Animal Disease Related Pre-event Investment and Post-event Compensation: A Multi-agent Problem

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Animal disease management involves both the potential adoption of pre event investments in disease prevention as well as post event participation in disease management including slaughter of infected animals. Both types of participation, while desirable from an industry wide viewpoint, are undertaken by individuals and may require compensation to occur at an appropriate level. Current compensation policy does not provide individual farmers incentives to invest in prevention actions, rather concentrating on compensation for slaughtered animals. This paper considers compensation design incorporating the risk and economic interests of both the government and the producer. In particular, this study investigates possible linkages between preventive investments and the post event compensation package. It also reviews the economic dimensions of the compensation problem and derives the optimal compensation package that induces individual producers to both truthfully disclose information on livestock disease and increase preventive investments.

Compensation and animal disease management. Once an outbreak of animal disease occurs government agencies frequently come into an area and slaughter all infected and contact animals. The Fifth Amendment of the US Constitution requires the government to compensate individuals when private property is taken for public use. USDA Animal and Plant Health Inspection Service (APHIS) designs and executes compensation that largely relies on diagnosis technology and farmers' self reporting to identify and trace the infected animals (Kuchler and Hamm 2000). In such a case an efficient compensation scheme needs to arrive at payments that are (a) low enough to prevent individual farmers from over-reporting, transporting animals from areas outside the event and contact zones, or manufacturing diseased animals; and (b) high enough to prevent under-reporting or hiding potentially sick animals. There is observational evidence showing compensation levels influence individual behavior: (a) Reaney (1998) reported that farmers are under pressure not to report cases of BSE due to a reduction of compensation for sick animals; (b) Stecklow (1998) reported that cattle farmers were paid more than the sick animal were worth so that there was no incentive to send a sick animal to the slaughterhouse; and (c) Kuchler and Hamm (2000) and Wineland, Detwiler and Salman (1998) observe that individual farmers increase their efforts to find scrapie-infected sheep within their flocks as the indemnity payments increase. Therefore, an appropriate and efficient compensation scheme is needed to ensure a truthful disclosure of privately hold information about animal disease and its management.

Compensation and animal disease prevention. Individual farmers may be reluctant to make pre event investments to prevent, control, or eradicate animal disease in their herd due to some mixture of the following reasons: (a) Investments cost money and margins are low. When an outbreak of animal disease like foot-and-mouth disease (FMD) occurs, a centralized control effort slaughters all contact animals no matter whether these animals are sick or not. In this sense, once the outbreak occurs the ex ante investment does not reduce the consequential loss----two farmers having an identical herd bear the same cost regardless one invests ex ante while another one does not; (b) The ability to benefit from the efforts of others associated with disease prevention and control (free ride) reduces individual producer incentives to investing ex ante; and (c) Current disease control policies and indemnity payments do not provide individuals with incentives to invest ex ante. The 2002 farm bill, Farm Security and Rural Investment Act of 2002, Title X, Subtitle E, Animal Health Protection Act, Public Law 107-171, states that the government is to pay fair market value for animals destroyed for disease control purposes and any compensation paid is to be reduced by any other funds received. Other funds would include any salvage value, indemnity paid by states or insurance. Thus, two individual farmers who have identical herds and claim for compensation will receive the same amount of indemnity no matter one has a far better preventive investment than another one, or one who has insurance will receive the difference net of the indemnity paid by the insurance.

Thus, current plans for compensation face two possible problems: (a) they may not induce a truthful disclosure regarding livestock disease outbreak; and (b) they do not provide a linkage between the ex ante preventive investment and ex post compensation scheme that might enhance preventive investment and reduce the likelihood of disease outbreaks and/or decrease the consequential event costs.

