AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

A Model of Incentive Compatibility under Moral Hazard in Livestock Disease Outbreak Response

Ben Gramig,
Richard Horan,
and
Christopher Wolf
Michigan State University

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

Copyright 2005 by Gramig, Horan and Wolf. All rights reserved. Readers may make verbatim copies of this document for non-commercial purposes by any means, provided that this copyright notice appears on such copies.

A Model of Incentive Compatibility under Moral Hazard in Livestock Disease Outbreak Response

The outbreak of disease in domestic livestock herds is an economic and potential human health risk that involves both the government and individual livestock producers. Economic justifications for public intervention in disease control include externalities, public good aspects, coordination failures, information failures, and income distribution considerations (Ramsay, Philip and Riethmuller). The potential to pose a large economic cost depends on many factors including trade laws and level of infectiousness. Public policies range from bounties for infected livestock to required herd depopulation and farm decontamination. The United States Department of Agriculture´s Animal and Plant Health Inspection Service (APHIS) provides inspection and quarantine services to prevent the introduction of disease across national borders and also coordinates response to disease outbreaks that originate from within the country. Border measures that protect against incursion of disease are provided to protect the safety of the American food production system and to prevent infection of the domestic livestock industry.

Diseases not endemic to or currently present in the U.S. are typically not accounted for in everyday farm biosecurity measures because their risk of occurrence is viewed as exogenous to individual farm-level decision making. Diseases that are highly contagious or have human health implications are often the target of government eradication programs. When livestock is taken by the government for public health or economic reasons, the Fifth Amendment of the US Constitution specifies that private property taken for public use must receive just compensation. This compensation takes the form of indemnity payments. The current federal compensation level is defined by the Animal Health Protection Act, Subtitle E of the Farm Security and Rural Investment Act of 2002 which states that compensation shall be based on the fair market value,

as determined by the Secretary of Agriculture, adjusted for any other compensation received for that event (i.e., disaster payments). States may also offer compensation in the form of indemnities.

Livestock taken for disease control or eradication reasons also results in consequential losses on the affected farms (which might include surrounding farms or related industries). These consequential losses include business interruption, lost market access, lost genetic stock, and increased surveillance and testing costs (Grannis and Bruch). Other government programs may be used to assist farms with the consequential losses. These include low interest emergency loans from the US Department of Agriculture Farm Service Agency or even disaster payments from the Federal Emergency Management Agency (Grannis and Bruch). There is also much recent talk about the potential for livestock disease insurance. However, indemnity payments are the primary form of compensation based on the livestock removed from the operation. The indemnity as it is currently used is designed to pay for assets taken by the government and encourage reporting of disease (Ott). The indemnity payments for diseased livestock represent an implicit insurance policy for livestock producers with respect to the diseases where they are applicable. Government indemnities must be designed with careful attention to the private incentives they create and the public objectives of livestock disease risk management. The current system to determine payment amounts largely ignores the issue of incentive compatibility.

Previous economic research dealing with livestock disease eradication and outbreak has examined producer response to prices in conjunction with government indemnity programs for scrapies in the U.S. (Kuchler and Hamm), optimal actions to contain Foot and Mouth Disease outbreak in France (Mahul and Gohin), the effect of government programs to eradicate disease

on prevalence level and private control efforts in New Zealand (Bicknell, Wilen and Howitt), and the dynamics of optimally controlling infection from a disease which is transmitted between wildlife and livestock (Horan and Wolf). The current paper uses a principal-agent model to examine incentive compatibility in the presence of information asymmetry between the government and individual farmers. A less formal discussion of these issues may be found in Gramig et al. (2005). Prior models of livestock disease have not incorporated this asymmetry. We investigate the role of incentives in producer behavior that influences the duration and magnitude of a disease epidemic. Our focus is on farm level biosecurity choices and disclosure of disease status.

Individuals have private information about preventive biosecurity measures in place on their farms prior to outbreak (*ex ante*), and following outbreak (*ex post*) they possess private information about the disease status of their herd. We first address the *ex post* case because once uncertainty about the occurrence of an outbreak is resolved, regardless of the *ex ante* actions taken by producers, disclosure of disease status (as opposed to discovery by another party through transmission, slaughter, or testing) is required for timely government response to limit the spread of infectious disease and eradicate it. The length of time between outbreak and discovery is very important in determining the duration and severity of epidemic (UN-FAO). For these reasons, an incentive structure that results in truthful disclosure of disease status is of great interest for a social planner. Second, we investigate the design of *ex ante* incentives for biosecurity along with incentives for *ex post* truthful disclosure. The characteristics of an incentive compatibile indemnity rule are derived for the case of a risk averse agent (the farmer) and a risk neutral principal (government agency). Implications of the theoretical model results for public policy and market insurance design are considered and conclusions are offered.

