Economic Modeling of Optimal Mitigation Strategies for Animal Related Biodefense Policies

Levan Elbakidze
Bruce A. McCarl
Texas A&M University
Department of Agricultural Economics
National Center for Foreign Animal and Zoonotic Disease Defense

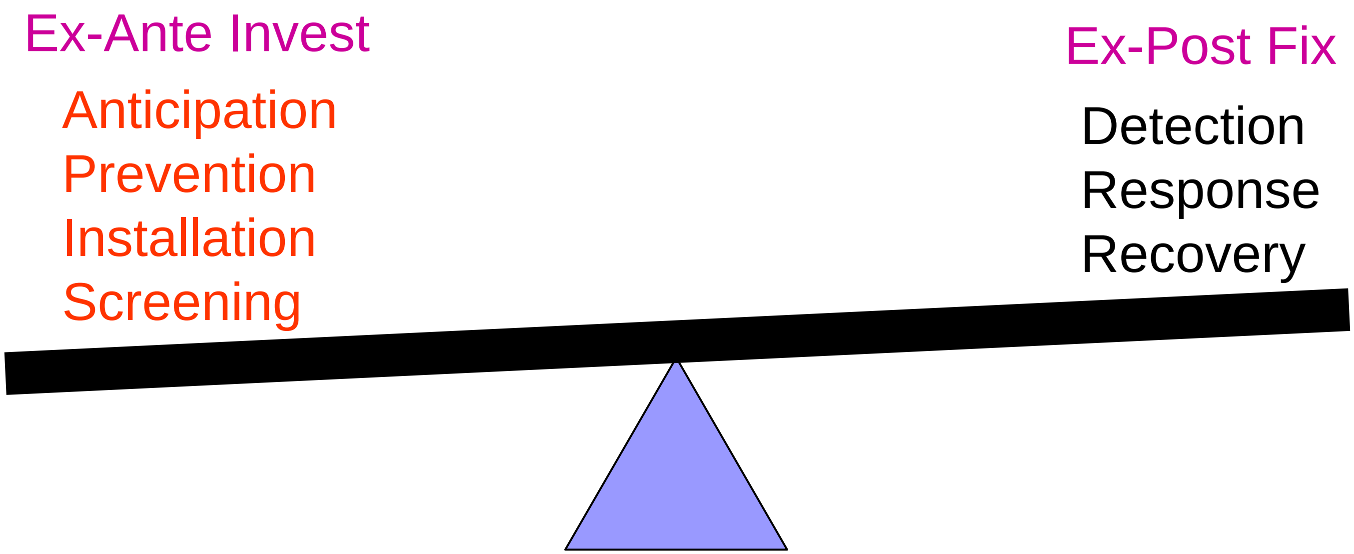
This research was supported by the Texas A&M University based National Center for Foreign Animal and Zoonotic Disease Defense (FAZDD) that was established by the Department of Homeland Security. However, views expressed are those of the authors and do not necessarily represent those of the FAZDD. All remaining errors are the authors.

Basic Components of Talk

- The economic problem
- Some theoretical deductions - hypotheses
- Conceptual modeling
- A simplistic first cut
- Broader project efforts

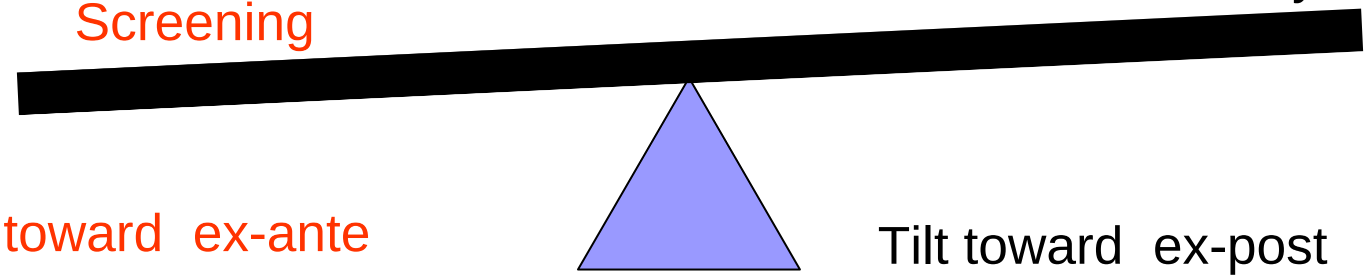
The Economic Problem

- Anticipation, prevention, detection, response and recovery all take money, much of which is spent in the absence of an event. So how do we
  - Form best investment strategies considering cost, disease vulnerability, risk, and event characteristics?
  - Best respond to an event?
  - Assess effects on markets?
  - Manage market information to minimize impacts?



H_0: Tilting Factors

Ex-Ante Invest	Ex-Post Fix
Anticipation	Detection
Prevention	Response
Installation	Recovery
Screening	



Tilt toward ex-ante	Tilt toward ex-post
Event is more likely	Event is less likely
Ex-ante Activity has multi benefits	Ex-ante Activity is single purpose
Ex-ante Activity is more effective	Ex-ante Activity is less effective
Ex-ante Activity is cheaper	Ex-ante Activity is expensive
Ex-post treatment more costly	Ex-post treatment less costly
Fast spreading disease	Slow spreading disease
More valuable target	Less valuable target
Big demand shift -- health	Little demand shift -- health

Background: Is the Problem a New One?

