EX ANTE VS. EX POST BIOTERRORISM MITIGATION:

BETTER SAFE THAN SORY?

LEVAN ELBAKIDZE
Assistant Research Professor
Department of Agricultural Economics
Texas A&M University
College Station, TX, 77843-2124
(979)845 3225
lelbakidze@tamu.edu

and

BRUCE A. MCCARL
Regents Professor
Department of Agricultural Economics
Texas A&M University
College Station, TX, 77843-2124
(979) 845 1706
mccarl@tamu.edu

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, July 24-27, 2005

This research was supported by National Center For Foreign Animal and Zoonotic Diseases established by Department of Homeland Security at Texas A&M University

Ex Ante vs. Ex Post Bioterrorism Mitigation: Better Safe than Sorry?

Abstract

This article examines a tradeoff between ex ante mitigation costs and ex post costs of response to a potential introduction of animal disease such as Foot and Mouth (FMD). In a simplified case study setting we examine the conditions for optimality 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 surveillance and response strategies. We show that the decision to invest in ex ante detection activities depends on such factors as likelihood of disease introduction, disease spread rate, relative costs, ancillary benefits and effectiveness of mitigation strategies. While for slow spreading disease the investment in surveillance and detection was found to be optimal only for high probabilities of introduction, the investment was optimal even for low probabilities of outbreak occurrence for fast spreading disease.

Ex Ante vs. Ex Post Bioterrorism Mitigation: Better Safe than Sorry?

September 11, 2001 proved that in spite of enormous expenses on national defense, uninterrupted prosperity was far from secure against deliberate terrorist acts. It became clear that military forces alone were not sufficient to ensure peace and stability. 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, which in 2002 accounted for $250 billion in gross domestic product and employed nearly 1.6 million people while feeding the US population (Bureau of Economic Analysis). Food and water contamination have been identified by some as a relatively easy way to initiate a bioterrorism attack (Khan et al. p. 3). From an economic perspective, a major consequence of agricultural terrorism is that it would cause disruptions in agricultural commodity and related markets due to possible human health implications (Henson and Mazzocchi, p. 371). In addition, potentially expensive and intrusive mitigation actions could also represent a significant portion of total costs of agricultural terrorism. Agriculturally related contamination events could have large consequences for consumers, producers and international trade as seen during recent mad cow events as they influenced conditions in the US, Canada, UK, and Asia.

This potential disruption has raised many issues involved with protection against potential events in vulnerable components of the economy as well as efficient response to attacks.   One such issue involves the balance between ex ante efforts to prevent or reduce the probability of certain classes of attacks and mainly ex post efforts to rapidly respond to attacks and otherwise minimize the associated damages. The key point here is the distinction between costs of ex ante and ex post decision making. While costs of ex ante decisions are encountered regardless of event occurrence, ex post mitigation costs are present only when responding to materialized attack. For example, costs of initiating animal health surveillance system are encountered whether or not the outbreak of animal disease takes place. However, costs of slaughter and disinfection arise only in the event of disease introduction.

Agricultural terrorism related decision making involves several economic issues. Economic welfare in the form of lost consumers' and producers' surpluses, plus the costs of ex ante prevention and ex post response strategies are at the forefront of the economic issues. Here an investigation will be done on how the characteristics of outbreak events and characteristics of mitigation options influence the choice of economically optimal policy and management strategies addressing those events. Emphasis will be placed on the optimal balance between the use of ex ante pre event alternatives versus ex post after event alternatives as influenced by potential event characteristics. For example, 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?

Our examination of this issue consists of two parts. First we will present a broad conceptual approach to the issue. Subsequently we will conduct an empirical case study in the context of foot and mouth disease.

Analytical explorations of balance

Figure 1 illustrates the stages, related events and activities. In stage one there is no act of agricultural terrorism. At this stage businesses have the options to either invest in ex ante actions, such as surveillance and prevention, or do nothing. In stage two there is a possibility of agricultural contamination. If contamination takes place then decision makers can either initiate ex post response and recovery actions, or do nothing. If there is no event then business continues as usual, although ex ante decisions made in the first stage will affect the profits. For example, severity of an outbreak of an animal disease such as Foot and Mouth Disease (FMD), in part, will depend on the length of time that the disease is allowed to spread uninterrupted. Surveillance and detection systems, which could be established in the first stage, could allow timely recognition and intervention to stop the spread. However, the costs of such systems will be incurred whether or not the outbreak occurs. As response measures in the second stage, various slaughter and vaccination strategies could allow reduction of economic losses by removing susceptible herds before infection.

