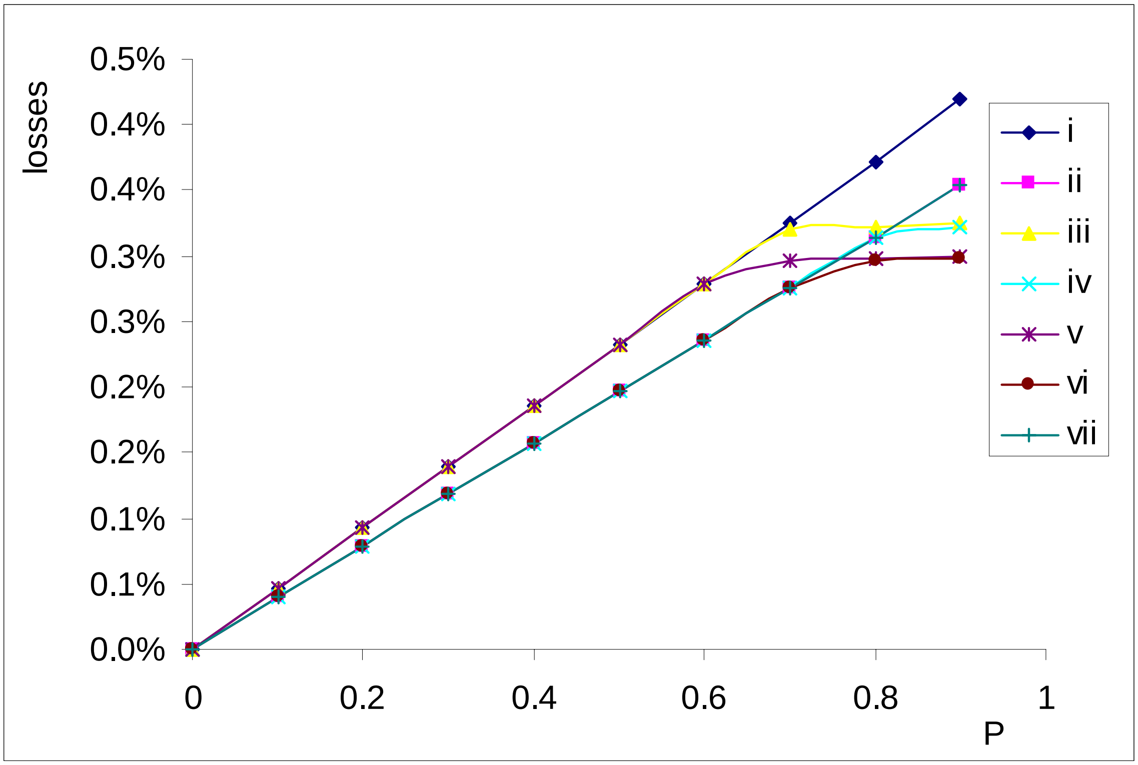
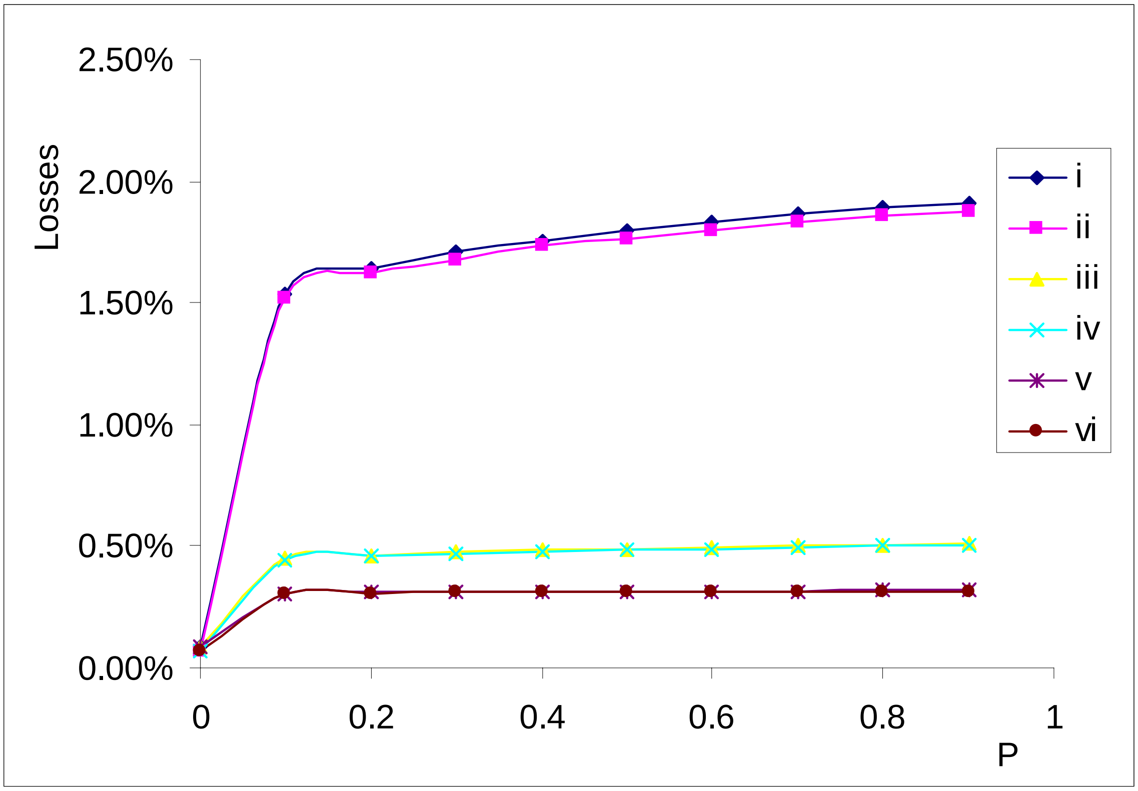
vi – 0.01VTC, RE=0.3

