A Government Decision Model for Invasive Species: Choosing the Most Efficient Government Program for the Management of Livestock Diseases

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Abstract

The impact of invasive species has grown substantially in recent years as evident by the trends in government expenditures in response to outbreaks. In this paper, authors analyze advantages and disadvantages of current government compensation measures for invasive species. The conceptual models are built to describe the relationship between producers' utility and the effect of adoption of different measures under different observability condition. As a case study, a survey is designed to analyze producer behavior in mitigating AI & END outbreaks.

Key words: invasive species, indemnification programs, insurance programs, tiered indemnification

Introduction

Invasive species are defined as non-native species and its introduction is likely to cause economic and environmental damage. Invasive species may include plants, animals, and other organisms such as microbes. Concern regarding the impact of invasive species has grown substantially in recent years as evident by the trends in government expenditures in response to outbreaks. APHIS (Animal and Plant Health Inspection Service) estimates that annual damage and control costs of invasive species and diseases are around 138 billion dollars per year (Pimentel, Zuniga and Morrison, 2005). There are three major approaches to compensate producers that suffer financial loss due to invasive species: (1) *Ex post* indemnification programs as typically administered by APHIS which do not require significant a prior institutional infrastructure or producer enrollment, but is costly and less efficient; (2) A prior insurance program as offered by RMA (Risk Management Agency) which would require enrollment and a government infrastructure with predefine indemnification and premium schedules; and (3) Tiered indemnification or insurance design that ties higher coverage to explicit risk reducing production practices.

Risk protection for producers is provided as a risk mitigation program, which means that the government provision of indemnification is provided to add economic stability for producers, no matter whether it is from an altruistic motive or based on industrial policy to avoid economic damage to a particular industry or region. Nevertheless, there is no specific model to tell government when and how to use these three alternative approaches with reasonable government cost while maximizing the utility of the producers who suffer from the diseases. This research provides a decision model for government policy makers to devise a more efficient policy system in fighting invasive diseases.

The primary goal of this research is to assess how government incentives encourage producer behavior in mitigating the spread of invasive diseases. For instance, APHIS indemnification is often provided to encourage the reporting of diseased animals to decrease the risk of disease spread. Similarly, there are attempts to provide incentives for prophylactic efforts which reduce the chance of disease occurrence as well as disease spread. These efforts can be considered positive externalities that are not fully rewarded in the marketplace.

This research will also assess the observability of preventive measures implemented by producers because their reaction to government policies is very important. Because producers could adopt different practices under different probabilities of disease infestation, how to predict their behavior and how to control it through policy mechanisms is essential for an effective government program. As a case study, this research focuses on diseases specific to the poultry industry, AI (Avian Influenza) and END (Exotic Newcastle Disease), where we investigate the effectiveness of alternative government programs in encouraging optimal disease mitigating practices specific to AI and END.

Current management measures

Here we review alternative government policies that best incentivize behavior consistent with the social goals of invasive species management. We will examine producer behavior in response to alternative coordinated strategies by the government to determine the most efficient strategy with each disease occurrence. Given a disease outbreak, should the event be handled by (1) *ex post* indemnification, (2) insurance, or (3) tiered indemnification/insurance. There are certainly instances where each approach has merit, and this research will resolve determining when each approach should be employed to avoid duplication of effort and expenditures, as well as when a particular approach is the most efficient course of action. While multiple programs are often used simultaneously, programs such as indemnification and insurance may confound each other when used together.

An *ex post* indemnity is a sum paid by government to producers by way of compensation for a particular loss caused by an invasive species. With *ex post* indemnification, the government can avoid the creation of institutions and programs which is particularly efficient when the probability of loss faced by producers is quite small. At an early stage of infestation, producer inexperience could lead to an underestimation of disease risk, resulting in little or no willingness to pay for insurance. Thus, indemnification may be the best course of the action at this stage of infestation and spread. Although *ex post* indemnification programs do not require significant prior infrastructure, the *ad hoc* nature of these programs often results in inefficient or inequitable indemnities (Ott, 2006).