In this paper, we employ a game-theoretic principal agent framework to analyze the individual farmer and governmental behavior pre- and post-animal disease outbreak. As agents, individual farmers maximize their expected monetary value including compensation for preventive investments and post-event animal slaughter. Government, as the principal, maximizes overall societal welfare. In this setting we will examine the gap between the privately optimal and socially optimal investment levels then investigate how a well-designed differentiated compensation scheme can close this gap. We also discuss whether and how the government can monitor and assess the privately held investment information, including preventive technology related methods and economic screening and monitoring.

1 The Model

The game-theoretic framework is summarized in Figure 1. It evolves in three stages. In the first stage, aiming to maximize profits and avoid risk individual farmer *k* (of which there are *K*) considers preventative investments that reduce the likelihood of disease outbreak and the consequential loss. There are various preventive biosecurity actions that farmers could undertake, including inspecting arriving lots of animals to keep infected animals off the farm, installing animal identification devices to facilitate animal tracking, and improving management-based activities that contribute to biosecurity. The other player is the relevant government agency, in this case APHIS, that designs the compensation scheme. Unlike the current practice, we assume that compensation can be conditional on the level of preventive investment and the severity of disease prevalence θ_k. Individual farmers know the disease prevalence θ_k in their herds. However, θ_k is privately held information, and is not observable at no cost to the government. In the second stage, market observations will reveal whether there is a disease outbreak. The likelihood of disease outbreak, which is denoted by ρ, is affected by the total preventive investment, i.e., $\rho = \rho(\sum_{k=1}^{K} I_k)$. An increase in the total preventive investment lowers the chance of disease outbreak in the region, i.e. $\frac{\partial \rho}{\partial I_k} < 0$. If farmers report an infection, the government will test the herds to identify the true disease prevalence and respond in a manner consistent with the disease management protocol. Since the true disease prevalence will be found no matter whether farmers truthfully report or not as long as they decide to disclose disease prevalence, farmers have no gain to under-estimate the disease prevalence and they will truthfully disclose their infected herds. Farmers who do not disclose the disease prevalence will face inspections. If an infected herd is found in inspections, we assume that an individual farmer has to pay a certain monetary penalty. If a disease outbreak like FMD is confirmed, a quarantine zone is determined and movement bans are imposed, and all the animals within the quarantine zone is ordered to be killed with a compensation paid to individual farmers in the last stage.