We adopt a welfare maximization approach to investigate the relationship between ex ante and ex post mechanisms. The goal is to maximize welfare by minimizing total costs associated with monetary damages from and mitigation of potential act of agricultural terrorism. Mitigation costs are composed of investments made in ex ante mitigation actions (s), and ex post mitigation actions (r). Monetary damages L(δ,r,s) are assumed to be a function of event severity (δ), and ex ante and ex post mitigation actions. Denoting probability of agricultural terrorism event with P we can write a utility maximization problem as:

$$U = P \cdot U_E\left(V - L(\delta, r, s) - w_s \cdot s - w_r \cdot r\right) + (1-P)U_{NE}\left(V - w_s s\right) \tag{1}$$

where U is welfare, or utility. U_E and U_{NE} are utilities under event and no event states of nature respectively. V is monetary wealth without losses due to terrorism act and without expenditures on mitigation actions. L(δ,r,s) is monetary damages inflicted by a terrorist attack. These damages are formulated to be a function of severity of an attack (δ), ex ante (s) and ex post (r) mitigation actions. w_s and w_r are costs of ext ante and ex post action respectively. U_E and U_{NE} are utilities in each state of nature. First order condition for the optimality of ex ante and ex post mitigation actions are as follows:

(2) $$U_s = -PU'_E \cdot (L_s + w_s) - (1-P) \cdot U'_{NE} w_s = 0$$

(3) $$U_r = -PU'_E (L_r + w_r) = 0$$

Using implicit function theorem, with the assumptions of continuity of partial derivatives, we can examine sensitivity of investment in ex ante activities toward parameters such as probability and severity of an attack, and costs of mitigation actions. Using equation (2) it could be shown:

(4) $$\frac{\partial s}{\partial P} = \frac{U'_{NE} w_s - U'_E \cdot (L_s + w_s)}{-PU''_E \cdot (L_s + w_s)^2 + PU'_E L_{ss} - (1-P) U''_{NE} w_s^2}$$

(5) $$\frac{\partial s}{\partial \delta} = \frac{PU''_E \cdot (L_s + w_s) L_\delta - PU'_E L_{s\delta}}{-PU''_E \cdot (L_s + w_s)^2 + PU'_E L_{ss} - (1-P) U''_{NE} w_s^2}$$

(6) $$\frac{\partial s}{\partial w_s} = \frac{P(L_s + w_s) s U''_E + (1-P) w_s s U''_{NE} - (PU'_E + (1-P) U'_{NE})}{-PU''_E \cdot (L_s + w_s)^2 + PU'_E L_{ss} - (1-P) U''_{NE} w_s^2}$$

(7) $$\frac{\partial s}{\partial w_r} = \frac{PU''_E \cdot r \cdot (L_s + w_s)}{-PU''_E \cdot (L_s + w_s)^2 + PU'_E L_{ss} - (1-P) U''_{NE} w_s^2}$$

The above equations could be used to generate some insight on the sensitivity of ex ante investments to likelihood and severity of contamination event, and costs if ex ante and ex post actions respectively. The sign of equation 4 appears to be determined by the sign of L_{ss}. The numerator is positive since $L_s<0$ and $|L_s| \geq w_s$ meaning that marginal decrease in damages due to ex ante action will be larger than marginal costs of ex ante actions. The denominator is positive under risk aversion or risk neutrality and convexity of *L*. This would be consistent with second order necessary condition for maximization problem. Under these conditions the increase in likelihood of terrorism act increases optimal level of ex ante actions. The numerator of equation (5) is positive under risk aversion or risk neutrality since $L_s<0$ and $L_{s\delta}<0$. Denominator sign of equation (5) is identical to that of equation (4). Hence under risk aversion or risk neutrality and convexity of *L* the increase in severity of an attack increases optimal investment if ex ante actions. It can similarly be observed that the sign of equation (6) is negative under risk neutrality and convexity of *L*. the numerator is most likely negative since the first term is positive while the second and third terms are negative. Thus, increase in the price of ex ante actions will probably have an opposite effect on the use of ex ante actions. However, under risk aversion the sign of equation (6) is ambiguous. Equation (7) can be shown to have a positive sign under convexity of L and risk aversion or risk neutrality conditions, implying that as ex post activities become more expensive it becomes more advantageous to invest in ex ante activities.