- No, has many well known variants
  - Food Quality/Safety from contaminants
  - Invasive species
  - Veterinary disease control
  - Water management and impoundment construction
  - Farmer machinery investment, crop mix
  - Inventory theory, quality control, waiting line design
  - Capital budgeting

- But with added features of deliberate actions at max points of vulnerability. Not an accident.
- All involve ex ante decisions but the ex post consequences occur only when event occurs - probabilistic

Project Goals

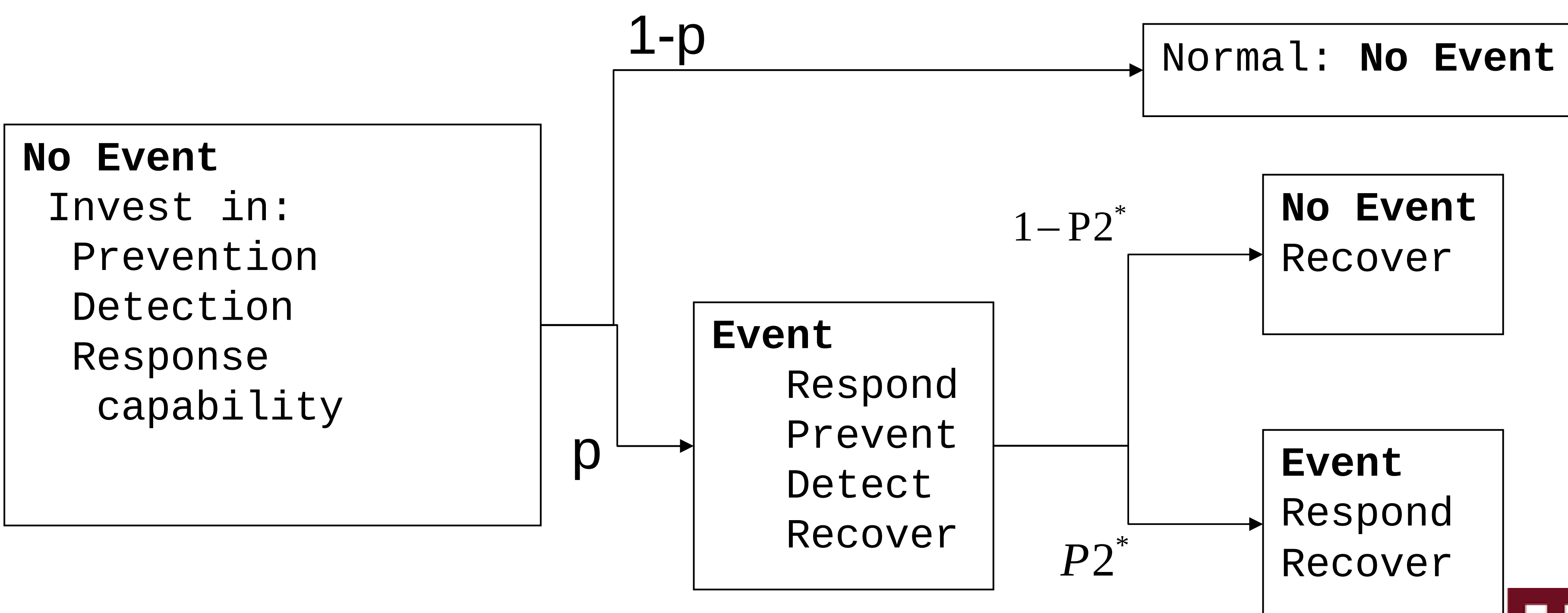
- Examine the optimal economic allocation of portfolio of anticipation, prevention, detection, response and recovery actions
- Look at event characteristics (disease spread and economic damage consequences) under which strategies dominate
- Evaluate anticipation, prevention, detection, response and recovery strategy alternatives in a value of research or technology adoption context
- Look at market effects and recovery enhancement strategies
- Educate on economic principles