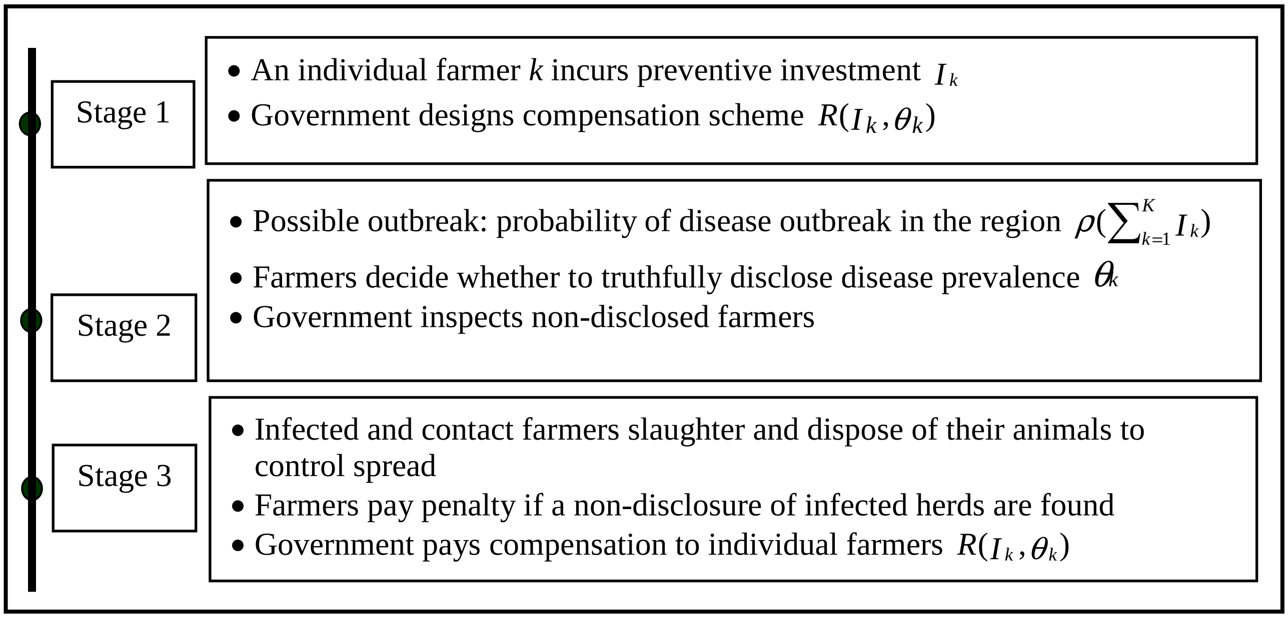

Figure 1: The timeline of the model

1.1 Agent's Problem and Privately Optimal Preventive Investment

As agents, individual farmers maximize their expected monetary value considering preventive investments, post-event animal slaughter, and compensation. The payoffs of an individual farmer who has an initial wealth Y_k and invests I_k on preventive biosecurity actions under different scenarios are illustrated in Figure 2. Under the first scenario when there is no disease outbreak, the preventive investment is foregone and the individual net wealth is $Y_k - I_k$. Should a disease outbreak occur, his livestock may be slaughtered for disease control and, hence, resulting in a consequential loss that could be at least partly recouped from compensation paid by the government $R(I_k, \theta_k)$. If the incidence of a disease in the herd is disclosed the farmer bears a loss of $C(I_k, \theta_k)$ where $C(I_k, \theta_k)$ includes the direct livestock loss and some governmental costs. Hence, under the second scenario when there is a disease outbreak, an individual farmer who discloses infected herds has a net payoff $Y_k - I_k + R(I_k, \theta_k) - C(I_k, \theta_k)$. On the other hand, if an individual farmer does not report disease prevalence, he bears the consequential loss

$L(I_k, \theta_k)$ and faces inspections. If infected herds are discovered at random inspections, an individual farmer has to pay a monetary penalty $P(\theta)$, and his net payoff is $Y_k - I_k + R(I_k, \theta_k) - L(I_k, \theta_k) - P(\theta)$. Otherwise, no disease is found in the premise and the individual net payoff of $Y_k - I_k + R(I_k, \theta_k) - L(I_k, \theta_k)$.