In the above sensitivity analysis the sign of derivatives seems to be influenced by characteristics of *L*. However, even under concave *L* and risk aversion, the signs of the above equations depend on relative magnitudes of $\left|PN''_E \cdot (L_s + w_s)^2 + (1-P)U''_{NE} w_s^2\right|$ and $\left|PU'_E L_{ss}\right|$. Therefore empirical investigation presented below was initiated to evaluate the optimality of investing in ex ante actions as examined in the case of possible Foot and Mouth disease introduction.

FMD case study

In this section we investigate the optimal combination of ex ante and ex post mitigation strategies under the scenario of possible introduction of FMD in a region such as the state of Texas, which in 2002 amounted to roughly 14 percent of the total U.S. cattle operations (NASS). Although the US has been free of FMD since 1929 (McCauley et al. p. 2), perhaps some mitigation options merit investigation to explore ways to minimize potential losses from possible future introduction of FMD which previously caused serious economic damages elsewhere. For example, Great Britain experienced an FMD outbreak in 2001 (Scudamore, 2002) where associated total losses are estimated to be £5.8-8.5 billion (Thompson et al., p. 25, Mangen and Barrell, p. 126).

Analysis of decision-making directed toward potential FMD outbreaks 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, Schoenbaum and Disney, Berentsen et al., McCauley et al., Ferguson et al.). All of these studies mainly concentrate on decision-making once an outbreak has occurred largely addressing post outbreak vaccination and slaughter as FMD disease spread management policies. In such cases vaccination strategies are generally found to be economically inferior to slaughter strategies or a combination of slaughter and vaccination strategies (Berentsen et al. p. 239, Schoenbaum and Disney, p. 49, Bates et al. 2003 b p. 205, Keiling, et al. p. 815) largely due to the fact that once vaccinated the current state of the science is that one cannot differentiate between infected and vaccinated animals and thus must destroy the vaccinated animals. 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 decreases the duration and damages of an epidemic.

Less attention has been devoted to ex ante decision-making regarding surveillance and detection systems, which if present upon a disease outbreak, would allow for timelier and more effective response actions. Although some attention has been raised towards surveillance systems (Bates et al. September 2003; Akhtar and White), no empirical investigation has been performed, to the best of our knowledge, on the economic balance that might be drawn between ex ante and ex post decision-making and associated expenditures/damages.

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 p. 609). 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. September, 2003 p. 609). Therefore, more reliable methods for detection of FMD may be appropriate. One of the possible surveillance and detection systems could be to conduct periodic screening of animals. Regular screening and testing of farm animals directed towards evaluating animal health could assist in preventing a possible intentional spread of FMD or similar disease. Latent period of FMD infected animal is around one to two weeks (Garner and Lack, p. 14, Carpenter et al. p 11), which means that frequent testing of animals could detect FMD carriers before the clinical signs of the disease appear. Earlier detection through periodic testing would allow for timelier implementation of response strategies such as slaughter, disposal, cleaning and disinfection. Hence, frequent animal testing could decrease the time of unobstructed spread of the disease. Therefore, periodic testing of animals could decrease the costs of 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.

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?

Analytical Framework and modeling

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, Cocks, Boisvert and McCarl, Ziari). 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. A two stage discrete stochastic model with recourse (Dantzig, Cocks, Boisvert and McCarl, Ziari) will be used in this setting.