Ex ante insurance is defined as the transfer of the risk of a loss, from one entity to another, in exchange for a premium. Insurance requires institutionalized premiums and indemnity structures for insurable risks. With insurance, losses should, at least in principle, take place at a known time, in a known place, and from a known cause. At more advanced stages of infestation and spread, the probability of loss increases. Producers have more direct experience with losses and are likely to have a positive willingness to pay for insurance. Assuming insurability, insurance may be the most efficient government response at this stage of infestation spread. Insurance allows producers and government officials to define an efficient and equitable program because more time is available to define and implement the program. An insurance program has the potential to reduce government cost by charging premiums. However, low participation may be a problem, particularly if the probability and economic cost of occurrence is low. Low participation may also be exacerbated by adverse selection or moral hazard when significant asymmetric information exists between the insurer and insured (Shaik et al., 2006).

In considering *ex post* indemnification and *ex ante* insurance, tiered indemnification or insurance, a modification of the previous two designs, may increase incentives for producer to implement disease mitigating practices. Instead of fixed compensation from a government indemnification or insurance program, the amount of compensation the producer receives becomes a function of their behavior. For example, when the producers adopt certain preventive practices they receive “full” indemnification, otherwise they receive a lower level of indemnification. The merit of tiered indemnification or insurance is that producers have a stronger incentive to adopt prevention measures. However, the disadvantage of a tiered design is that it requires a level of observability in order to be effective.

Conceptual Model

In this section, we describe how the producers are influenced by the following factors: input and output prices, input and output quantities, errors in evaluating the probability of loss, indemnification levels, the percentage of losses indemnified, and insurance premiums. Optimal producer behavior is assumed to result from the expected utility maximization problem. Additionally, their utility is conditioned on the initial wealth plus total revenue, minus their total cost, when there is no invasive species occurrence. The solution to this problem is a set of choices over inputs that are potentially both risk increasing and decreasing and are conditional upon the perceived risk, exogenous risk, and individual risk preferences. Indemnification and insurance programs can be added to this model by incorporating an indemnity function and premiums. For *ex post* indemnification, producers do not need to pay up-front cost to receive government indemnification. In contrast, with insurance, premiums are an expense to producers which should be subtracted revenue in the model. The indemnification function equals a portion of the total loss (in value). As typical, a deductible reflects the portion of losses incurred by the producer. A tiered indemnification system conditional on risk mitigating inputs can be modeled by making the deductible level a function of the risk decreasing inputs. When producers use certain risk decreasing inputs, they can get a lower deductible which increases the level of indemnification. The observability of certain behaviors is another factor which should be included in the model, as both *ex post* indemnification and insurance programs will face the moral hazard problem. Thus, the successful application of tiered indemnification will be affected by the observability of risk decreasing behavior.

Insurance Model

With insurance, producer behavior is a function of premiums, which are defined as *PR*; the probability of occurrence of invasive species is defined as ρ, and other variables. Other variables include: x (input measure); x_1 is input when producers perform certain prevention measures; x_0 is input when producers do not perform certain prevention measures; r is the price of inputs; Wo is initial welfare of producers; P is price of output; Y is quantity of output; C is cost; d is indemnification level; L is the disease loss; δ is a dummy variable where $\delta = 1$ when producers do x_1, $\delta = 0$ otherwise.

The utility maximization problem for the producer is specified as follows:

$$\begin{aligned}
\mathbf{Max}_{x} \;\; L = {} & \left(1-\delta\right)\Big[\left(1-\rho(x_0)\right)U\big(W_0 + PY - C - rx_0 - PR(d)\big) \\
& +\rho(x_0)U(W_0 + PY - C - rx_0 - PR(d) - L + (1-d)L) \Big] \\
& +\delta\Big[\left(1-\rho(x_1)\right)U(W_0 + PY - C - rx_1 - PR(d)) + \\
& \rho(x_1)U(W_0 + PY - C - rx_1 - PR(d) - L + (1-d)L) \Big]
\end{aligned} \tag{1}$$

In equation (1), the utility of the producer is represented by two alternatives. The first two lines represent when a producer does not execute certain prevention measures ($\delta = 0$). At same time, the probability of occurrence of an invasive species outbreak is

$\rho(x_0)$ instead of $\rho(x_1)$. Thus, 1- $\rho(x_0)$ is the probability that an invasive species outbreak will not happen. When no invasive species outbreak occurs, there is no loss for the producer and no indemnification; on the other hand, when an invasive species outbreak does occur, the producers will suffer a loss L, as well as get indemnification, which is represented by $(1-d)L$.