**Figure 25 Proportion of cattle industry’s monetary value lost under fast exponential spread**



i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 26 Proportion of cattle industry's monetary value lost under slow RF spread**



i – Full Variable Costs (VTC), Response Effectiveness (RE)= 0.17
ii – VTC, RE=0.3
iii – 0.1VTC, RE=0.17
iv – 0.1VTC, RE=0.3
v – 0.01VTC, RE=0.17
vi – 0.01VTC, RE=0.3

**Figure 27. Proportion of cattle industry's monetary value lost under fast RF spread**

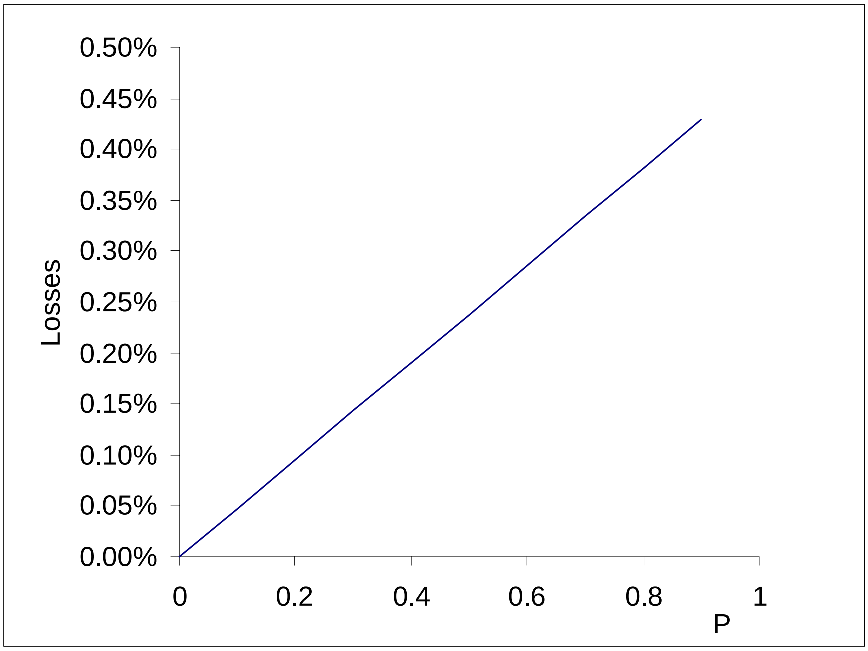


**Figure 28 Proportion of cattle industry's monetary value lost under slow exponential spread with no surveillance and detection**

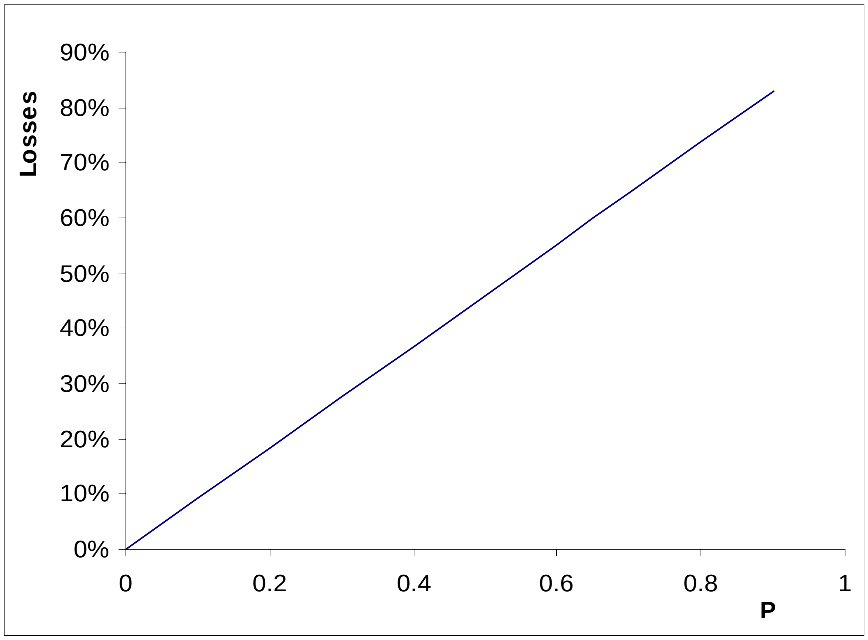


**Figure 29. Proportion of cattle industry's monetary value lost under fast exponential spread with no surveillance and detection**