Total costs in this model include expenses on surveillance and detection, costs of response strategies, and economic damages from a potential outbreak. Surveillance and detection costs encompass fixed costs of installing testing facilities and variable costs of administering tests that are incurred regardless of outbreak occurrence. Response costs include costs associated with vaccination and/or slaughter. Economic damages from potential outbreak include cattle values lost due to infection and earnings lost per infected animal. This can be expressed mathematically as follows. Suppose an outbreak has probability P of occurrence, then total cost equals

$$L(N,R) = Y \times FTC + N \times VTC + P \times \left[V \times H(R) \times D(t) + CR \times R \right] \tag{8}$$

where L(N,R) is costs and losses associated with prevention of, response to and occurrence of potential FMD outbreak. N is a number of tests performed annually. R represents response activities under the state of nature where outbreak occurs. V is value of losses associated with each animal infected with FMD. 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 is the 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.

Empirical Specification

The response effectiveness function, H(R), is hypothesized to be convex implying that as more response actions, such as slaughtering, are employed the damages from FMD outbreak will decrease. However, too much of the response actions could increase the costs. Therefore, a convex quadratic form was assumed for the damage function.

$$H(R) = \left(a_1 + a_2 R + a_3 R^2\right) \tag{9}$$

where, R represents the level of response actions. For empirical analysis this variable was normalized to1. Schoenbaum and Disney 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. Suppose that the damage function is minimized at R=1, corresponding to the most effective response scenario according to Schoenbaum and Disney. Then 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. Consequently, the response effectiveness function used in this analysis was $H(R)=1-0.34R+0.17R^2$.

The disease spread function, D(t), represents the number of herds infected on any given day *t* after the initial infection in the region. Here, *t* is 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. In other words, an increase in 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.

$$\hat{D}_{t'} = \left[TN - \sum_{t=0}^{t=t^*-1} \hat{D}_t \right] \left[1 - q^{CI} \right] \tag{10}$$

D(t) is assumed to have a Reed-Frost equation form[1] (Carpenter et al. p. 12) where, TN is total number of herds in the area and $\hat{D}_t$ is number of infected animals on 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. Therefore, 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 per day. k was assumed to have slow, 0.15, and fast 0.4 rates according to Schoenbaum and Disney (p. 28). 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 reflects the fact that in the early stages of FMD outbreak the disease will be spreading at an 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.

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:

$$V = C \times NH + \left(CV + \frac{GI}{TN} \right) \times NH \tag{11}$$

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, p. 807). 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 assumed 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). 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, p. 36) 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, in equation (1) 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, p.36), 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 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, p. 36). Thus, costs of response were calculated to be $1175 per herd. Optimal number of herds slaughtered under response strategy in Schoenbaum and Disney 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. p. 4, Bates et al. February 2003 a p. 806, Schoenbaum and Disney p. 36). However, we rely on Schoenbaum and Disney's results, which show that the most effective response strategy did not involve vaccination. We exclude vaccination 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.

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 (12). The Reed-Frost formulation was used to simulate daily spread of FMD under slow and fast rates of spread. In other words, daily numbers of infected herds were simulated using equation (10). TN was 286100, *k* was 0.15 and 0.4 for slow and fast spreads respectively.

$$D(t) = \frac{TN}{1+\beta_1 e^{\beta_2 t}} \tag{12}$$

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, β_1=512040, β_2=-0.319. For slow disease spread β_1=14554.2, β_2=-0.012, R^2=0.97. Letting t=(365/N+1) and plugging (12) into (8) the optimal values for N were derived under various scenarios for Reed-Frost disease spread approximated by logistic function.

Model experimentation and results

The model is used to examine the optimality of investing in ex ante animal surveillance and detection mechanism to minimize expected costs of possible FMD introduction. Specifically the model is used to evaluate the effects of likelihood and severity of an outbreak, along with effectiveness and costs of mitigation options on the decision to invest in ex ante surveillance and detection system. To evaluate the effects of threat characteristics the outbreak likelihood and disease spread rate were varied. Probability of FMD introduction was varied from 0.001 to 0.9 and two disease spread rates were considered. The effect of mitigation costs were analyzed by decreasing the variable testing costs by tenfold and hundredfold consecutively. The effects of response strategy effectiveness were analyzed by considering two levels of response effectiveness. One implied a 17 percent decrease in animal losses due to response actions compared to no response actions (Schoenbaum and Disney, p. 49). The other implied a 30 percent decrease in animal losses due to more effective response actions. The possibility that detection activities could provide ancillary benefits by identifying for example other animal health problems was also considered. Specifically, per herd fixed costs associated with instituting the surveillance systems were decreased. The motivation behind this decrease 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. Finally, the effects of post event recovery actions on optimality of animal screening were investigated.