Analytic Conceptualization: Three Stages

STAGE 1
Pre Event

STAGE 2
Possible Event

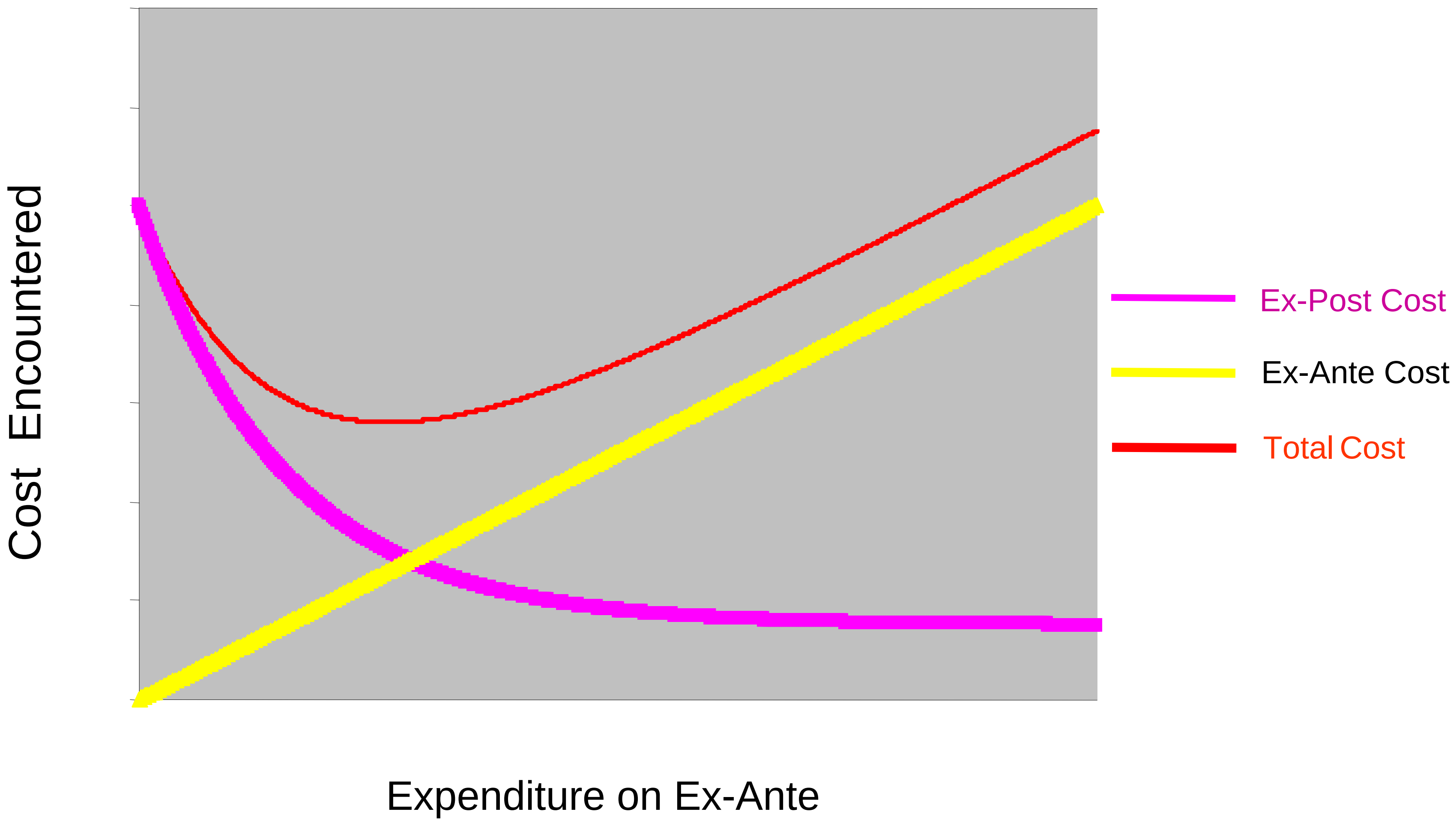
STAGE 3
National and Local Management Decisions



Analytic Conceptualization

- Major elements
  - Irreversibility – cannot instantly install investments when an event occurs
  - Conditional response depending on investments
  - Fixed cost versus infrequent occurring events
  - Income depends on event and there is a large span of possible events
  - Tradeoff between ex ante investment cost and occasional ex post event needs and associated costs
  - Best strategy depends on investment cost, operating cost and probability

Analytic Conceptualization



Simple Example of model

Suppose we have the following decision. Today we can invest in a facility which costs $10 and protects 10 units. During the facility life we use it under differing price, and yield events that are uncertain. We have 200 units to protect. Two projected futures exist. At the time we use the facilities we know the conditions. Two states of nature can occur

	Price	Yield with invest	Yield w/o invest	Probability
No event	**4**	**1.2**	**1.1**	**(1-pr)**
Event	**3**	**0.9**	**0.1**	**pr**

Simple Example of model

Problem will have 2 stages

Stage 1 **Investment stage when we choose whether to construct facility for which we define a single variable Y**

Stage 2 **Operation stage when we use facility and know prices, and yield which results in variable to operate with (I) or without (NI) the investment under each state of nature (the 4 variables X)**

Simple Example of model

$$\text{Max } -10Y+(1-pr)*4(1.9*X_{1,I}+1.8*X_{1,NI})+prob*3(1.9*X_{2,I}+0.1*X_{2,NI})$$

$$\begin{array}{llllll}
\text{s.t.} & -10Y & +X_{1,I} & & & \leq 0 \\
& & +X_{1,I} & +X_{1,NI} & & \leq 200 \\
& -10Y & & & +X_{2,I} & \leq 0 \\
& & & & +X_{2,I} \quad +X_{2,NI} & \leq 200 \\
& X,Y \geq 0 & & & &
\end{array}$$

Result Y=20 (invest in facility) if prob ≥ 0.119

Very Simplistic Case study

- Impact of prevention and treatment strategies in FMD setting
- Region Texas
- Unknown probability
- Investigate adoption of
  - Ex-ante periodic animal examinations
  - Ex-post ring slaughter of affected animals as a treatment strategy
- Look at expenditure balance as influenced by
  - Probability level
  - Spread rate
  - Costs of implementation
  - Effectiveness of response
  - Recovery programs