A Model of Ex Post Moral Hazard

Consider a simple model of a single, risk-averse farmer with a livestock herd at risk of contracting a disease. The farmer's indirect utility function is defined as $V(\pi)$ ($V'>0$, $V''<0$), where π represents profits. If the herd is not infected, then $\pi = \pi_0$, where π_0 represents a constant, deterministic value. The farmer suffers regulatory or disease related losses in the event of a disease outbreak, but he may also qualify for government provided indemnity payments. For now, we assume there are no externalities associated with the disease—that is, the infection cannot be spread to other herds, and there are no regulatory or pecuniary externalities associated with regional or national trade bans and/or quarantines. Rather, all losses only accrue to the farmer with the infected herd.

We assume that the farmer knows the true disease prevalence rate in his herd, $\theta \in [0,1]$, but that the regulator does not know θ without testing or disclosure by the farmer. If a herd is infected, then profits depend on whether or not that farmer discloses the disease outbreak to the regulator. We assume that an infected farmer who discloses the disease will face regulatory costs and other losses, $C(\theta)$, that are non-decreasing in the disease prevalence rate, but he will be compensated (at least to some degree) with an indemnity payment, $I(\theta)$. Profits in the case of disclosure are therefore $\pi = \pi_0 + I(\theta) - C(\theta)$. In the case of non-disclosure, the farmer only incurs losses directly due to the disease, $L(\theta)$, and he is not indemnified, so that profits are $\pi = \pi_0 - L(\theta)$.

If the farmer reports an infection, the regulator will test the herd to find the true prevalence rate, and respond in a manner consistent with protocol specific to the nature of the particular disease; culling infected animals and providing an appropriate indemnity payment, for

example. Hence, a farmer who chooses to disclose will report truthfully because there are no gains from under-reporting θ. But will a farmer with infected livestock choose to disclose? Depending on the design of the indemnity payments (whether or not indemnities are inclusive of direct animal losses and consequential losses from business interruption) and the magnitude of regulatory costs, the farmer would have an incentive to withhold this information if he expects to be worse off after disclosure. Hence, a moral hazard problem exists in light of the government or policy objective of truthful disclosure of disease status. We follow the convention set forth in the literature and refer to this as an *ex post* moral hazard problem, in that the farmer already knows the true value of θ (the state of nature). In the following section, we also consider an *ex ante* moral hazard problem in which the farmer makes biosecurity choices, which are unobservable to the regulator, prior to the realization of θ.

The farmer will disclose truthfully as long as disclosure improves his utility. Since utility depends only on profits and since there is no uncertainty associated with the decision to disclose, utility will be improved as long as the profits from disclosing are not less than the profits from not disclosing

(1) $\pi_0 + I(\theta) - C(\theta) \geq \pi_0 - L(\theta)$.

Assuming the regulator is able and willing to pay enough for disclosure (but no more) and that an indifferent farmer will disclose, then the optimal indemnity payment that encourages truthful disclosure is

(2) $I(\theta) = C(\theta) - L(\theta)$.

Hence, the farmer is fully indemnified against the alternative state (i.e., that which arises under non-disclosure). This means that the optimal indemnity payment is not simply the market value

of animals that the regulator culls in response to the infection, as is the case under current APHIS guidelines, but is reduced by any losses that the farmer would incur even without disclosure. It also means that optimal indemnity payments are positive for cases where farm losses with the disease are less than the costs related to reporting (including market value and consequential losses).

Note that the indemnity payment is designed to induce truthful reporting and therefore does not require monitoring farmers who do not report incidence of disease. Rather, monitoring only occurs on infected farms in the form of testing after disclosure. This is consistent with actual policy, where any reported incidence of disease is verified by testing, and indemnities paid are based on actual prevalence and regulator response to the severity of the specific disease. Special government indemnity programs for eradication of persistent diseases are not uncommon in the United States (Kuchler and Hamm; Wolf).