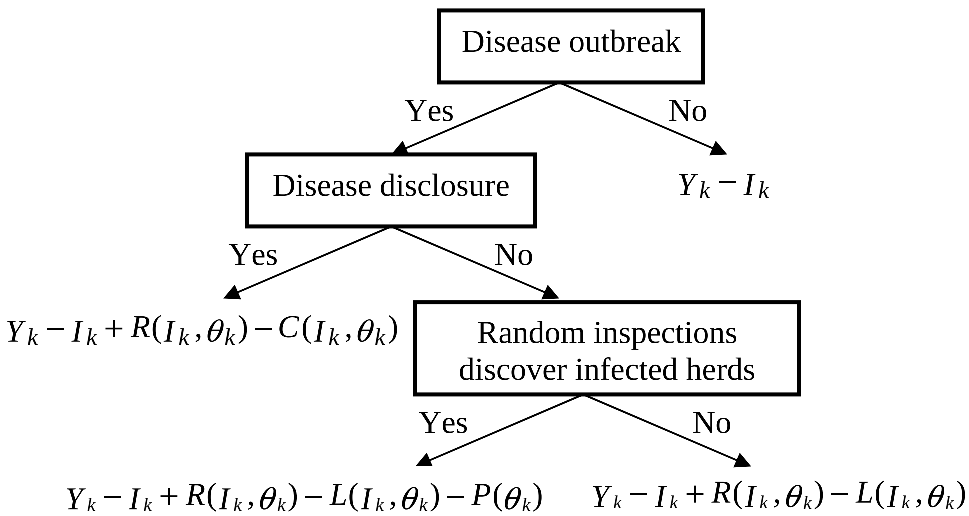

Figure 2: Payoffs of individual farmers under different scenarios

It is ambiguous whether farmers face a greater consequential loss when they truthfully report infected herds. Despite some governmental costs, an individual farmer may bear a low consequential cost if he truthfully reports infected herds since it allows for appropriate response actions conducted by APHIS and reduces the consequential loss. No disclosure or even hiding sick animals will cause a wider disease spread and, thus, increases the consequential loss. However, covering up possible disease prevalence may avoid and/or reduce the likelihood of livestock slaughter and, thus dramatically reduces the consequential loss. Logically, farmers will disclosure the disease prevalence if non-disclosure does not reduce the costs. Therefore, we assume $C(I_k, \theta_k) > L(I_k, \theta_k)$ holds, and the potential penalty imposed on non-disclosure will induce a truthful disclosure of infected herds.

Now suppose that the consequential loss also depends on the level of preventive investment and the magnitude of disease prevalence: (a) $\frac{\partial L}{\partial I_k} \geq 0$ and $\frac{\partial C}{\partial I_k} \geq 0$, which implies that a higher preventive investment may reduce the number of infected animals and/or cause more timely disease management strategies, thus, reduces the consequential loss. Also suppose that $\frac{\partial L}{\partial \theta_k} \geq 0$ and $\frac{\partial C}{\partial \theta_k} \geq 0$, which indicates that farmers with higher level of disease prevalence face higher losses.

Unlike under current compensation practices, we assume that the magnitude of compensation depends the amount of preventive investment and whether farmers disclose the disease prevalence: (a) the higher the preventive investment, the greater the compensation that an individual farmer receives, i.e., $\frac{\partial R}{\partial I_k} > 0$. That is, among two individual farmers with identical herds and levels of disease prevalence, the one with the higher preventative investment would receive higher compensation. This assumption ensures a positive linkage between compensation and preventive investment thus, inducing farmers to invest more ex ante. Furthermore, an individual farmer who truthfully discloses disease prevalence in his herd in a timely manner will be compensated more than another who does not disclose. Hence, truthful disclosure of disease prevalence is encouraged.

Farmers have to pay a monetary penalty $P(\theta_k)$ if they do not disclose an infected herd and disease prevalence is discovered by inspections. We assume $P(\theta_k)$ is increasing with the severity of disease outbreak and the likelihood of being discovered is $\beta(\theta_k)$, where $\frac{d\beta}{\partial \theta_k} > 0$ indicates detection is more likely for herds with a high prevalence rate. The break even incentive comparability condition under which farmers will truthfully disclose disease prevalence in their herds is

$$(1) \quad \begin{aligned} &Y_k - I_k + R(I_k, \theta_k) - C(I_k, \theta_k) \\ &= \beta(\theta_k)\big(Y_k - I_k + R(I_k, \theta_k) - L(I_k, \theta_k) - P(\theta)\big) + \big(1 - \beta(\theta_k)\big)\big(Y_k - I_k + R(I_k, \theta_k) - L(I_k, \theta_k)\big)' \end{aligned}$$

When equation (1) is satisfied, farmers have the same amount of the net payoff if they report infected herds or not. Equation (1) can be simplified as

$$(2) \qquad P(\theta_k) = \frac{C(I_k, \theta_k) - L(I_k, \theta_k)}{\alpha(\theta_k)}.$$

Equation (2) shows that the optimal penalty for no-disclosure when the disease is present. The optimal penalty is conditional on the level of the disease prevalence rate, the difference between the consequential loss when disclosing or not, and disease discovery rate. Penalties can be used to induce the truthful disclosure if the government can obtain information of preventive investment and disease prevalence by inspections and/or other mechanisms. If it is the case, farmers will always truthfully report the infected herd to avoid penalty and, thus, penalty is used as a credible threat and it is actually never executed.