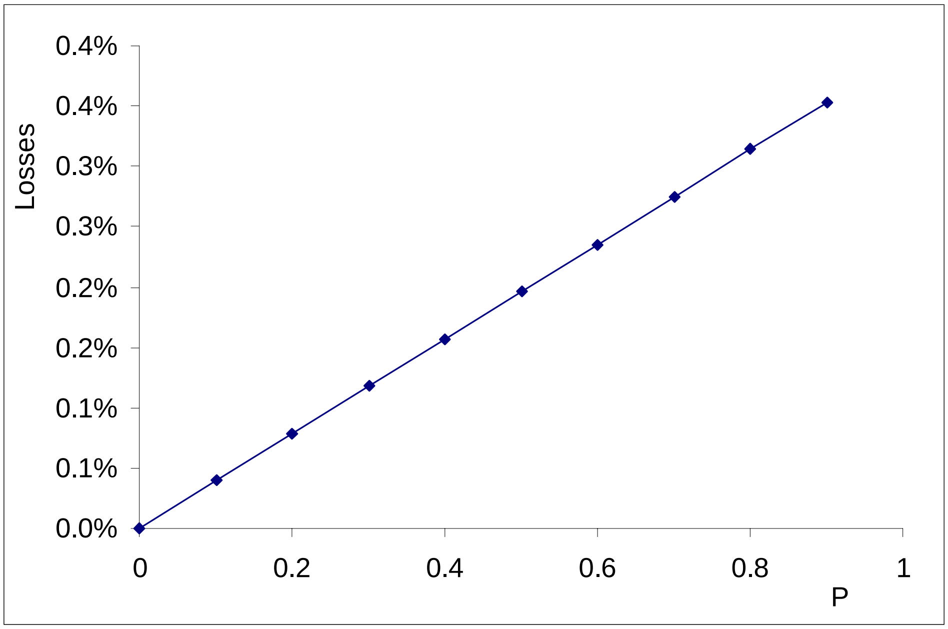


**Figure 30.** **Proportion of cattle industry's monetary value lost under slow RF spread with no surveillance and detection**

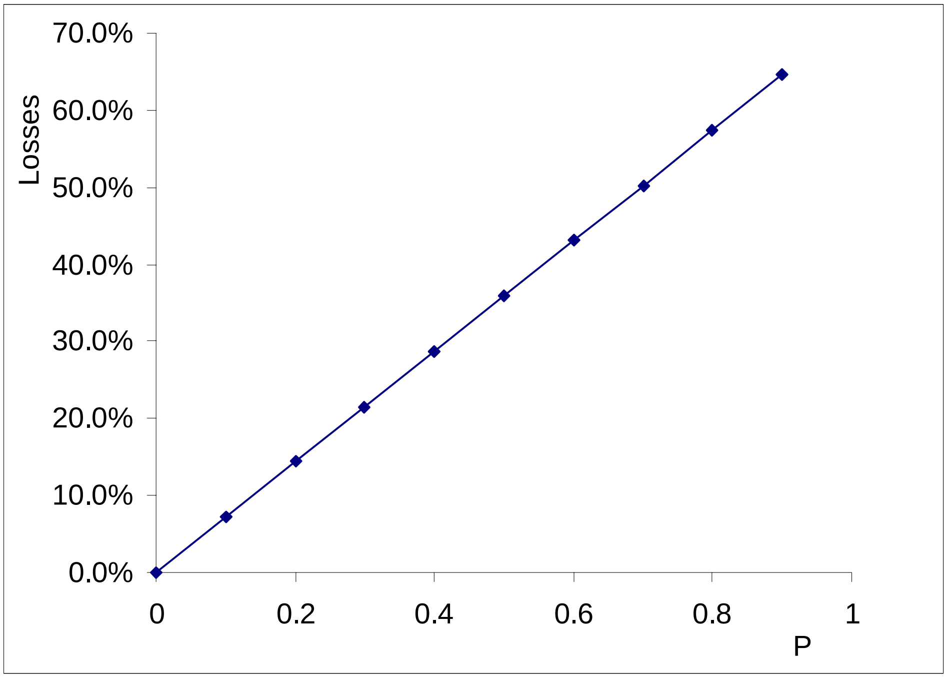


**Figure 31.** **Proportion of cattle industry's monetary value lost under fast RF spread with no surveillance and detection**