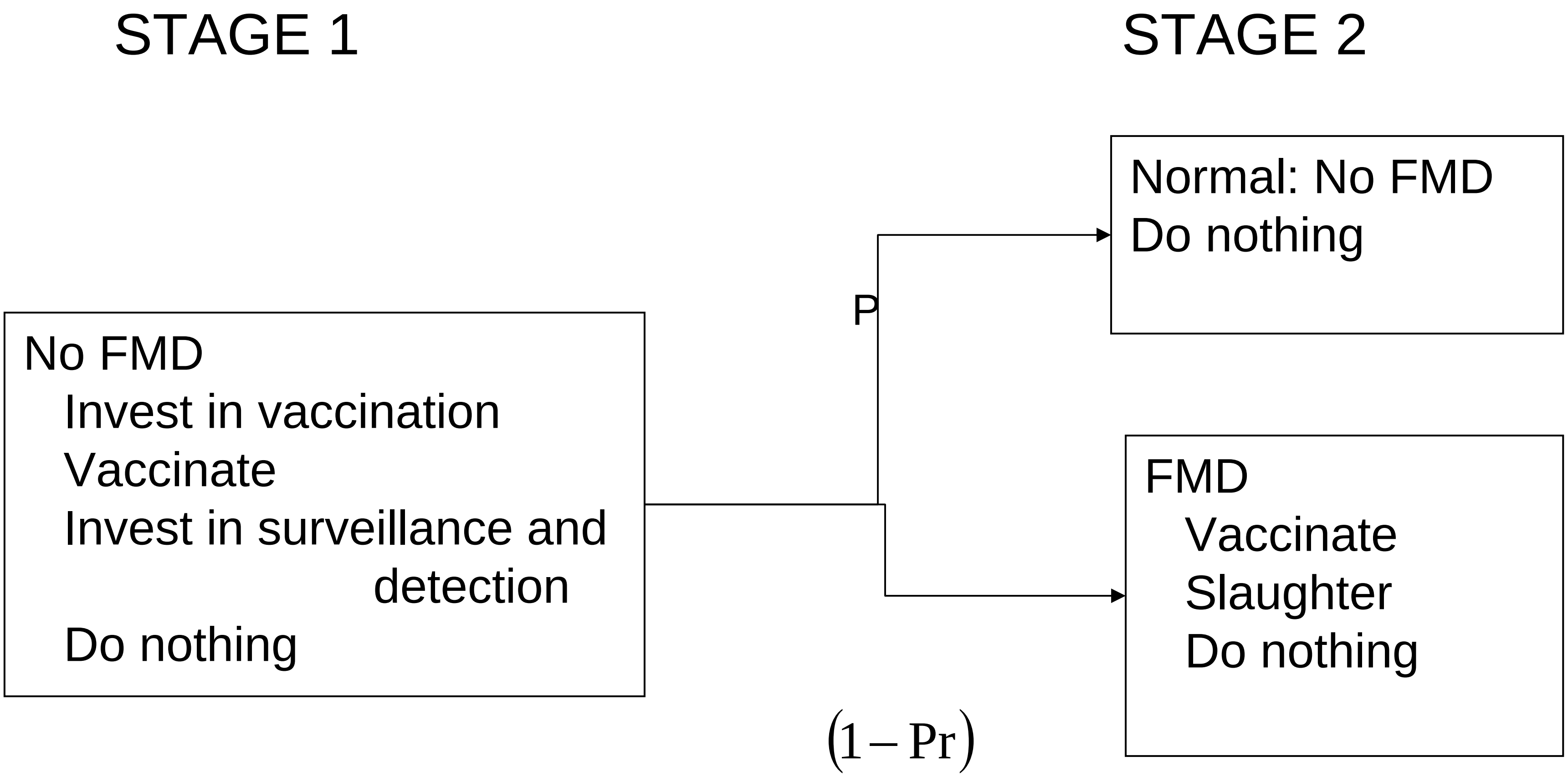
FMD mitigation options

- Vaccination (Schoenbaum and Disney 2003, Carpenter and/or Bates, Ferguson 2001,Berentsen 1992, etc.)
- Slaughter (Schoenbaum and Disney 2003, Carpenter and/or Bates, Ferguson 2001,Berentsen 1992, etc.)
- Movement Ban (Ferguson 2001)
- Surveillance and Detection (McCauley et al. 1979)
- Monitoring imports (McCauley et al. 1979)
- Monitoring travel
- Tracing
- Recovery/information (Ryan et al. 1987)

Formation of Animal Disease Management System

- Prevention -- systems where there are actions undertaken to try to avoid disease introduction
- Detection -- systems designed to screen animals to detect disease early to allow more rapid treatment and much lower spread than would otherwise be the case
- Response – systems which involve actions to stop the spread and ultimately eradicate the disease and to avoid further economic losses.
- Recovery -- systems put in place to restore lost assets or demand shifts due to introduction of animal disease

Simpler Example -Two Stages



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

P – Probability of outbreak

L(N,R) - losses associated with prevention, response and occurrence of potential FMD outbreak.

N - number of tests performed annually on cattle in the region.

R - response activities in the state of nature where outbreak occurs.

Y - binary variable representing investment in surveillance system.

CR - costs of response activities

FTC - fixed testing costs

VTC - variable testing costs.

H(R) – response effectiveness function. proportion of animals lost in case of an outbreak under various levels of response actions

D(t) - is the disease spread function expressed in terms of days that the disease is allowed to spread before detection.

V – Value of losses per infected herd

t – Maximum number of days disease is undetected, 365/(N+1)

Assumptions

- Cost minimization of ex-ante costs plus probabilistic weighted cost of response.
- Response effectiveness
  - Slaughter (Schoenbaum and Disney, 2003)
  - Convexity
- Disease spread
  - Exponential (Anderson and May, 1991)and Reed-Frost (Carpenter et al. 2004)
  - Fast (0.4) and slow (0.15) contact rates (Schoenbaum and Disney, 2003)