Note also from (2) that total indemnity payments are not necessarily increasing in disease prevalence, but rather depend on the difference between marginal regulatory costs and marginal losses

(3) $$I'(\theta) = C'(\theta) - L'(\theta)$$

which may be positive or negative. That is, this rule designates that the indemnity payment may be increasing over some range of prevalence and declining past that prevalence. Consider a case where losses related to reporting a disease are initially greater than private losses with the disease unreported, but as prevalence increases, private losses exceed the losses from reporting (Figure 1). If (2) does not hold, as may occur when indemnities are based solely on the market value of condemned animals, (1) may never hold, or it may only hold for a subset of θ. So, for instance, there might be a threshold value of θ, denoted θ*, such that farmers report truthfully whenever θ

$\geq \theta^*$, and they are untruthful when $\theta < \theta^*$. The situation where (1) does not hold because of the structure of indemnities, forms the essence of the principal-agent problem that exists between the regulator and the farmer and it highlights the conflicting incentives at work in the agency relationship. The features of an incentive compatible contract or mechanism that avoids this pitfall are our focus.

Ex Ante and Ex Post Moral Hazard

Now consider farmer incentives to make *ex ante* investments in biosecurity that can reduce the risk of a disease outbreak. Specifically, the farmer can purchase biosecurity, b, at a per unit price of w, in order to affect the probability density of prevalence, $f(\theta,b)$, where $F(\theta,b)$ is the cumulative density function with $F_b(\theta,b) \geq 0$ – that is, F satisfies first-order stochastic dominance.[1] The farmer has private incentives to make biosecurity investments to the extent that these investments will reduce the risk of any non-indemnified losses. However, the level of investment may differ from the level that the regulator might deem to be optimal (we discuss the regulator objective function below). In that case, the regulator would want to encourage additional investment. Policy could achieve this by either subsidizing b, or by making indemnity payments contingent on b, assuming that b is observable. But the more interesting and relevant case, to which we direct our attention, is when b is unobservable.

In principle, biosecurity choices that involve capital investment, such as fencing to keep infected wildlife off the farm, are observable (although their maintenance and proper use is likely not observable), while management-based activities that contribute to biosecurity, such as

[1] Subscripts denote partial derivatives throughout. Also, the distribution is conditional on biosecurity, b, throughout. We write the distribution as $F(\theta,b)$ following Holmstrom.

quarantining potentially infected animals introduced onto the farm, are unobservable. Unobservable choices are a potential source of ex ante moral hazard. For instance, suppose $L(\theta)=0$, so that the truth-telling indemnity payment from (2) is $I(\theta) = C(\theta)$. In this case, profits are always $\pi = \pi_0 - wb$ and the farmer bears no risk of losses from infection. The government fully insures all farmers and there is no premium associated with this coverage level. Clearly, $b=0$ is the optimal farmer choice in this case. When $L(\theta)>0$, then the farmer does bear some risk and hence has some incentives to invest in biosecurity, but perhaps not enough from the regulator's perspective, given that the regulator incurs all indemnification expenses when losses arise.

It is generally understood that two policy instruments are needed to address the two moral hazard problems that exist in the current situation (Timbergen). When dealing with only the *ex post* moral hazard problem, we used indemnity payments to eliminate the problem. When dealing with both *ex post* and *ex ante* moral hazard, however, we will use indemnity payments to address the *ex ante* moral hazard problem and introduce penalties to deal with the *ex post* moral hazard problem. As described below, penalties impose more risk on the producer in the non-disclosure state and reduce the indemnity required to overcome the *ex post* moral hazard problem.

Consider applying penalties of the form $P(\theta)$ in the case that the farmer does not disclose an infected herd and is discovered. The probability of being discovered is denoted by $\alpha(\theta)$, with $\alpha_\theta>0$ so that detection is more likely for herds with a high prevalence rate. In this case, assuming that disclosure occurs under indifference, the farmer will disclose truthfully any value $\theta>0$ as long as the following condition holds

$$V(\pi_0 + I(\theta) - C(\theta) - wb) = \alpha(\theta)V(\pi_0 - L(\theta) - P(\theta) - wb) + (1-\alpha(\theta))V(\pi_0 - L(\theta) - wb) \tag{4}$$

Equation (4) represents the incentive compatibility condition in reporting disease status. Given $I(\theta)$ and $\alpha(\theta)$, the penalty function $P(\theta)$ can be set to ensure that condition (4) holds.[2] Assuming this is done, the farmer will always disclose truthfully (and hence the penalty will never actually be used, although random inspections of those who do not disclose must still be made for the penalty to be deemed credible). Moreover, the farmer knows this ex ante and will therefore choose biosecurity to maximize $E\{V(\pi_0 + I(\theta) - C(\theta) - wb)\}$, where E is the expectations operator with respect to θ.