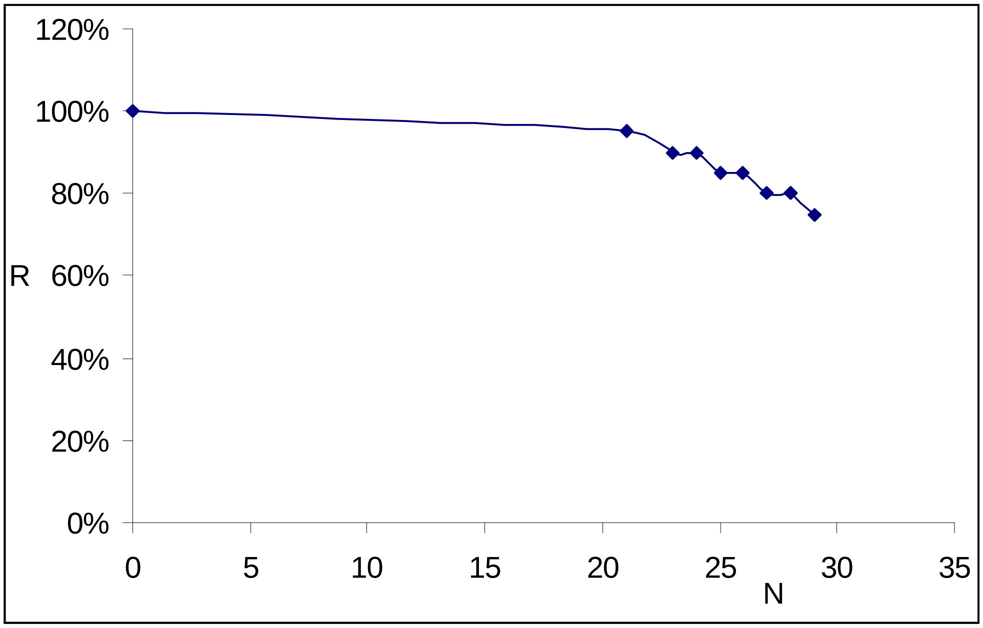


**Figure 32. Response and number of annual tests under fast RF spread with minimal variable costs**

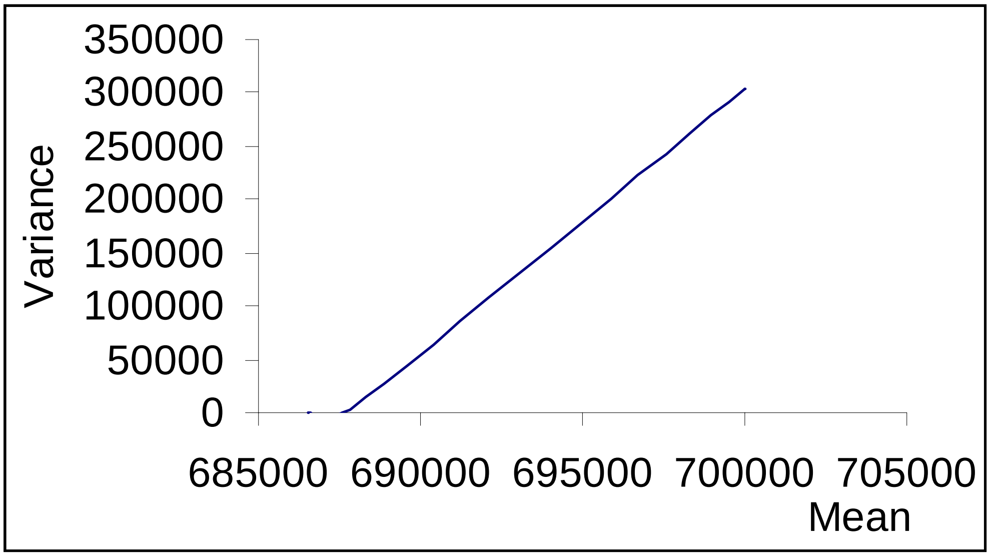
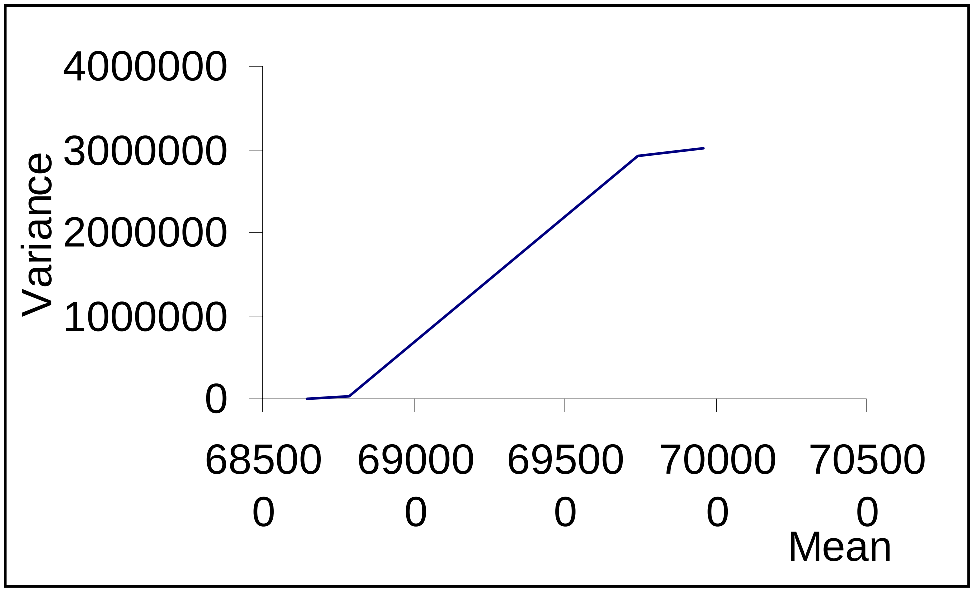
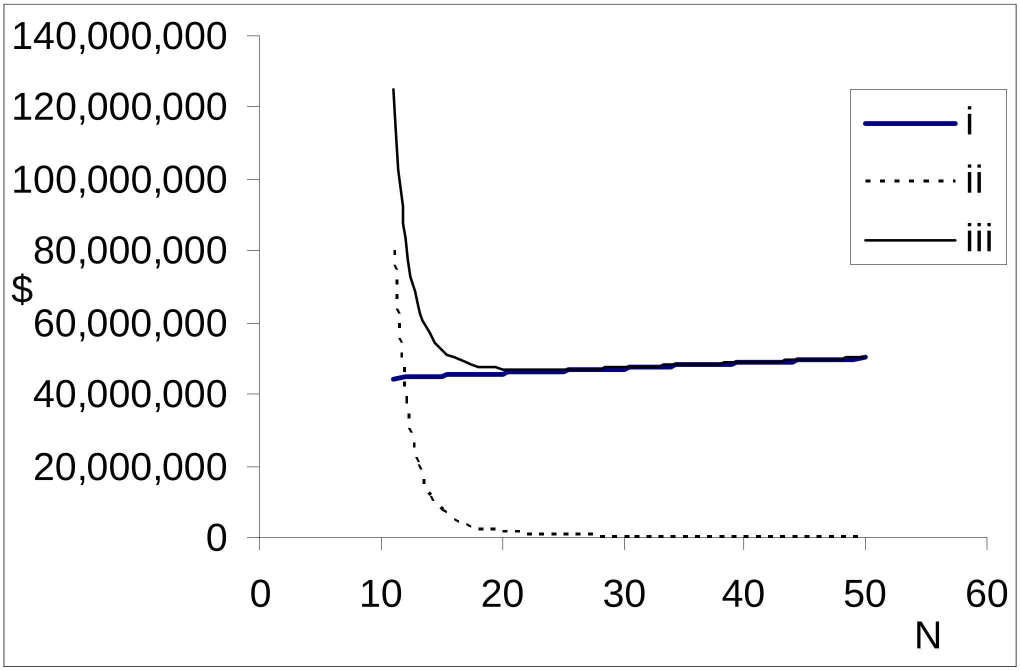


**Figure 33. Combinations of variance and mean profits**



**Graph 34. Combinations of variance and mean profits under increased threat level**



i – Surveillance and detection costs
ii – Expected costs of outbreak
iii – Total costs to be minimized.