Ex post indemnification Model

With *ex post* indemnification, the expected utility function does not include premiums (PR) and (1) could be respecified as

$$\begin{aligned} &\underset{x}{\mathbf{Max}}\ L = (1-\delta)\big[\ (1-\rho(x_0))U(W_0+PY-rx_0-C)+ \\ &\rho(x_0)U(W_0+PY-C-rx_0-L+(1-d)L)\ \big] \\ &+\delta\big[\ (1-\rho(x_1))U(W_0+PY-C-rx_1)+ \\ &\rho(x_1)U(W_0+PY-C-rx_1-L+(1-d)L)\ \big] \end{aligned} \tag{2}$$

The difference between (1) *ex ante* insurance and (2) *ex post* indemnification is that the producers do not pay premiums in order to get compensation when an outbreak occurs.

Tiered indemnification or insurance

For tiered indemnification or insurance, the indemnification is no longer a constant, but a function of the discrete input choice x. x may take a value equal either zero or one, depending on whether the risk mitigating input is chosen. Premiums, PR are a function of x, such that $PR(x_1) < PR(x_0)$. The insurance deductible (d) is conditional on the government observation of x such that $d(x_1) < d(x_0)$. Thus, a producer pays a lower deductive and receives higher indemnification coverage with x_1.

The utility maximization problem with tiered indemnification or insurance with complete observability on the part of the government is specified as (with indemnification *PR* = 0)

$$
\begin{aligned}
&\underset{x}{\mathbf{Max}}\ \ L = (1-\delta)\big[\ \ (1-\rho(x_0))U(W_0 + PY - C - rx_0 - PR(x_0)) + \\
&\rho(x_0)U(W_0 + PY - C - rx_0 - PR(x_0)\ \ - L + (1-d(x_0))L)\ \ \big] + \\
&\delta\big[\ \ (1-\rho(x_1))U(W_0 + PY - C - rx_1 - PR(x_1)) + \\
&\rho(x_1)U(W_0 + PY - C - rx_1 - PR(x_1)\ \ - L + (1-d(x_1))L)\ \ \big]
\end{aligned}
\tag{3}
$$

In (3), if producers do x_1 it is assumed that their behavior can be observed. Correspondingly, they pay $d(x_1)$ and $PR(x_1)$ in the event of an outbreak.

Lastly, we consider the option of tiered indemnification or insurance when x is not completely observable. This is reflected by the parameter γ in (4) which is the probability that the government mistakenly assumes $x = x_1$ when in fact $x = x_0$. In other words, the government mistakenly assumes the producer has implemented certain preventive measures. Given incomplete observability, the utility maximization problem can be written as

$$
\begin{aligned}
&\underset{x}{\mathbf{Max}}\ \ L = (1-\rho(x_1))U(W_0 + PY - F - C - rx_1 - PR(x_1)) \\
&+\rho(x_1)U(W_0 + PY - F - C - rx - PR(x_1) - L + (1-d(x_1))L) \\
&+(1-\gamma)(1-\rho(x_0))U(W_0 + PY - F - C - rx_0 - PR(x_0)) \\
&+(1-\gamma)\rho(x_0)U(W_0 + PY - F - C - rx_0 - PR(x_0) - L + (1-d(x_0))L) \\
&+\gamma(1-\rho(x_0))U(W_0 + PY - F - C - rx_0 - PR(x_1)) \\
&+\gamma\rho(x_0)U(W_0 + PY - F - C - rx_0 - PR(x_1) - L + (1-d(x_1))L)
\end{aligned}
\tag{4}
$$

The third and forth lines in (4) represent the case where the producer does x_0 and it is correctly realized by the government. The forth and fifth lines describe the case where the producer does x_0 and the government believes the producers has done x_1.