Although the penalty is never applied, it has the desired effect—it increases the risk associated with non-disclosure so that the farmer always discloses. Additionally, because risk is increased in the non-disclosure state (right-hand side of equation (4)) and because equation (4) guarantees that the farmer is indifferent between disclosing and not disclosing, this means that the indemnity payments can be set in such a way that, *ex ante*, the farmer is exposed to more risk within the disclosure state (left-hand side of equation (4)). Indeed, from (4), it is straightforward to show that $I'(\theta) < C'(\theta) - L'(\theta)$ as long as P' is positive (or not too negative, although we expect that it would be positive). The marginal indemnity payments are reduced and the farmer is exposed to greater ex ante risk relative to the case in which only the ex post moral hazard problem arises. This increased risk creates the necessary incentives for farmers to choose the

[2] We assume that setting $P(\theta)$ optimally, where there is a tradeoff between the penalty level and the probability of detection, α, achieves the behavior desired by the principal. There is an extensive literature on the economics of monitoring and enforcement which we do not address in depth, but use a general result that if P and α have equivalent power in deterring undesirable actions (which we assume), setting P to induce desired behavior is optimal because increasing α is more costly for the regulator. The seminal work addressing this tradeoff is Becker (1968) and reviews of the literature can be found in Polinsky and Shavell (2000) and Russell (2003). An application to regulation of animal agriculture can be found in Gramig (2004).

level of biosecurity that the regulator would have him choose in addition to truthfully reporting disease status.

Assuming the penalty solves the *ex post* moral hazard problem, we can now focus on the design of indemnity payments that solve the *ex ante* moral hazard problem. First, however, we specify the regulator's objective function. Following Hyde and Vercammen (1997) and Baron and Myerson (1982), we adopt the following form

$$
(5) \quad \begin{aligned} &\underset{I(\theta),b}{Max} \int_0^1 V(\pi_0 + I(\theta) - C(\theta) - wb) f(\theta,b) d\theta + \kappa \int_0^1 (-I(\theta) - m) f(\theta,b) d\theta \\ &s.t. \qquad \mathrm{b} \in \underset{\hat{b} \in B}{\operatorname{argmax}} \int_0^1 V(\pi_0 + I(\theta) - C(\theta) - w\hat{b}) f(\theta,\hat{b}) d\theta \end{aligned}
$$

where κ is the weight the regulator applies to budgetary outlays, *m* is the monitoring cost of infected herds, and the constraint represents the farmer's choice of biosecurity that maximizes his expected utility.[3] The farmer's optimal selection of $\hat{b}$ is constrained to be *b*, the regulator's desired investment in biosecurity, without loss of generality by the revelation principle (Myerson, 1979; Dasgupta, Hammond, and Maskin, 1979). The regulator chooses *I*(θ) to maximize farmer utility while taking into account the cost of indemnities and monitoring required to implement the chosen disease risk management policy.

Following Holmstrom (1979) and Mirrlees (1976), we substitute the agent's first-order condition for the constraint in problem (5), so that (5) can be rewritten

[3] As discussed in the previous footnote, *P* is optimally chosen to ensure that the incentive compatibility condition (4) holds while minimizing the cost of implementation for the regulator. Monitoring costs, *m*, in the regulator's objective function are taken to include both testing costs incurred following disclosure and additional monitoring resources devoted to discovery of disease under non-disclosure that determine the magnitude of α. Note that our assumption involving optimal selection of *P* implies that a minimum level of additional monitoring outside of response to disclosure will occur. The choice of the level of these additional monitoring resources cannot be determined from the maximization of (5) and is not addressed here.

$$
(6) \qquad \begin{aligned} &\underset{I(\theta),b}{Max} \int_0^1 V(\pi_0 + I(\theta) - C(\theta) - wb) f(\theta,b) d\theta + \kappa \int_0^1 (-I(\theta) - m) f(\theta,b) d\theta \\ &s.t. \quad \int_0^1 [-V'(\pi) w + V(\pi) \frac{f_b(\theta,b)}{f(\theta,b)}] f(\theta,b) d\theta = 0 \end{aligned}
$$

This method of solving the problem is called the first-order approach (e.g., Spence and Zeckhauser 1971; Ross 1973; Harris and Raviv 1979; Holmstrom 1979; Mirrlees 1975; Rogerson 1985). The Lagrangian for the regulator's problem is

$$
(7) \qquad \begin{aligned} \mathcal{L} = &\int_0^1 V(\pi_0 + I(\theta) - C(\theta) - wb) f(\theta,b) d\theta + \kappa \int_0^1 (-I(\theta) - m) f(\theta,b) d\theta \\ &+ \mu \int_0^1 [-V'(\pi) w + V(\pi) \frac{f_b(\theta,b)}{f(\theta,b)}] f(\theta,b) d\theta \end{aligned}
$$

where μ is the shadow value of the constraint. The existence of the constraint, due to the farmer's freedom to make their own biosecurity decision, renders this a second-best problem. In the Appendix we illustrate that μ>0 because the regulator would like the farmer to increase his investment in biosecurity given the optimal indemnity payment (Holmstrom (1979) also finds such a result).