**Graph 35. Example of total cost minimization under fast RF spread, p=0.2**

## Table 1. Slow Exponential Spread Scenarios

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| VC | 0.17 | 0.001 | 0 | 100% | 72465.85 |
| VC | 0.17 | 0.1 | 0 | 100% | 7246585.40 |
| VC | 0.17 | 0.2 | 0 | 100% | 14493170.00 |
| VC | 0.17 | 0.3 | 0 | 100% | 21739760.00 |
| VC | 0.17 | 0.4 | 0 | 100% | 28986340.00 |
| VC | 0.17 | 0.5 | 0 | 100% | 36232930.00 |
| VC | 0.17 | 0.6 | 0 | 100% | 43479510.00 |
| VC | 0.17 | 0.7 | 0 | 100% | 50726100.00 |
| VC | 0.17 | 0.8 | 0 | 100% | 57972680.00 |
| VC | 0.17 | 0.9 | 1 | 85% | 59017910.00 |
| VC | 0.3 | 0.001 | 0 | 100% | 61135.77 |
| VC | 0.3 | 0.1 | 0 | 100% | 6113577.39 |
| VC | 0.3 | 0.2 | 0 | 100% | 12227150.00 |
| VC | 0.3 | 0.3 | 0 | 100% | 18340730.00 |
| VC | 0.3 | 0.4 | 0 | 100% | 24454310.00 |
| VC | 0.3 | 0.5 | 0 | 100% | 30567890.00 |
| VC | 0.3 | 0.6 | 0 | 100% | 36681460.00 |
| VC | 0.3 | 0.7 | 0 | 100% | 42795040.00 |
| VC | 0.3 | 0.8 | 0 | 100% | 48908620.00 |
| VC | 0.3 | 0.9 | 0 | 100% | 55022200.00 |
| 0.1VC | 0.17 | 0.001 | 0 | 100% | 72465.85 |
| 0.1VC | 0.17 | 0.1 | 0 | 100% | 7246585.40 |
| 0.1VC | 0.17 | 0.2 | 0 | 100% | 14493170.00 |
| 0.1VC | 0.17 | 0.3 | 0 | 100% | 21739760.00 |
| 0.1VC | 0.17 | 0.4 | 0 | 100% | 28986340.00 |
| 0.1VC | 0.17 | 0.5 | 0 | 100% | 36232930.00 |
| 0.1VC | 0.17 | 0.6 | 0 | 100% | 43479510.00 |
| 0.1VC | 0.17 | 0.7 | 2 | 45% | 46230220.00 |
| 0.1VC | 0.17 | 0.8 | 2 | 45% | 46295100.00 |
| 0.1VC | 0.17 | 0.9 | 2 | 45% | 46359990.00 |
| 0.1VC | 0.3 | 0.001 | 0 | 100% | 61135.77 |
| 0.1VC | 0.3 | 0.1 | 0 | 100% | 6113577.39 |
| 0.1VC | 0.3 | 0.2 | 0 | 100% | 12227150.00 |
| 0.1VC | 0.3 | 0.3 | 0 | 100% | 18340730.00 |
| 0.1VC | 0.3 | 0.4 | 0 | 100% | 24454310.00 |
| 0.1VC | 0.3 | 0.5 | 0 | 100% | 30567890.00 |
| 0.1VC | 0.3 | 0.6 | 0 | 100% | 36681460.00 |
| 0.1VC | 0.3 | 0.7 | 0 | 100% | 42795040.00 |
| 0.1VC | 0.3 | 0.8 | 0 | 100% | 48908620.00 |
| 0.1VC | 0.3 | 0.9 | 2 | 70% | 46295460.00 |

**Table 1 Continued**

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| 0.01VC | 0.17 | 0.001 | 0 | 100% | 72465.85 |
| 0.01VC | 0.17 | 0.1 | 0 | 100% | 7246585.40 |
| 0.01VC | 0.17 | 0.2 | 0 | 100% | 14493170.00 |
| 0.01VC | 0.17 | 0.3 | 0 | 100% | 21739760.00 |
| 0.01VC | 0.17 | 0.4 | 0 | 100% | 28986340.00 |
| 0.01VC | 0.17 | 0.5 | 0 | 100% | 36232930.00 |
| 0.01VC | 0.17 | 0.6 | 0 | 100% | 43479510.00 |
| 0.01VC | 0.17 | 0.7 | 2 | 4500% | 43655320.00 |
| 0.01VC | 0.17 | 0.8 | 2 | 4500% | 43720200.00 |
| 0.01VC | 0.17 | 0.9 | 4 | 0% | 43715370.00 |
| 0.01VC | 0.3 | 0.001 | 0 | 100% | 61135.77 |
| 0.01VC | 0.3 | 0.1 | 0 | 100% | 6113577.39 |
| 0.01VC | 0.3 | 0.2 | 0 | 100% | 12227150.00 |
| 0.01VC | 0.3 | 0.3 | 0 | 100% | 18340730.00 |
| 0.01VC | 0.3 | 0.4 | 0 | 100% | 24454310.00 |
| 0.01VC | 0.3 | 0.5 | 0 | 100% | 30567890.00 |
| 0.01VC | 0.3 | 0.6 | 0 | 100% | 36681460.00 |
| 0.01VC | 0.3 | 0.7 | 0 | 100% | 42795040.00 |
| 0.01VC | 0.3 | 0.8 | 2 | 70% | 43662840.00 |
| 0.01VC | 0.3 | 0.9 | 2 | 70% | 43720560.00 |