First we investigated the effect of potential outbreak likelihood and disease spread rate. The hypothesis is that the higher the disease introduction likelihood and spread rate the more the optimal strategy would rely on detection systems. The results show (Figure 2) that testing and screening becomes considerably more advantageous for fast spreading disease than for slow spreading disease. 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. This also implies that optimal mix of mitigation activities also depends on the probability of an event. Overall, increasing the probability of an outbreak increased the use of surveillance systems. Figure 2 also shows the effects of changing the variable costs of surveillance and detection. It can easily be observed that decreasing variable costs of testing and screening increases the worth of investing in such systems. In case of a slow spreading disease, decreasing the costs of animal testing changes surveillance/screening systems from inefficient to efficient at high levels of outbreak likelihood. If variable testing costs were decreased hundredfold, then the number of annual tests in case of slow disease spread goes from 0 to 6 (Figure 2). In the case of fast disease spread, the results are more illustrative. 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 (Figure 2).

Next we investigated the effect of response effectiveness, ancillary benefits, herd size, and effectiveness of recovery activities on adoption of testing and screening. We 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 slightly decreases the number of annual animal health tests.

Investing in surveillance systems for detection of FMD could have ancillary benefits in terms of facilitating other animal health and management activities. Testing could also facilitate keeping inventory of farm animals in the region, which could be of benefit to researchers and policy makers. To examine this possibility we ran the scenarios with the fixed costs of testing decreased by $50 per herd. It was found that under slow spread scenarios lowering fixed costs affected the outbreak probability at which it was optimal to start investing in surveillance systems. For example, 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 higher variable costs of testing. However, for fast spread scenarios, 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.

Optimal number of annual animal tests was also affected by the average herd size and effectiveness of recovery activities, which are activated after the event takes place and are intended to minimize the market effects of an outbreak. After changing the current average herd size of 50 to 400, 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. Effects of recovery activities were examined by decreasing lost gross income per infected animal by 30%. 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. This implies that cattle value losses avoided by detection are large enough to justify use of detection and surveillance even under substantial recovery program.

Although ex ante and ex post measures do not necessarily preclude one-another, they act as 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 under 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.

Economic costs of potential agricultural sabotage, in the form of FMD outbreak, and various mitigation strategies were calculated in terms of expected monetary 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 3**.** Losses varied from around \$60,000 to around \$280,000,000 depending on outbreak likelihood, spread rate, and mitigation strategy. Under fast spread scenarios, the economic losses are significantly higher than under slow spread. 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 had a minor effect on decreasing the losses.

Figure 4 shows expected losses as a percentage of total monetary worth of regional Texas cattle industry under the possibility of fast spreading FMD outbreak with surveillance and detection system in place. The value of cattle industry was supposed to consist of monetary values of live animals and annual gross revenues generated by those animals. Hence, losses calculated in this work provide a lower bound of potential losses from a possible FMD outbreak since they do not include losses in trade or consumer surplus. Under such calculations, losses from a potential FMD outbreak reached almost 2% of total cattle industry's economic worth under high probabilities of outbreak when surveillance and detection systems were adopted. The losses with active surveillance and detection system are considerably lower than losses under no surveillance and detection system. Up to 70% of Texas cattle industry value could be lost under no surveillance and detection. Response action, consisting of slaughtering only infected and contact herds, was the only mitigation policy in such scenario.

Conclusions

The goal of this work was to evaluate the optimality of adopting ex ante versus ex post mitigation actions to fight possible agricultural terrorism event. Aspects such as event likelihood and severity, along with costs and effectiveness of mitigation options were considered as they influence optimal combination of ex ante and ex post actions. Using utility maximization approach we formulated the framework where utility of wealth is maximized by minimizing the damages and costs associated with possible agricultural contamination and mitigation activities respectively. Theoretical analysis showed that under risk neutrality or risk aversion and convexity of damage function with respect to ex ante actions, the use of ex ante actions increases with event severity and likelihood, reduction in costs of ex ante actions and increase in costs of ex post actions.