Following Holmstrom (1979), pointwise optimization with respect to $I(\theta)$ yields the following necessary condition, which must hold for all θ

$$
(8) \qquad V'(\pi) - \kappa = \mu [V''(\pi) w - V'(\pi) \frac{f_b(\theta,b)}{f(\theta,b)}].
$$

Condition (8) implicitly defines $I(\theta)$, the second-best indemnity as a function of θ. The following adjoint equation is also necessary

$$(9)\quad \frac{\partial \mathcal{L}}{\partial b} = \int_0^1 [-V'(\pi)w + V(\pi)\frac{f_b(\theta,b)}{f(\theta,b)}] f(\theta,b)d\theta + \kappa\int_0^1 (-I(\theta)-m) f_b(\theta,b)d\theta$$
$$+ \mu\int_0^1 [V''(\pi)w^2 f(\theta,b) - 2V'(\pi)wf_b(\theta,b) + V(\pi) f_{bb}(\theta,b)]d\theta = 0$$

Using condition (8) and recognizing that the final term can be written as $\mu\frac{\partial^2 E\{V\}}{\partial b^2}$, condition (9) reduces to

$$(10)\quad \kappa\int_0^1 (-I(\theta)-m) f_b(\theta,b)d\theta + \mu\frac{\partial^2 E\{V\}}{\partial b^2} = 0$$

Condition (10) determines μ (while the constraint in (6) determines *b*).

How do second-best indemnity payments compare to first-best payments? First-best payments arise when there are no constraints on the regulator's problem – that is, the regulator is neither constrained by the farmer's first order condition nor is truthful disclosure an issue, so that there is neither an ex post nor ex ante moral hazard problem. In this case, condition (8) reduces to

$$(11)\quad V'(\pi) - \kappa = 0$$

implicitly defining the first-best indemnity payment $I^*(\theta)$ (with $I^{*\prime}(\theta) = C'(\theta) > 0$). Comparing condition (11) with condition (8), we find that the following must hold

$$(12)\quad \begin{aligned} I(\theta) < I^*(\theta) \quad &\Leftrightarrow \quad \frac{f_b(\theta,b)}{f(\theta,b)} + \frac{-V''(\pi)}{V'(\pi)}w < 0 \\ I(\theta) > I^*(\theta) \quad &\Leftrightarrow \quad \frac{f_b(\theta,b)}{f(\theta,b)} + \frac{-V''(\pi)}{V'(\pi)}w > 0 \end{aligned}$$

As shown by Holmstrom (1979), the second-best payment is larger than the first-best payment when the farmer's marginal return from increased biosecurity is positive, and the second-best payment is smaller when the farmer's marginal return is negative. Holmstrom (p.79) points out

that the term f_b / f is simply the derivative of the maximum likelihood function ln(*f*), when *b* is taken as an unknown variable, and suggests that f_b / f measures "how strongly one is inclined to infer from θ that the agent did not undertake the assumed action." The second best solution is dependent on the distribution of θ and its relationship to biosecurity, *b*. The deviation from perfect risk sharing implies that the farmer (agent) must carry excess responsibility for the disease outcome.

Implications for Public Policy and Market Insurance Design

Status quo indemnification for livestock disease losses by USDA has paid producers on the basis of "fair market value" for any animals culled as a result of government intervention to contain the spread of disease (disease eradication programs like the scrapies bounty are an exception). There are no pre-established compensation rules in place prior to a disease event, budget allocations to respond to disease are made on an ad hoc basis, and compensation does not explicitly take into account consequential losses that result from government mandated culling or quarantine. These aspects of current risk management policy may actually contribute to farmer uncertainty about the outcome of an outbreak and further demonstrate the origins of the agency problem considered. Our model suggests that the structure of indemnities should take into account consequential losses rather than merely direct losses, but that the government likely should not fully insure farmers in an environment of asymmetric information. This is a standard result in the principal-agent literature dealing with hidden action (Laffont and Martimort, 2002) and in the broader insurance literature (Arrow, 1963; Raviv, 1979).