**Table 2. Fast Exponential Spread Scenarios**

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| VC | 0.17 | 0.001 | 5 | 100% | 123835900.00 |
| VC | 0.17 | 0.1 | 8 | 100% | 173646800.00 |
| VC | 0.17 | 0.2 | 9 | 100% | 186153200.00 |
| VC | 0.17 | 0.3 | 9 | 100% | 193399800.00 |
| VC | 0.17 | 0.4 | 9 | 100% | 200646300.00 |
| VC | 0.17 | 0.5 | 10 | 100% | 204655000.00 |
| VC | 0.17 | 0.6 | 10 | 100% | 208393000.00 |
| VC | 0.17 | 0.7 | 10 | 100% | 212131000.00 |
| VC | 0.17 | 0.8 | 10 | 100% | 215869000.00 |
| VC | 0.17 | 0.9 | 10 | 100% | 219607000.00 |
| VC | 0.3 | 0.001 | 5 | 100% | 122364300.00 |
| VC | 0.3 | 0.1 | 8 | 100% | 171097100.00 |
| VC | 0.3 | 0.2 | 9 | 100% | 183887200.00 |
| VC | 0.3 | 0.3 | 9 | 100% | 190000700.00 |
| VC | 0.3 | 0.4 | 9 | 100% | 196114300.00 |
| VC | 0.3 | 0.5 | 9 | 100% | 202227900.00 |
| VC | 0.3 | 0.6 | 10 | 100% | 204892200.00 |
| VC | 0.3 | 0.7 | 10 | 100% | 208046700.00 |
| VC | 0.3 | 0.8 | 10 | 100% | 211201300.00 |
| VC | 0.3 | 0.9 | 10 | 100% | 214355800.00 |
| 0.1VC | 0.17 | 0.001 | 6 | 100% | 53150430.00 |
| 0.1VC | 0.17 | 0.1 | 11 | 100% | 60806040.00 |
| 0.1VC | 0.17 | 0.2 | 12 | 100% | 62790510.00 |
| 0.1VC | 0.17 | 0.3 | 12 | 100% | 64145260.00 |
| 0.1VC | 0.17 | 0.4 | 13 | 95% | 65156140.00 |
| 0.1VC | 0.17 | 0.5 | 13 | 95% | 66067300.00 |
| 0.1VC | 0.17 | 0.6 | 14 | 95% | 66825050.00 |
| 0.1VC | 0.17 | 0.7 | 14 | 95% | 67472230.00 |
| 0.1VC | 0.17 | 0.8 | 14 | 95% | 68119400.00 |
| 0.1VC | 0.17 | 0.9 | 15 | 95% | 68698130.00 |
| 0.1VC | 0.3 | 0.001 | 6 | 100% | 52891630.00 |
| 0.1VC | 0.3 | 0.1 | 10 | 100% | 60374530.00 |
| 0.1VC | 0.3 | 0.2 | 11 | 100% | 62290350.00 |
| 0.1VC | 0.3 | 0.3 | 12 | 100% | 63514690.00 |
| 0.1VC | 0.3 | 0.4 | 13 | 100% | 64593890.00 |
| 0.1VC | 0.3 | 0.5 | 13 | 100% | 65364490.00 |
| 0.1VC | 0.3 | 0.6 | 13 | 100% | 66135090.00 |
| 0.1VC | 0.3 | 0.7 | 14 | 95% | 66778060.00 |
| 0.1VC | 0.3 | 0.8 | 14 | 95% | 67326070.00 |
| 0.1VC | 0.3 | 0.9 | 14 | 95% | 67874080.00 |
| 0.01VC | 0.17 | 0.001 | 8 | 100% | 44222320.00 |
| 0.01VC | 0.17 | 0.1 | 15 | 95% | 45541380.00 |
| 0.01VC | 0.17 | 0.2 | 17 | 90% | 45935080.00 |
| 0.01VC | 0.17 | 0.3 | 18 | 85% | 46209110.00 |

## Table 2 Continued

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| 0.01VC | 0.17 | 0.5 | 20 | 80% | 46623630.00 |
| 0.01VC | 0.17 | 0.6 | 20 | 80% | 46793150.00 |
| 0.01VC | 0.17 | 0.7 | 21 | 75% | 46942620.00 |
| 0.01VC | 0.17 | 0.8 | 22 | 75% | 47085030.00 |
| 0.01VC | 0.17 | 0.9 | 22 | 75% | 47212890.00 |
| 0.01VC | 0.3 | 0.001 | 8 | 100% | 44196820.00 |
| 0.01VC | 0.3 | 0.1 | 14 | 95% | 45465710.00 |
| 0.01VC | 0.3 | 0.2 | 16 | 95% | 45832620.00 |
| 0.01VC | 0.3 | 0.3 | 17 | 95% | 46097610.00 |
| 0.01VC | 0.3 | 0.4 | 18 | 90% | 46307750.00 |
| 0.01VC | 0.3 | 0.5 | 19 | 90% | 46486630.00 |
| 0.01VC | 0.3 | 0.6 | 20 | 90 | 46647970.00 |
| 0.01VC | 0.3 | 0.7 | 20 | 90 | 46793300.00 |
| 0.01VC | 0.3 | 0.8 | 21 | 85 | 46924950.00 |
| 0.01VC | 0.3 | 0.9 | 21 | 85 | 47050690.00 |