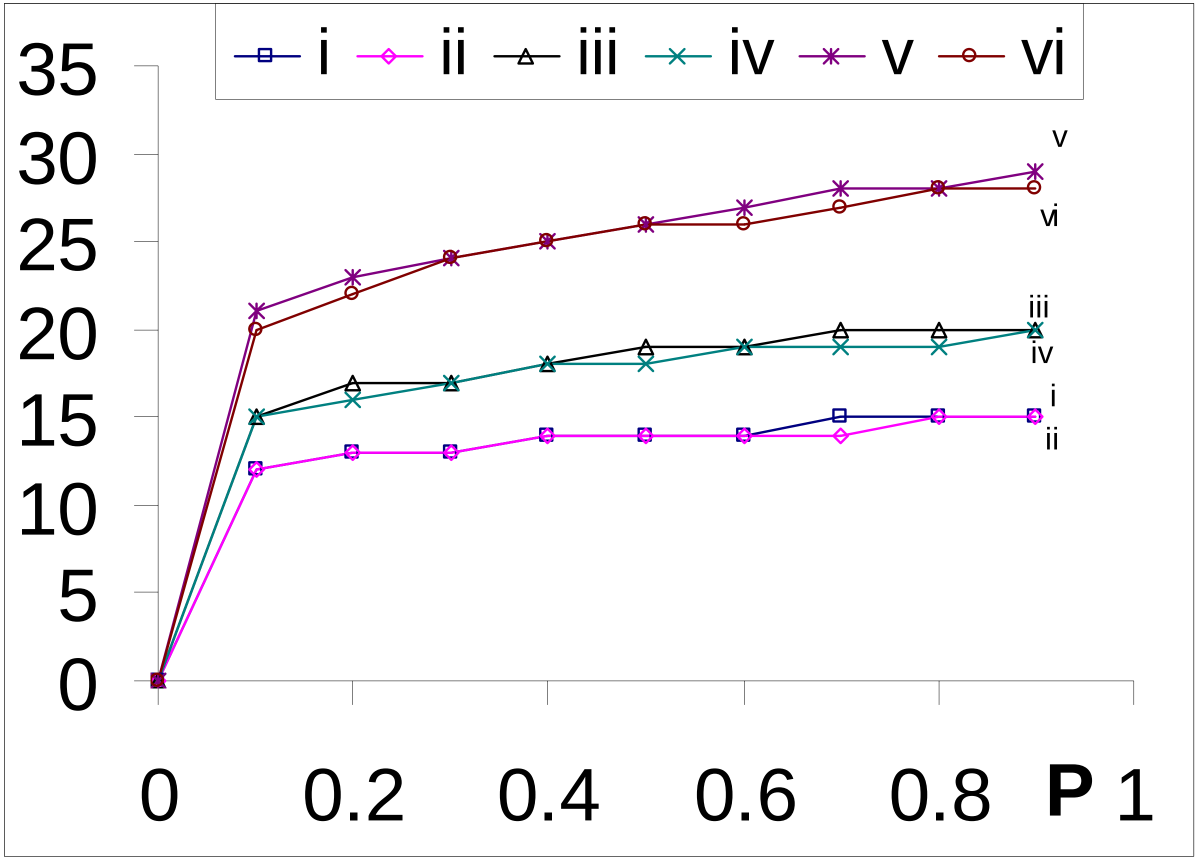
Source: Elbakidze, Levan, *Agricultural Bio-Security as an Economic Problem: An Investigation for the Case of Foot and Mouth Disease, In process PhD Thesis,* Department of Agricultural Economics, Texas A&M University, 2004.

Model Experimentation

- Event levels: Probability 0.001 – 0.9
- Severity or spread rate: slow vs. fast
- Response effectiveness: 17% - 30%
- Variable costs of detection 0.1TVC, 0.01VTC
- Average herd size: 50 to 400.
- Ancillary benefits: FTC-$50 per herd
- Recovery actions: decrease loss of GI per animal by 30%