In considering status quo risk management policy, animal health authorities are, in general, relying on a single mechanism—indemnities—to facilitate both *ex ante* and *ex post*

farmer effort. Where localized eradication programs for a particular disease are in place, subsidization of biosecurity or bounties for sick animals may be instituted as mechanisms to achieve desired individual behavior. Our model suggests that in order to provide incentives for biosecurity and truthful disclosure, an indemnity is not sufficient as a lone mechanism. Indemnities alone facilitate disclosure in the *ex post* moral hazard model, but without a second mechanism the incentives are not strong enough to implement the social planner's desired level of *ex ante* biosecurity. We propose using indemnities to achieve desired levels of biosecurity while implementing optimal penalties that induce disclosure of disease status. Even without the introduction of penalties or some other mechanism that places additional risk on the farmer, the model suggests that current government indemnification procedures fail to satisfy incentive compatibility for even a single dimension of farmer effort that is subject to moral hazard. Indemnities must include consequential losses above fair market value in order to solve the ex post disclosure problem under asymmetric information.

One possible form for the incentive compatible indemnity schedule is a declining marginal (per head) indemnity that incorporates consequential losses more heavily over a range of lower prevalence levels. This form improves upon the status quo by creating incentives for disclosure even at very low levels of prevalence and still maintains incentive compatibility over higher prevalence levels because aggregate indemnities still cover consequential losses in excess of direct animal losses. Disclosure over all positive prevalence levels prevents widespread losses from disease by limiting opportunities for transmission and thereby minimizing social losses from disease outbreak.

A second approach to implementing constrained efficient disease risk management policy would be to make indemnities contingent on self-reporting. In this scenario, no indemnities are

paid out unless disease is discovered as a result of self-disclosure. If disease is traced back to a farm as a result of a livestock sale, testing at slaughter, or via a contact herd, no indemnities would be paid if disease was detectable or preventable through best practices. The reporting incentives produced by such a program are very strong. As long as indemnities are only paid for animals that are actually confirmed to be sick after testing, incentives for good management should not be distorted. Paying farmers for false positives will not facilitate the desired behavior and has the potential to inflate the cost of the program. A proposal of this kind may or may not be considered politically feasible, but the implementation cost of incentive compatible policy may be minimized with such a compensation rule by reducing additional monitoring resources necessary to ensure that condition (4) holds when penalties are optimally selected. In Belgium and the Netherlands, similar efforts to induce early reporting no longer compensate producers for dead animals and only partially compensate them for diseased stock (Horst, deVos, Tomassen, and Stelwagen).

The discussion of incentive compatibility applies not only to public policy but also to the development of private insurance for livestock disease protection. If private coverage is available to farmers, the incentives provided by livestock insurance contracts could potentially be in competition with the objectives of policy while satisfying the individual objectives of producers (i.e., income smoothing as risk management). Careful consideration in the design of private market coverage for livestock disease losses is required in order to ensure that public policy and private risk management products are jointly incentive compatible. Also, design of public policy should take into account the role that private coverage could play in achieving public policy objectives and how government decisions may hinder or bolster private markets for

insurance. If this is not the case then the constrained efficient result analyzed here will not be achievable.

Conclusions

Information is inherently asymmetric between farmers and government agencies responsible for livestock disease prevention and eradication. Incentive compatibility is crucial to overcoming the ex ante (private biosecurity) and ex post (disclosure of disease status) hidden action problems present in the implementation of risk management policy. We find that two separate mechanisms are needed to solve both moral hazard problems jointly, while current policy relies on a single indemnity based on a fair market value calculation. Our theoretical model predicts that when optimally chosen penalties can be used to ensure truthful disclosure, total indemnities must exceed direct losses and marginal indemnities should increase at a slower rate than marginal costs to achieve the social planner's desired level of private biosecurity. Full insurance is not optimal when these incentive compatibility conditions are satisfied as risk averse farmers must bear some of the risk.

Several topics not considered in this analysis are topics for future research. Greater consideration of the cost requirements of ongoing monitoring needed to achieve incentive compatibility in ex post reporting is an important issue for government agencies or private insurers. The nature of reciprocating externalities in livestock disease epidemics is of particular interest given the complex effect that this may have on private decision making. Such externalities result not only from disease transmission, but also from market impacts that result from localized infection (quarantine areas within a country where disease is contained) or

widespread epidemic which can lead to trade restrictions that affect an entire livestock sector regardless of individual farm disease status.