## Table 3. Slow RF Spread Scenarios

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| VC | 0.17 | 0.001 | 0 | 100% | 70680.02 |
| VC | 0.17 | 0.1 | 0 | 100% | 7068001.90 |
| VC | 0.17 | 0.2 | 0 | 100% | 14136000.00 |
| VC | 0.17 | 0.3 | 0 | 100% | 21204010.00 |
| VC | 0.17 | 0.4 | 0 | 100% | 28272010.00 |
| VC | 0.17 | 0.5 | 0 | 100% | 35340010.00 |
| VC | 0.17 | 0.6 | 0 | 100% | 42408010.00 |
| VC | 0.17 | 0.7 | 0 | 100% | 49476010.00 |
| VC | 0.17 | 0.8 | 0 | 100% | 56544020.00 |
| VC | 0.17 | 0.9 | 0 | 100% | 63612020.00 |
| VC | 0.3 | 0.001 | 0 | 100% | 59629.65 |
| VC | 0.3 | 0.1 | 0 | 100% | 5962964.80 |
| VC | 0.3 | 0.2 | 0 | 100% | 11925930.00 |
| VC | 0.3 | 0.3 | 0 | 100% | 17888890.00 |
| VC | 0.3 | 0.4 | 0 | 100% | 23851860.00 |
| VC | 0.3 | 0.5 | 0 | 100% | 29814820.00 |
| VC | 0.3 | 0.6 | 0 | 100% | 35777790.00 |
| VC | 0.3 | 0.7 | 0 | 100% | 41740750.00 |
| VC | 0.3 | 0.8 | 0 | 100% | 47703720.00 |
| VC | 0.3 | 0.9 | 0 | 100% | 53666680.00 |
| 0.1VC | 0.17 | 0.001 | 0 | 100% | 70680.02 |
| 0.1VC | 0.17 | 0.1 | 0 | 100% | 7068001.90 |
| 0.1VC | 0.17 | 0.2 | 0 | 100% | 14136000.00 |
| 0.1VC | 0.17 | 0.3 | 0 | 100% | 21204010.00 |
| 0.1VC | 0.17 | 0.4 | 0 | 100% | 28272010.00 |
| 0.1VC | 0.17 | 0.5 | 0 | 100% | 35340010.00 |
| 0.1VC | 0.17 | 0.6 | 0 | 100% | 42408010.00 |
| 0.1VC | 0.17 | 0.7 | 2 | 90% | 48539330.00 |
| 0.1VC | 0.17 | 0.8 | 2 | 90% | 48934090.00 |
| 0.1VC | 0.17 | 0.9 | 2 | 90% | 49328850.00 |
| 0.1VC | 0.3 | 0.001 | 0 | 100% | 59629.65 |
| 0.1VC | 0.3 | 0.1 | 0 | 100% | 5962964.80 |
| 0.1VC | 0.3 | 0.2 | 0 | 100% | 11925930.00 |
| 0.1VC | 0.3 | 0.3 | 0 | 100% | 17888890.00 |
| 0.1VC | 0.3 | 0.4 | 0 | 100% | 23851860.00 |
| 0.1VC | 0.3 | 0.5 | 0 | 100% | 29814820.00 |
| 0.1VC | 0.3 | 0.6 | 0 | 100% | 35777790.00 |
| 0.1VC | 0.3 | 0.7 | 0 | 100% | 41740750.00 |
| 0.1VC | 0.3 | 0.8 | 0 | 100% | 47703720.00 |
| 0.1VC | 0.3 | 0.9 | 2 | 95% | 48791480.00 |
| 0.01VC | 0.17 | 0.001 | 0 | 100% | 70680.02 |
| 0.01VC | 0.17 | 0.1 | 0 | 100% | 7068001.90 |
| 0.01VC | 0.17 | 0.2 | 0 | 100% | 14136000.00 |

**Table 3 Continued**

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| 0.01VC | 0.17 | 0.4 | 0 | 100% | 28272010.00 |
| 0.01VC | 0.17 | 0.5 | 0 | 100% | 35340010.00 |
| 0.01VC | 0.17 | 0.6 | 0 | 100% | 42408010.00 |
| 0.01VC | 0.17 | 0.7 | 5 | 85% | 45002620.00 |
| 0.01VC | 0.17 | 0.8 | 6 | 80% | 45194670.00 |
| 0.01VC | 0.17 | 0.9 | 6 | 80% | 45372340.00 |
| 0.01VC | 0.3 | 0.001 | 0 | 100% | 59629.65 |
| 0.01VC | 0.3 | 0.1 | 0 | 100% | 5962964.80 |
| 0.01VC | 0.3 | 0.2 | 0 | 100% | 11925930.00 |
| 0.01VC | 0.3 | 0.3 | 0 | 100% | 17888890.00 |
| 0.01VC | 0.3 | 0.4 | 0 | 100% | 23851860.00 |
| 0.01VC | 0.3 | 0.5 | 0 | 100% | 29814820.00 |
| 0.01VC | 0.3 | 0.6 | 0 | 100% | 35777790.00 |
| 0.01VC | 0.3 | 0.7 | 0 | 100% | 41740750.00 |
| 0.01VC | 0.3 | 0.8 | 5 | 90% | 44971320.00 |
| 0.01VC | 0.3 | 0.9 | 5 | 90% | 45138950.00 |