The empirical model is based on minimizing probabilistic weighted costs of potential FMD outbreak and associated ex ante and ex post mitigation measures. We investigated ex ante cattle screening and ex post responsive cattle slaughter in light of potential FMD outbreak in a region such as Texas. A cost minimizing model was developed that traded 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. 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. Damages considered here include loss of cattle values and loss of gross income. Periodic testing and screening of cattle as means to detect potential infection before the appearance of clinical signs was considered as an ex ante mitigation option. This strategy is adopted prior to a realization of an outbreak and thus introduces costs that are incurred regardless of whether or not an outbreak occurs. Slaughter of infected herds and direct contact herds corresponding to Schoenbaum and Disney was considered as an ex post measure, which is activated only in case of disease introduction.

The results suggest that the optimal combination of preventative and responsive strategies depends on such factors as disease spread rate, strategy effectiveness, likelihood of disease introduction, and costs of mitigation strategies. It was found that investment in ex ante surveillance increases with increased likelihood of disease introduction, reduced costs of surveillance, increased disease spread rate, decreased response effectiveness, and increased average herd size.

The empirical results of this work 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. Although exponential diseases spread was also investigated in this work and the results were compatible with those of RF spread, true spread mechanics could be different from those considered in this study. Moreover, since the exact rate of disease spread is not known, the model was analyzed under slow and fast spread rates based on Schoenbaum and Disney (p. 28) and Bates et al., (2001 p. 1121). 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 ex ante and ex post activities will stay the same.

The damages considered in this investigation include lost value of infected and slaughtered cattle and associated lost 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, ex ante strategies may be even more advantageous than reported in this study. Even though the results of empirical investigation reported in this article are contingent on the assumptions made regarding the disease spread and the simplifications made regarding the damages of outbreak and benefits of mitigation strategies, the results shed some light on broad disease management approaches. Effectiveness of ex ante actions seem to depend on various context attributes such as likelihood and severity of potential agricultural terrorism event, costs and effectiveness of ex ante and ex post mitigation strategies, and ancillary benefit of those strategies.

Footnotes

[1] Exponential spread was also considered where $D(t) = e^{\beta t} = e^{\beta \frac{365}{N+1}}$ (Anderson and May).

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.

Anderson R., and R. May, "Infectious Diseases of Humans: Dynamics and Control." Oxford University Press, New York, 1991

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, "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, 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, 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.

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

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.

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.

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

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.

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.

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.

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.

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.

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.

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.

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.

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.