Results

Event probability, Response effectiveness, VTC costs

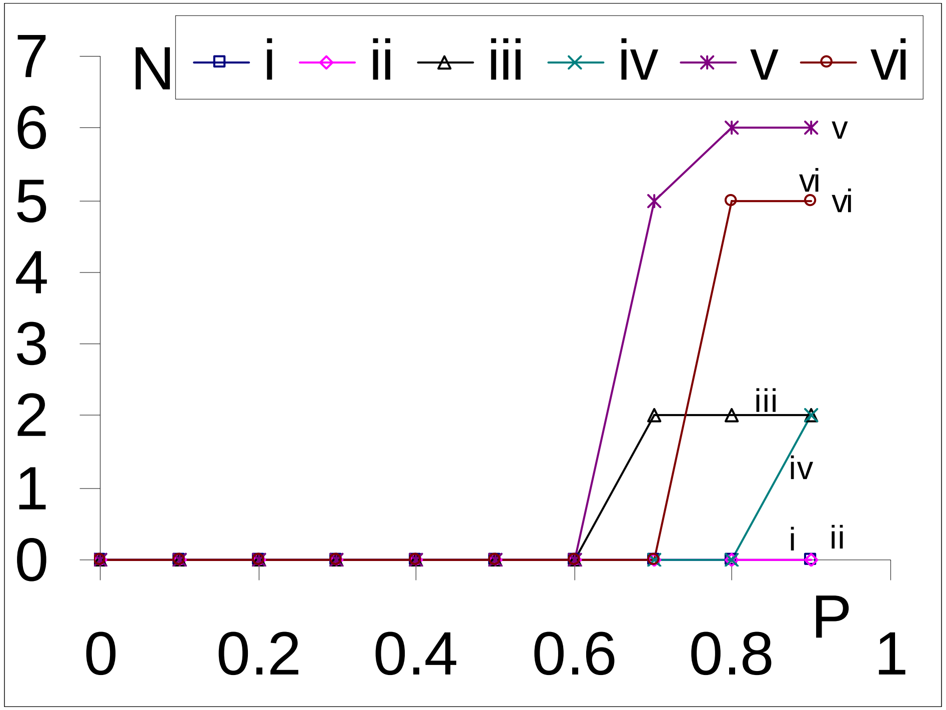


RF

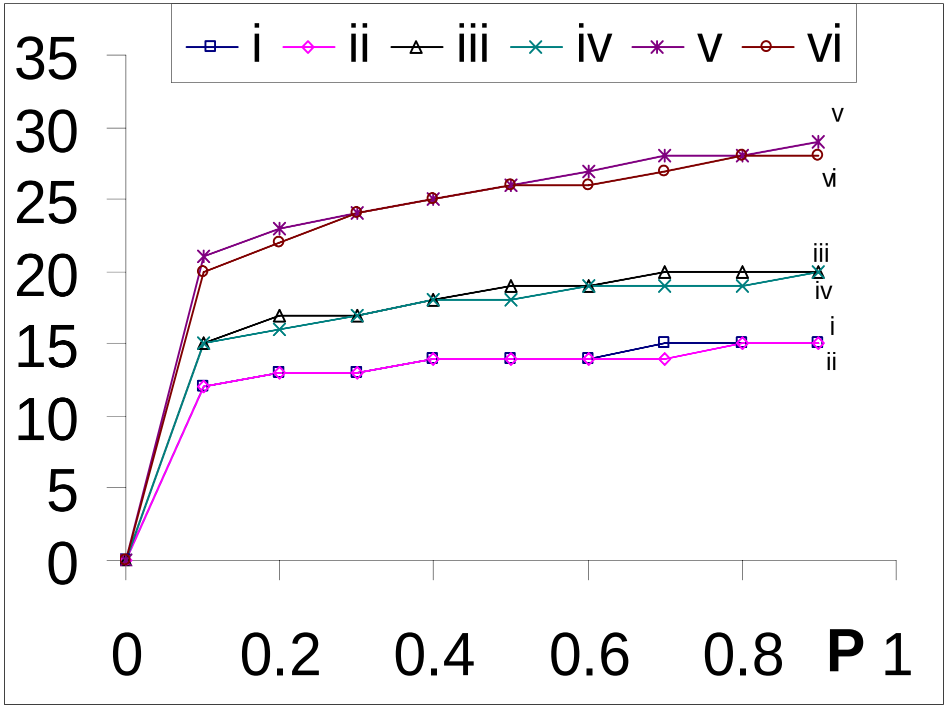
i – Full variable Costs (VC), Response Effectiveness (RE)=0.17
ii – VC, RE =0.3
iii – 0.1VC, RE=0.17
iv – 0.1VC, RE=0.3
v – 0.01VC, RE=0.17
vi – 0.01VC, RE=0.3

Spread Rate

Slow RF



Fast RF

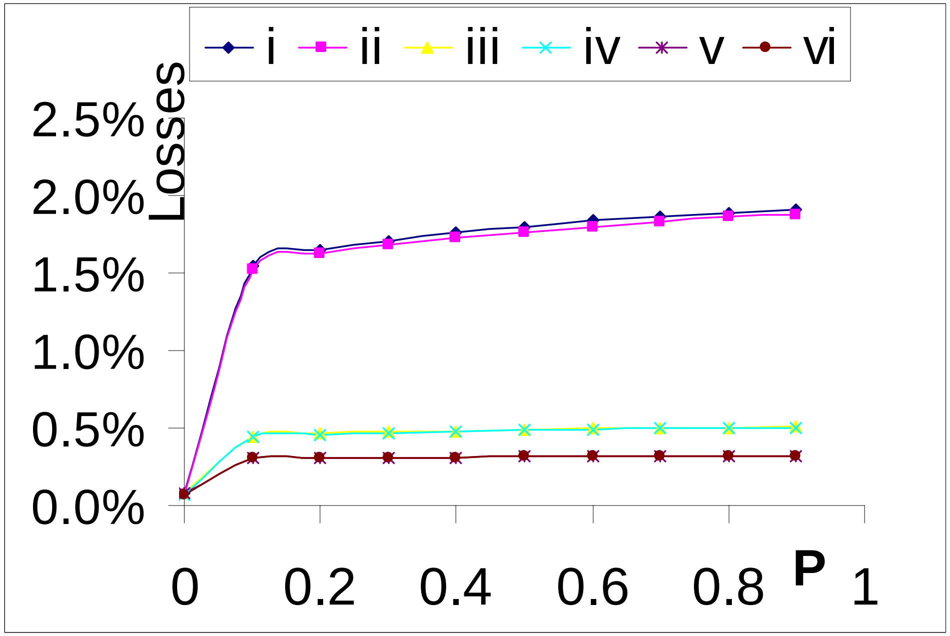


i – Full variable Costs (VC), Response Effectiveness (RE)=0.17
ii – VC, RE =0.3
iii – 0.1VC, RE=0.17
iv – 0.1VC, RE=0.3
v – 0.01VC, RE=0.17
vi – 0.01VC, RE=0.3