## Table 4. Fast RF Spread Scenarios

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| VC | 0.17 | 0.001 | 0 | 100% | 12932130.00 |
| VC | 0.17 | 0.1 | 12 | 100% | 233891400.00 |
| VC | 0.17 | 0.2 | 13 | 100% | 249412600.00 |
| VC | 0.17 | 0.3 | 13 | 100% | 259678900.00 |
| VC | 0.17 | 0.4 | 14 | 100% | 266873800.00 |
| VC | 0.17 | 0.5 | 14 | 100% | 272796000.00 |
| VC | 0.17 | 0.6 | 14 | 100% | 278718200.00 |
| VC | 0.17 | 0.7 | 15 | 100% | 283089400.00 |
| VC | 0.17 | 0.8 | 15 | 100% | 286746400.00 |
| VC | 0.17 | 0.9 | 15 | 100% | 290403500.00 |
| VC | 0.3 | 0.001 | 0 | 100% | 10906640.00 |
| VC | 0.3 | 0.1 | 12 | 100% | 230868000.00 |
| VC | 0.3 | 0.2 | 13 | 100% | 246200600.00 |
| VC | 0.3 | 0.3 | 13 | 100% | 254860900.00 |
| VC | 0.3 | 0.4 | 14 | 100% | 263171500.00 |
| VC | 0.3 | 0.5 | 14 | 100% | 268168100.00 |
| VC | 0.3 | 0.6 | 14 | 100% | 273164700.00 |
| VC | 0.3 | 0.7 | 14 | 100% | 278161300.00 |
| VC | 0.3 | 0.8 | 15 | 100% | 282180100.00 |
| VC | 0.3 | 0.9 | 15 | 100% | 285266400.00 |
| 0.1VC | 0.17 | 0.001 | 0 | 100% | 12932130.00 |
| 0.1VC | 0.17 | 0.1 | 15 | 100% | 68029550.00 |
| 0.1VC | 0.17 | 0.2 | 17 | 100% | 70511110.00 |
| 0.1VC | 0.17 | 0.3 | 17 | 100% | 72149920.00 |
| 0.1VC | 0.17 | 0.4 | 18 | 95% | 73343930.00 |
| 0.1VC | 0.17 | 0.5 | 19 | 95% | 74417550.00 |
| 0.1VC | 0.17 | 0.6 | 19 | 95% | 75282160.00 |
| 0.1VC | 0.17 | 0.7 | 20 | 95% | 76133190.00 |
| 0.1VC | 0.17 | 0.8 | 20 | 95% | 76791500.00 |
| 0.1VC | 0.17 | 0.9 | 20 | 95% | 77449810.00 |
| 0.1VC | 0.3 | 0.001 | 0 | 100% | 10906640.00 |
| 0.1VC | 0.3 | 0.1 | 15 | 100% | 67458760.00 |
| 0.1VC | 0.3 | 0.2 | 16 | 100% | 69838870.00 |
| 0.1VC | 0.3 | 0.3 | 17 | 100% | 71385880.00 |
| 0.1VC | 0.3 | 0.4 | 18 | 100% | 72619080.00 |
| 0.1VC | 0.3 | 0.5 | 18 | 100% | 73607850.00 |
| 0.1VC | 0.3 | 0.6 | 19 | 100% | 74482650.00 |
| 0.1VC | 0.3 | 0.7 | 19 | 100% | 75214010.00 |
| 0.1VC | 0.3 | 0.8 | 19 | 100% | 75945370.00 |
| 0.1VC | 0.3 | 0.9 | 20 | 95% | 76541670.00 |
| 0.01VC | 0.17 | 0.001 | 0 | 100% | 12932130.00 |
| 0.01VC | 0.17 | 0.1 | 21 | 95% | 46433470.00 |
| 0.01VC | 0.17 | 0.2 | 23 | 90% | 46875520.00 |

## Table 4 Continued

| Variable Costs (VC) of Testing | Response Effectiveness | Event probability | Number of tests | Response level | Losses |
|---|---|---|---|---|---|
| 0.01VC | 0.17 | 0.4 | 25 | 85% | 47428500.00 |
| 0.01VC | 0.17 | 0.5 | 26 | 85% | 47635120.00 |
| 0.01VC | 0.17 | 0.6 | 27 | 80% | 47815870.00 |
| 0.01VC | 0.17 | 0.7 | 28 | 80% | 47979720.00 |
| 0.01VC | 0.17 | 0.8 | 28 | 80% | 48131050.00 |
| 0.01VC | 0.17 | 0.9 | 29 | 75% | 48265680.00 |
| 0.01VC | 0.3 | 0.001 | 0 | 100% | 10906640.00 |
| 0.01VC | 0.3 | 0.1 | 20 | 95% | 46333410.00 |
| 0.01VC | 0.3 | 0.2 | 22 | 95% | 46759870.00 |
| 0.01VC | 0.3 | 0.3 | 24 | 95% | 47058480.00 |
| 0.01VC | 0.3 | 0.4 | 25 | 90% | 47290810.00 |
| 0.01VC | 0.3 | 0.5 | 26 | 90% | 47489800.00 |
| 0.01VC | 0.3 | 0.6 | 26 | 90% | 47660900.00 |
| 0.01VC | 0.3 | 0.7 | 27 | 90% | 47815590.00 |
| 0.01VC | 0.3 | 0.8 | 28 | 85% | 47960700.00 |
| 0.01VC | 0.3 | 0.9 | 28 | 85% | 48090740.00 |

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