Farmers choose the optimal preventive investment to maximize their expected benefit conditional on truthful disclosure of disease prevalence resulting from the credible optimal penalty:

$$
\begin{aligned}
(3)\qquad & \max_{I_k} \rho\left(\sum_{k=i}^{K} I_k\right)\left(Y_k - I_k + R(I_k,\theta_k) - C(I_k,\theta_k)\right) + \left(1-\rho\left(\sum_{k=i}^{K} I_k\right)\right)\left(Y_k - I_k\right) \\
& s.t. \qquad P(\theta_k) = \frac{C(I_k,\theta_k) - L(I_k,\theta_k)}{\alpha(\theta_k)}
\end{aligned}
.
$$

The Lagrangian for this private maximization problem is

$$
\begin{aligned}
(4)\qquad & L = \rho\left(\sum_{k=i}^{K} I_k\right)\left(Y_k - I_k + R(I_k,\theta_k) - C(I_k,\theta_k)\right) + \left(1-\rho\left(\sum_{k=i}^{K} I_k\right)\right)\left(Y_k - I_k\right), \\
& \quad + \lambda\left[C(I_k,\theta_k) - L(I_k,\theta_k) - P(\theta_k)\,\alpha(\theta_k)\right]
\end{aligned}
$$

where λ is the shadow value of the constraint on truthful disease disclosure. The necessary first-order condition with respect to preventive investment I_k is

$$
(5)\quad \underbrace{\left[\frac{d\rho}{d\,I_k} R(I_k,\theta_k) + \rho\frac{\partial R(I_k,\theta_k)}{\partial\, I_k}\right]}_{\substack{\text{marginal effect} \\ \text{throught compensation}}} + \underbrace{\left[-\frac{d\rho}{d\,I_k} C(I_k,\theta_k) - \rho\frac{\partial C(I_k,\theta_k)}{\partial\, I_k}\right]}_{\substack{\text{marginal effect throught} \\ \text{consequential loss}}} + \lambda\underbrace{\left[\frac{\partial C(I_k,\theta_k)}{\partial\, I_k} - \frac{\partial L(I_k,\theta_k)}{\partial\, I_k}\right]}_{\substack{\text{marginal effect} \\ \text{through penalty}}} = 1\,.
$$

Equation (5) shows that the privately optimal preventive investment is achieved when the marginal gain on the right-hand side equals the marginal cost on the left-hand side. The marginal gain can be decomposed into three components, including those through compensation, consequential loss, and penalty. An increase in the individual preventive investment decreases the amount of consequential loss $\left(\frac{\partial C(I_k,\theta_k)}{\partial\, I_k} < 0\right)$ and increases the amount of compensation $\left(\frac{\partial R(I_k,\theta_k)}{\partial\, I_k} > 0\right)$, and also boosts the regional preventive investment level and, thus, decreases the likelihood of disease outbreak in this region $\left(\frac{d\rho}{d\,I_k} < 0\right)$. Hence, the marginal effect through consequential loss, $-\frac{d\rho}{d\,I_k} C(I_k,\theta_k) - \rho\frac{\partial C(I_k,\theta_k)}{\partial\, I_k}$, is positive, while the sign of the marginal effect through compensation, $\frac{d\rho}{d I_k} R(I_k, \theta_k) + \rho \frac{\partial R(I_k, \theta_k)}{\partial I_k}$, is not determined yet depending on the magnitudes of two components. The last term on the right-side hand of equation (5) reflects the marginal change through penalty. An increase in the preventive investment will decrease the consequential loss and may change the optimal amount of penalty.