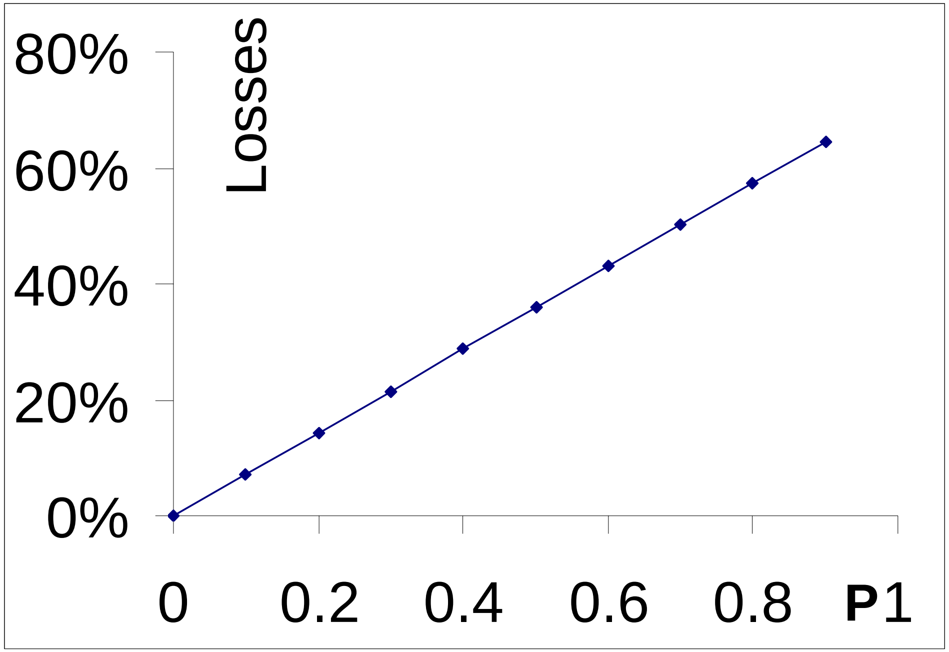
- Herd Size
  - Increasing herd size from 50 to 400
    - increase # of tests. Reached 39 for fast spread.
- Ancillary benefits
  - Decrease FTC by $50 per herd
    - No change in # of tests
    - Lower the probability of adoption in slow spreads
- Recovery actions
  - Decrease in losses of GI per animal by 30%
    - Did not have a noticeable effect on surveillance intensity.

Costs of an outbreak with and without ex ante action

With detection



Without detection, Only response



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

Hypotheses / Deductions

- The best investment/management strategy
- For slow spreading attacks addressed at low-valued targets with low consumer sensitivity would focus investment more on response and recovery.
- For rapid spreading attacks addressed at high valued targets with high consumer sensitivity items would focus more on prevention, rapid detection and rapid response (for example hoof and mouth).
- Would favor alternatives with value both under terrorism events and normal operations as opposed to single event oriented strategies (for example a comprehensive testing strategy that would also catch routine animal diseases).

Conclusions

- Investigated relationship between detection (prevention) and slaughter (response) strategy.

  - effort in a priori surveillance increases with threat level, cost reductions in surveillance, with disease spread rate, lower degree of effectiveness in response, and average herd size

- Estimates of lower bounds of losses due to FMD outbreak. Trade, consumer scare, other industries not considered.

Conclusions

- Caution: functional forms, parameters, cost estimates.

- Future:
  - Explicitly include vaccination, recovery,
  - Disaggregate to localized strategies
    - Cooperation/non-cooperation
  - Include Risk Aversion
  - Link to epidemiology model

Future Work: Items of Economic Concern

Animal categories

- Unaffected
- Euthanized
- Dead from disease
- Impaired by disease
- Vaccinated

Affected animal disposal

- Market value and use
- Carcass disposal

Investment study

- Strategy costing
- Risk distribution
- Fixed vs event specific costs

Markets

- Information management and demand
- Dynamic response
- Demand suppression

Policy design

- Cooperation
- Ex ante -- ex post balance

Future work: link to epidemiology

- An economic model linked to epidemiologic model
  - Multiple types of outbreaks
    - Event occurrence and severity
    - Consistency across strategies for comparison
  - Broader mix of strategies
  - Multiple vs. single purpose strategies
  - Risk aversion
    - Effects on optimal mix of strategies
  - Possibly three stage formulation
    - Localized decision making