Appendix

The first order condition associated with the farmer's problem is given by the constraint to problem (6), or

$$\text{(A1)} \quad \frac{\partial E\{V\}}{\partial b} = \int_0^1 [-V'(\pi)w + V(\pi)\frac{f_b(\theta,b)}{f(\theta,b)}] f(\theta,b) d\theta = 0$$

This is an optimal response to the indemnity payment, $I(\theta)$; however, the indemnity payment is only second-best because the regulator is constrained by the farmer's response. If the regulator were not constrained, then for a first-best outcome it would have the farmer choose additional biosecurity, such that $\frac{\partial E\{V\}}{\partial b} < 0$. Generalize condition (A1) to be

$$\text{(A2)} \quad \frac{\partial E\{V\}}{\partial b} = c,$$

where c is a constant. c=0 for the farmer's problem, while c=c*<0 for the first-best outcome. Using this notation, the Lagrangian can be re-written as

$$\text{(A3)} \quad \begin{aligned} \mathcal{L} = & \int_0^1 V(\pi_0 + I(\theta) - C(\theta) - wb) f(\theta,b) d\theta + \kappa \int_0^1 (-I(\theta) - m) f(\theta,b) d\theta \\ & + \mu[\int_0^1 [-V'(\pi)w + V(\pi)\frac{f_b(\theta,b)}{f(\theta,b)}] f(\theta,b) d\theta - c] \end{aligned}$$

Clearly, $\left.\frac{\partial \mathcal{L}}{\partial c}\right|_{c=0} = -\mu < 0$ since an increase in c when c=0 implies a decrease in welfare as the solution moves farther away from the first-best outcome c*<0. Hence, μ>0.

References

Arrow, K.J. "Uncertainty and the Welfare Economics of Medical Care." *American Economic Review* 53(1963):941-973.

Baron, D.P. and R.B. Myerson. "Regulating a Monopolist with Unknown Costs." *Econometrica* 50(July1982):911-30.Becker, G.S. "Crime and Punishment: An Economic Approach." *Journal of Political Economy* 76(March-April 1968):169-219.

Bicknell, K. B., J. E. Wilen, and R.E. Howitt. "Public Policy and Private Incentives for Livestock Disease Control." *Australian Journal of Agricultural and Resource Economics* 43(1999): 501-21 .

Dasgupta, P., P. Hammond, and E. Maskin. "The Implementation of Social Choice Rules: Some Results on Incentive Compatibility." *Review of Economic Studies* 46(1979):185-216.

Gramig, B.M. "Regulation of Concentrated Animal Feeding Operations: An Application of Economic Theory to Firm Decision Making and Considerations for Public Policy." Unpublished electronic M.S. thesis, University of Kentucky. January 2004. <http://lib.uky.edu/ETD/ukyagec2004t00134/GramigBM.pdf>.

Gramig, B.M., B.J. Barnett, J.R. Skees, and J. Roy Black. "Incentive Compatibility in Livestock Disease Risk Management." In *The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies*. D. Hoag, S. Koontz, and D. Thilmany, eds. CABI press. 2005.

Grannis, J.L. and M.L. Bruch. "The Role of USDA-APHIS in Livestock Disease Management within the US." In *The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies*. D. Hoag, S. Koontz, and D. Thilmany, eds. CABI press. 2005.

Harris, M. and A. Raviv. "Optimal Incentive Contracts with Imperfect Information." *Journal of Economic Theory* 20(1979):231-259.

Holmstrom, B. "Moral Hazard and Observability." *Bell Journal of Economics* 10(1979):74-71.

Horan, R.D. and C.A. Wolf. "The economics of managing infectious wildlife disease." *American Journal of Agricultural Economics*. August 2005.

Horst, H.S., C.J. deVos, F.H.M. Tomassen, and J. Stelwagen. "The Economic Evaluation of Control and Eradication of Epidemic Livestock Diseases," In *The economics of animal disease control*, Coordinated by B.D. Perry. Office International Des Epizooties Scientific and Technical Review Vol 18(August 1999)367-379.

Hyde, C.E. and J.A. Vercammen. "Costly Yield Verification, Moral Hazard, and Crop Insurance Contract Form." *Journal of Agricultural Economics*, 48(1997):393-407.

Kuchler, F. and S. Hamm. "Animal disease incidence and indemnity eradication programs." Agricultural Economics 22(2000):299-308.

Laffont, J.-J. and Martimort, D. *The Theory of Incentives: The Principal-Agent Problem*. Princeton University Press, 2002.

Mahul, O. and A. Gohin. "Irreversible Decision making in contagious animal disease control under uncertainty: An illustration using FMD in Brittany." *European Review of Agricultural Economics* 26(1999):39-58.

Myerson, R. "Incentive Compatibility and the Bargaining Problem." *Econometrica* 47(1979):61-74.

Mirrlees, J. "The Theory of Moral Hazard and Unobservable Behavior—Part I." Mimeo, Nuttfield College, Oxford, 1975. Reprinted in *Review of Economic Studies* 66(1999):3-21.