1.2 Principal's Optimization Problem and Socially Optimal Preventive Investment

The government, as a principal, maximizes expected overall societal welfare. The social welfare has two components, the aggregated benefit among farmers and the budgetary outlays. The government does not have perfect information on disease prevalence in individual herds unless they conduct inspections. However, the distribution of disclosed disease prevalence (θ_k) is public information, and we assume follows a density function $f(\theta_k)$. Based on farmers' expected benefit that is written in equation (3), the aggregated welfare across farmers, denoted by w_1, is given as

(6) $$w_1 = \int_0^1 \sum_{k=1}^{K} \left\{ \rho\left(\sum_{k=i}^{K} I_k\right)(Y_k - I_k + R(I_k, s) - C(I_k, s)) + \left(1 - \rho\left(\sum_{k=i}^{K} I_k\right)\right)(Y_k - I_k) \right\} f(s) ds .$$

In addition to compensation, we assume another two sources of budgetary outlays. The first one is the cost of inspections, denoted by *INSP*, which ensures the credibility of penalty to induce truthful disclosure of disease prevalence. The second source of budgetary outlays is the cost of obtaining preventive investment on randomly inspected farmers, which is denoted by *C*. Thus, the total budget outlay is

(7) $$w_2 = \int_0^1 \sum_{k=1}^{K} R(I_k, s) f(s) ds + INSP + C .$$

Following Hyde and Vercammen (1997), Baron and Myerson (1982), and Cramig, Horan, and Wolf (2005), we specify the social welfare maximization problem for the government by incorporating the budgetary outlays. That is, the government maximizes the sum of the expected benefit aggregating across farmers and the weighted budgetary outlays by choosing the socially optimal preventive investment conditional on the truthful disclosure of disease prevalence:

$$\begin{aligned} &\max_{I_k} \{w_1 - \gamma w_2\} \\ &s.t. \quad P(\theta_k) = \frac{C(I_k, \theta_k) - L(I_k, \theta_k)}{\alpha(\theta_k)}, \end{aligned} \tag{8}$$

where γ is the weight that government applies to budgetary outlays. The Lagrangian for the government's social welfare maximization problem is

$$L = w_1 - \gamma w_2 + \lambda[C(I_k, \theta_k) - L(I_k, \theta_k) - P(\theta_k)\,\alpha(\theta_k)]. \tag{9}$$

Following Holmstrom (1979), pointwise optimization with respect to preventive investment I_k yields the following necessary first-order condition,

(10)

$$\underbrace{\left[\frac{d\rho}{d I_k} R(I_k, \theta_k) + (\rho - \gamma)\frac{\partial R(I_k, \theta_k)}{\partial I_k}\right]}_{\substack{\text{marginal effect} \\ \text{throught compensation}}} + \underbrace{\left[-\frac{d\rho}{d I_k} C(I_k, \theta_k) - \rho\frac{\partial C(I_k, \theta_k)}{\partial I_k}\right]}_{\substack{\text{marginal effect throught} \\ \text{consequential loss}}} + \underbrace{\lambda\left[\frac{\partial C(I_k, \theta_k)}{\partial I_k} - \frac{\partial L(I_k, \theta_k)}{\partial I_k}\right]}_{\substack{\text{marginal effect} \\ \text{through penalty}}} = 1,$$

which holds for θ_k where $k=1, 2,\ldots,K$.

Equation (10) is similar to equation (5) except there is additional term in the marginal effect through compensation $\left(-\gamma\frac{\partial R(I_k, \theta_k)}{\partial I_k} < 0\right)$ that captures the effect of preventive investment through the budgetary outlays.