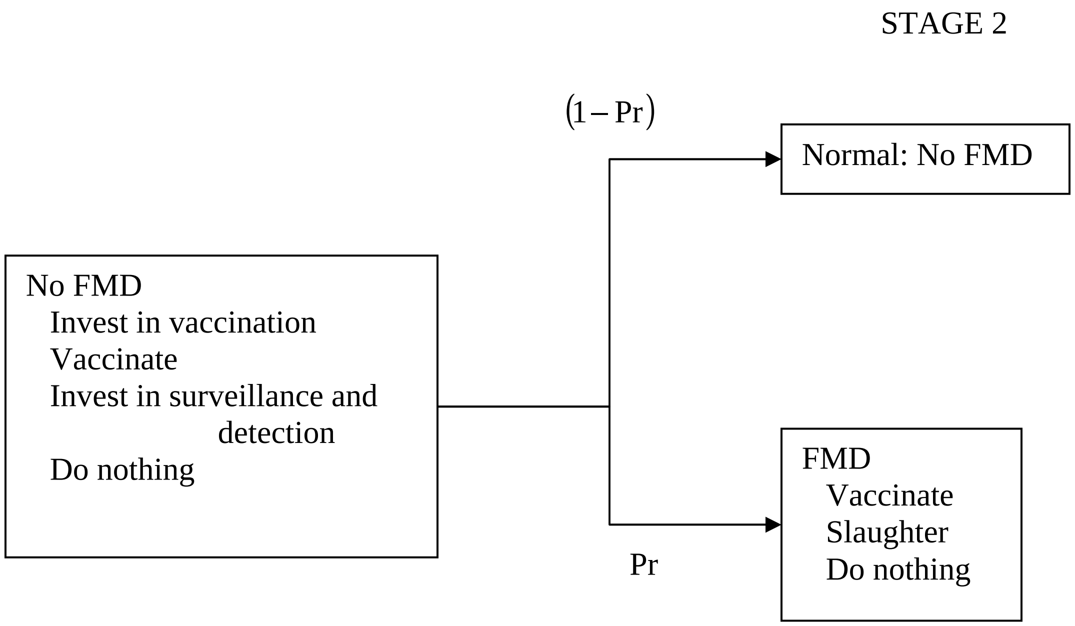
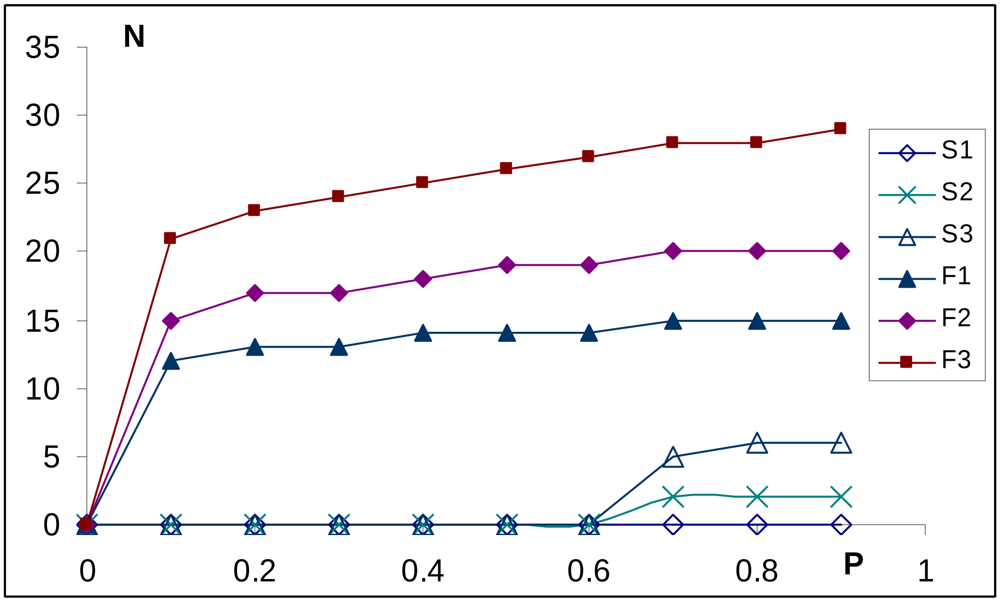


Figure 1. Stages of decision support tool



S1 – Slow Spread, Full Variable Costs (FVC)

S2 – Slow Spread, Variable Costs = 0.1FVC

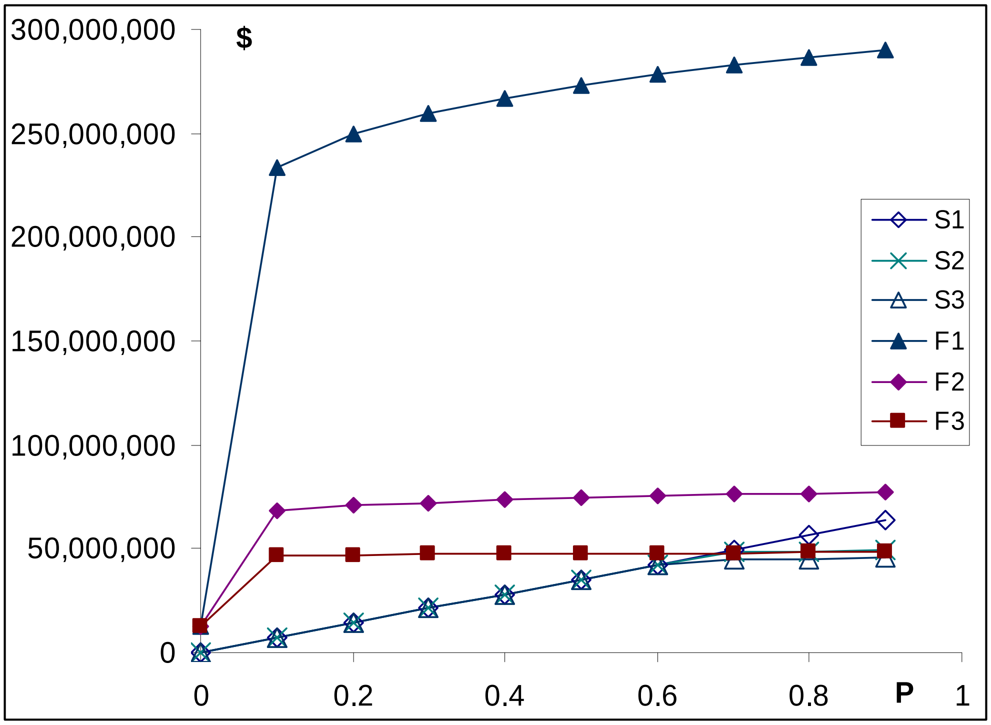
S3 – Slow Spread, Variable Costs = 0.01FVC