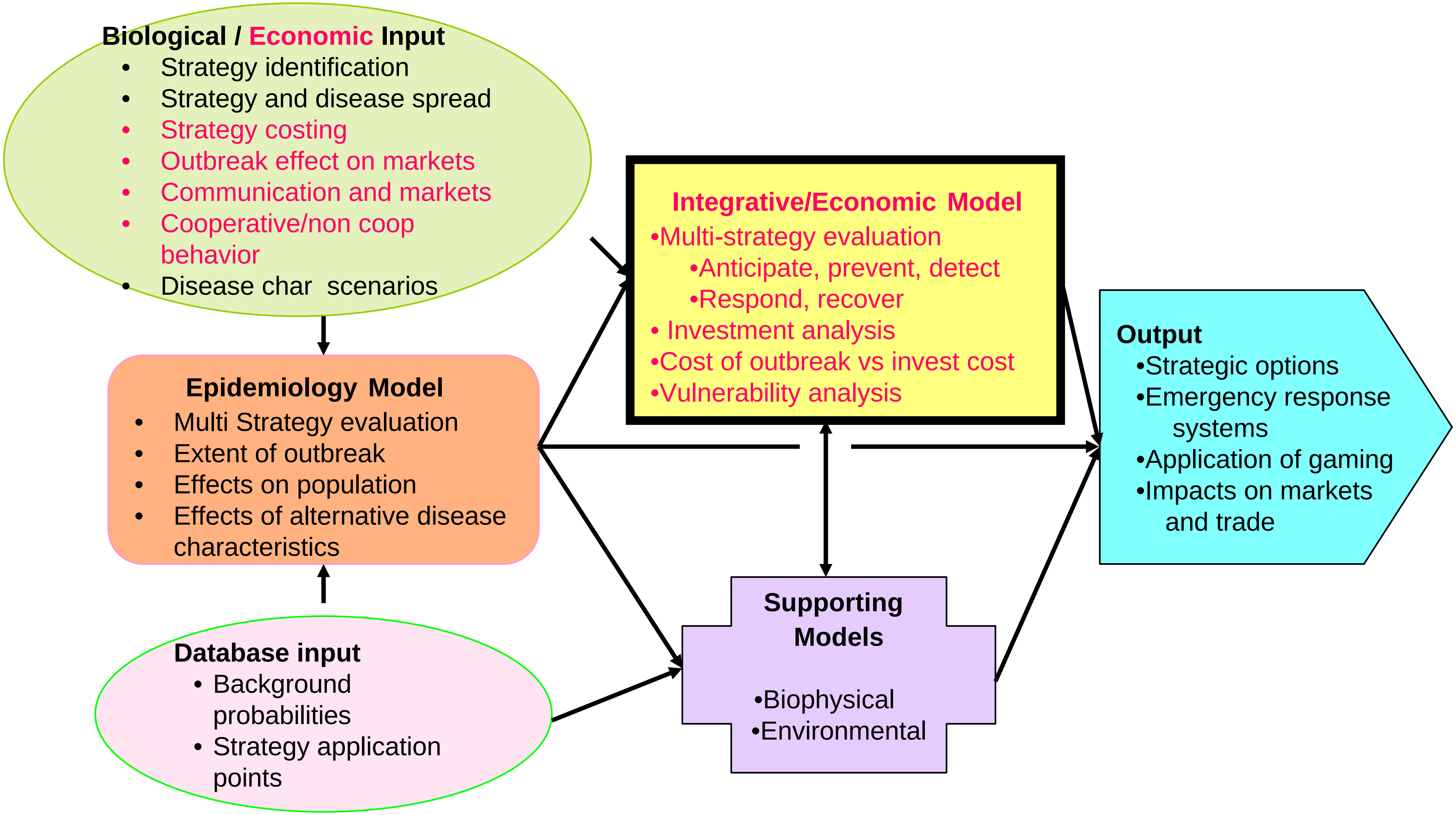
Data from Epidemiology

- $N_{(r)}(s,k,i,j,h)$
  - s – State of nature
  - k - region
  - i - vaccinated, dead, infected, preventatively slaughtered, unaffected,
  - j - stage along supply chain: cow/calf, stocker, feed yard.
  - h - mitigation strategy
  - t - days
  - r – random trial

Type of outbreak	Region	Farm Operation	Animal Health	Mitigation Strategy				
				h1	h2	h3	…	hn
S1	K1	Feedlots	Vaccinated	N	N	N	N	N
			Slaughtered	N	N	N	N	N
			Unaffected	N	N	N	N	N
			Dead	N	N	N	N	N
			⋮	⋮	⋮	⋮	⋮	⋮
		Stockers						
			⋮	⋮	⋮	⋮	⋮	⋮
		Cow/calf						
			⋮	⋮	⋮	⋮	⋮	⋮
	K2							
		⋮	⋮	⋮	⋮	⋮	⋮	⋮

* N is either a probability distribution across randomized trials, or there needs to be a table of the above form for each random trial.

More General Modeling Conceptualization



Red areas are economists playground

Expands on existing regional, trade and national modeling (ASM)

Modeling Conceptualization

- Big elements
  - Multi disciplinary study
    - Domain experts, Veterinarians, Epidemiologists, Information technologists, Economists …
  - Ties together a number of models
  - Designed for insights not numbers
  - Will run backwards to see what characteristics of diseases and event probabilities merit what types of strategies

Contemplated Studies

- Vulnerability / risk assessment
  - Effects of events without new strategies
  - Cost of waiting in detection
  - Attack scope and costs thereof
- Component strategy evaluations
  - Anticipation
  - Prevention
  - Detection
  - Response
  - Recovery
- Investment / strategy mix study
  - Strategy use
  - Effects of disease characteristics
  - Event probability that mandates actions
  - Event specific vs multi outcome strategy value
  - Risk / investment assessment
- Other
  - Recovery information management
  - Carcass disposal
  - Policy design and cooperative behavior

Plans

- Economists will participate in multidisciplinary efforts directed toward:
  - Development of modeling approaches simulating events and consequences of strategy use to facilitate event planning and overall agri-food terrorism management approaches.
  - Construction of a threat simulation gaming environment that can be used in training decision makers, responders and industry members.

Plans

Economists will participate in multidisciplinary efforts:

- **Examination of possible events assessing costs/losses and identifying key sources of vulnerability**
- **Study of optimal investment patterns across prevention, detection, response and recovery to see how "best" total threat management is altered by threat characteristics.**
- **Investigation of the consequences of different management strategies for prevention, detection, response and recovery investments and operating rules.**
  - **Managing information to facilitate faster recovery.**
  - **Size of circles of treatment surrounding event – how far out to euthanize, vaccinate, quarantine, test etc.**
  - **Compensation schemes to facilitate compliance and discourage concealment.**