1.3 Comparison between Privately and Socially Optimal Preventive Investment

Now let's examine optimal preventive investment levels for the three parties:

$$(11)\quad \begin{cases} I_k^{p*} & \text{privately optimal preventive investment} \\ I_k^{sf*} & \text{first best socially optimal preventive investment} \\ I_k^{ss*} & \text{second best socially optimal preventive investment} \end{cases}.$$

I_k^{sf*} is the socially optimal investment when there no constraints on the government's problem. That is, the government is not constrained by truthful disclosure or the budget. I_k^{ss*} is defined as the second best socially optimal investment when the government has no budgetary constraint. Based on equations (5) and (10) we are able to write out the effect of preventive investment on the expected individual benefit *WP* and the total social welfare *w* under two scenarios, respectively:

$$(12\text{-a})\quad \frac{dWP}{d\,I_k} = A \text{ for the privately optimal investment};$$

$$(12\text{-b})\quad \frac{d\,w^s}{d\,I_k} = A - \gamma \frac{\partial R(I_k, \theta_k)}{\partial\, I_k} \text{ for the second best socially optimal investment};$$

$$(12\text{-c})\quad \frac{d\,w^f}{d\,I_k} = A - \lambda \left[\frac{\partial C(I_k, \theta_k)}{\partial\, I_k} - \frac{\partial L(I_k, \theta_k)}{\partial\, I_k} \right] \text{ for the first best socailly optimal investment},$$

where $A = \left[\frac{d\rho}{d\,I_k} R(I_k, \theta_k) + \rho \frac{\partial R(I_k, \theta_k)}{\partial\, I_k} \right] - \left[\frac{d\rho}{d\,I_k} C(I_k, \theta_k) \rho \frac{\partial C(I_k, \theta_k)}{\partial\, I_k} \right] + \lambda \left[\frac{\partial C(I_k, \theta_k)}{\partial\, I_k} - \frac{\partial L(I_k, \theta_k)}{\partial\, I_k} \right] - 1$.

Let's assume the privately optimal investment I_k^{p*}, which is implicitly defined by equation (5), is achieved. Hence, equation (12-a) equals zero. Substituting I_k^{p*} into equations (12-b) and (12-c) yields the following inequalities,

$$(13\text{-a})\quad \frac{d\,w^s}{d\,Ik} \bigg| \{I_k = I_k^{p*}\} = \left\{ \frac{dWP}{d\,I_k} - \gamma \frac{\partial R(I_k, \theta_k)}{\partial\, I_k} \right\} \bigg| \{I_k = I_k^{s*}\} = -\left\{ \gamma \frac{\partial R(I_k, \theta_k)}{\partial\, I_k} \right\} \bigg| \{I_k = I_k^{s*}\} < 0 \text{, and}$$

(13-b)
$$\left.\frac{d\,w^{f}}{d\,I_k}\right|\left\{I_k = I_k^{p*}\right\} = \left.\left\{\frac{dWP}{d\,I_k} - \lambda\left(\frac{\partial C(I_k,\theta_k)}{\partial\,I_k} - \frac{\partial L(I_k,\theta_k)}{\partial\,I_k}\right)\right\}\right|\left\{I_k = I_k^{s*}\right\}$$
$$= -\left.\left\{\lambda\left(\frac{\partial C(I_k,\theta_k)}{\partial\,I_k} - \frac{\partial L(I_k,\theta_k)}{\partial\,I_k}\right)\right\}\right|\left\{I_k = I_k^{s*}\right\} > 0 .$$

Based on inequalities (13-a) and (13-b) we are able to compare the magnitudes of three different levels of preventive investment:

(14) $I_k^{fs*} > I_k^{p*} > I_k^{ss*}$.

Hence, we find that the positive linkage between compensation and preventive investment has the following effects: (a) it induces a higher investment ex ante than the second best socially optimal level when the government faces constraints, i.e., $I_k^{p*} > I_k^{ss*}$; and (b) When the government does not face any budgetary constraint, the first best socially optimal investment is achieved, which is higher than the privately optimal level, i.e., $I_k^{fs*} > I_k^{p*}$. Therefore, a well-designed differentiated compensation scheme that is positively linked with preventive investment can induce private investment to increase approaching the first best socially optimal level.