F1 – Fast Spread, Full Variable Costs

F2 – Fast Spread, Variable Costs = 0.1FVC

F3 – Fast Spread, Variable Costs = 0.01FVC

Figure 2. Number of annual tests under slow and fast spreads with various costs.



S1 – Slow Spread, Full Variable Costs (FVC)

S2 – Slow Spread, Variable Costs = 0.1FVC

S3 – Slow Spread, Variable Costs = 0.01FVC

F1 – Fast Spread, Full Variable Costs

F2 – Fast Spread, Variable Costs = 0.1FVC

F3 – Fast Spread, Variable Costs = 0.01FVC

Figure 3. Economic losses under slow and fast spread

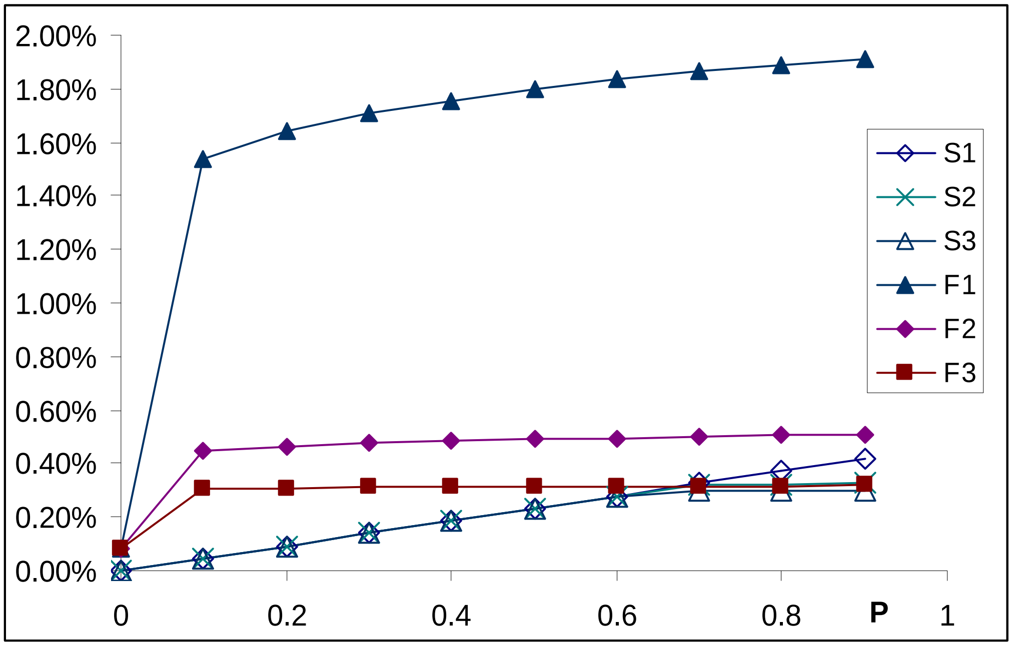


Figure 4. Proportion of cattle industry's monetary value lost under slow and fast spread with surveillance and detection