Ott. S. "Issues Associated with US Livestock Disease Compensation in the 21st Century." In *The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies*. Dana Hoag, Steve Koontz, and Dawn Thilmany, eds. CABI press. 2005.

Polinksy, A.M. and S. Shavell. "The Economic Theory of Public Enforcement of Law." *Journal of Economic Literature* 38 (March 2000):45-76.

Ramsay, G.C., P. Philip and P. Riethmuller. "The economic implications of animal diseases and disease control at the national level." In *The economics of animal disease control*, Coordinated by B.D. Perry. Office International Des Epizooties Scientific and Technical Review 18(August 1999):343-354.

Raviv, A. "The Design of an Optimal Insurance Policy." *American Economic Review* 69(1979):84-96.

Rogerson, W.P. "The First-Order approach to Principal-Agent Problems." *Econometrica* 53(November 1985):1357-1367.

Ross, S. "The Economic Theory of Agency: The Principal's Problem." *The American Economic Review* 63(1973):134-139.

Russell, C.S., ed. *The Economics of Environmental Monitoring and Enforcement*. Burlington VT: Ashgate Publishing Company, 2003.

Spence, M. and R. Zeckhauser. "Incentives, Risk, and Individual Action." *The American Economic Review* 61(1971):380-387.

Tinbergen, J. *On the Theory of Economic Policy*. North-Holland: Amsterdam, 1952.

United Nations Food and Agricultural Organization, Committee on Commodity Problems. "Animal Diseases: Implications for International Meat Trade." Intergovernmental Group on Meat and Dairy Products, Nineteenth Session, Rome, August 27-29, 2002. CCP:ME 02/3.

Wolf, C.A. "Livestock Disease Eradication Programs and Farm Incentives: The Case of Bovine Tuberculosis in Michigan." In The Economics of Livestock Disease Insurance: Concepts, Issues and International Case Studies. Dana Hoag, Steve Koontz, and Dawn Thilmany, eds. CABI press. 2005.

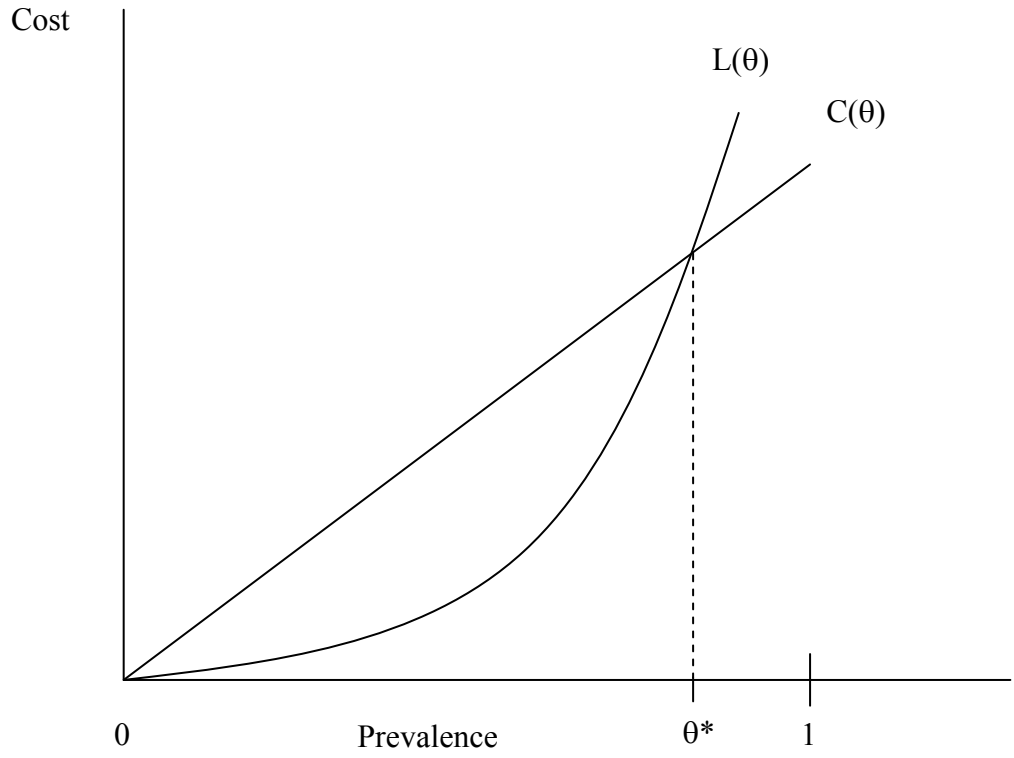

Figure 1. Indemnity with ex post moral hazard