2 Implications for Compensation Policy

In previous section we assume that farmers who do not disclosure face a penalty that optimally depends on disease prevalence and the level of preventive investment. What is the logic behind this assumption? Farmers who choose not to report face inspections. These inspections allow for identifying the true disease prevalence if there is any but are costly. However, it may be harder for the government to obtain information on ex ante preventive investment, since farmers may simply do not want to report that information, or they may over-report the investment level in order to receive a higher compensation. Besides the costs, whether the government can truthfully obtain such privately-hold investment information partly depends on technologies of prevention strategies. For example, it is much easier to figure out the costs of inspection or animal identification investment than the cost of management-based biosecurity investment. Thus, it is important to differentiate different technologies of preventive investment.

The current indemnification for livestock disease loss by USDA pays farmers on the basis of "fair market value" for any loss resulting from public interventions to combat disease spread. It does not provide farmers with incentives to truthfully disclose their infected herds, or invest in preventive actions. Our theoretic model suggests that adding these features would be desirable, which is consistent with findings by Cramig, Horan and Wolf (2005). They propose using indemnities conditional only on disease prevalence to achieve desirable levels of biosecurity investment and implementing optimal penalties to induce truthful disclosure of disease status. However, in their case both the indemnity and penalty are conditional only on disease prevalence. Our model indicates it would be desirable to establish:

- a penalty for farms where disease is found that have not disclosed disease incidence conditional both on the level of disease prevalence and the level of preventive investment that would induce truthfully disclosure of infected herd; and
- enhanced compensation for those using certified ex ante preventive investments that would induce a greater investment approaching to the first best socially optimal level.

In order to achieve the first best socially optimal level of preventative investment, one possible compensation scheme would exhibit increasing marginal compensation with respect to preventive biosecurity investment. This form has the following two positive effects: (a) It provides farmers with incentives to invest more since the large part of investment can be recouped from compensation if disease outbreak occurs; and (b) An increase in preventive biosecurity investment narrows the difference of consequential loss between disclosing or not, which induces farmers to report infected herds truthfully. A high disclosure of disease status prevents widespread and cuts down social loss. Therefore, implementing an increase marginal compensation with respect to preventive biosecurity investment may improve social welfare.

3 Concluding Remarks

We employed a game-theoretic framework to analyze the individual farmer and governmental behavior pre- and post-animal disease outbreak. Our results also show that the privately optimal investment is generally lower than the first best socially optimal level, and a well-designed differentiated compensation scheme conditional on ex ante biosecurity investment can induce private preventive investment at least greater than the second best socially optimal level when the government face constraints, or even increase approaching the first best socially optimal level.

To achieve this our results suggest that compensation schemes be expanded to encompass features that provide incentives for ex ante biosecurity investment and ex post truthful disclosure. Specifically inclusion of the following two mechanisms is warranted: (a) a penalty for farms who are found to have disease incidence but have not disclosed that information. In this case the penalty would be set based on both on the levels of disease prevalence and preventive investment; and (b) a positive link between the compensation ex post and preventive investment.

Beyond our study, several topics merit future research efforts. First, it is extremely hard for the government to obtain information of some preventive investments such as management-based biosecurity investment. Therefore, penalties conditional on preventive investment and disease prevalence may not efficiently induce truthful disease disclosure, and also indemnities conditional on preventive investment may not be easy to design and execute. In the face of this, further investigation should consider cases where the government cannot observe preventive investment but knows its distribution. Secondly, as shown by inequality (13-b), the privately optimal ex ante biosecurity approaches the first best socially optimal level. But they are not the same level unless the marginal effect of investment on the consequential loss when disclosing disease prevalence or not equals $\left(\frac{\partial C(I_k,\theta_k)}{\partial I_k} - \frac{\partial L(I_k,\theta_k)}{\partial I_k} = 0\right)$. It is of the government's interest to identify practical mechanisms to satisfy this condition so that the privately optimal investment is also the first best socially optimal level.

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