Data Collection and Survey Design

A survey is designed where we focus on producer behavior in mitigating outbreaks of critical poultry diseases high pathogenic avian influenza, the H5 and H7 subtypes of low pathogenic avian influenza which can mutate into high-path, and Exotic Newcastle disease because these diseases have had or could have substantial economic impacts on the poultry industry. Additionally, there already are different levels of experience with these different diseases, ranging from virtually no experience to moderate levels of experience. This allows an examination of risk perceptions based on different experience levels with a disease, as well as the potential for management to mitigate these risks. The survey questions are based on AI (Avian Influenza) and END (Exotic Newcastle Disease). Experts in the poultry field are asked to respond to the survey because they have a lot of experience in invasive species issues

In the survey design, we include two parts: the first section provides background information and context, which gives the experts a presumed production environment and a description of several risk decreasing measures which include the following:

1) Avoid taking birds away from the premises and returning them during an AI outbreak.
2) All flocks should be fenced or confined in order to avoid contact with any wild birds, especially waterfowl.
3) Introduce new stock only from sources known to be AI free and not from areas in or near an AI outbreak zone.

4) Anyone on the site must wear rubber boots, and wear them only on his/her premises to avoid ‘tracking in’ disease.
5) All dead birds must be disposed of on the farm in a bio-secure manner.
6) Eggs must be held on the premise until the farm is released from quarantine.
7) Before another generation of chickens enters the farm, wash and sanitize the chicken house.

The second part of the survey asks for probability assessments. Questions are repeated for each practice. An example practice is “Avoid taking birds to (or bringing birds home from) the premises during an AI outbreak.” Questions related to this practice are expressed below:

1) Assuming the company and each production unit have done every measurement perfectly, how many AI outbreaks would you expect the company to incur on the 1,000 units during the next year?
2) Assuming the company and each production unit have done all the measurements except “Avoid taking birds to (or bringing birds home) from the premises during an AI outbreak”, what is the probability of an out break for this company?
3) Assuming the company and each production unit have done all the measurements except the measure “Avoid taking birds to (or bringing birds home) from the premises during an AI outbreak”, what is the probability of the out break for this company?

4) Consider typical industry practices what is the probability a company will consistently follow the practice “Avoid taking birds to (or bringing birds home) from the premises during an AI outbreak.” From scale 0 to 100 (0 is no change at all and 100 is absolute certainty), what is the probability each practice will be followed consistently during the previous 12 months?
5) If AI outbreaks in this company’s production unit and APHIS inspector want to investigate the reason. What is the probability the inspectors can accurately assess whether “Avoid taking birds to (or bringing birds home) from the premises during an AI outbreak”, was followed during the previous 12 months?
6) Assume APHIS was to randomly check 10 of the 1000 units each year with an unannounced visit. Each of the 11 measures would be examined. If violations were observed the company would be fined $10,000. What is the probability the inspectors can accurately assess whether “Avoid taking birds to (or bringing birds home) from the premises during an AI outbreak”, was followed during the previous 12 months?
7) Assume the company and each production unit knows that if an outbreak occur and APHIS concludes the facility has not followed all listed practices no indemnity will be paid. What is the probability of an outbreak for this company?

8) Assuming the company and each production unit knows that APHIS will do random spot checks of 10 facilities each year. What is the probability of an outbreak for this company?

Finally, some questions are aimed to get some general industry information.

1) The average industry fixed cost for a one thousand bird production unit is how much?
2) When an invasive species outbreak occurs, what will be the loss level, for example, what percentage of total bird should be eradicated?

Conclusions and Future Research

This paper describes the current measures used by USDA to mitigate the risk of invasive disease in livestock such as Avian Influenza and makes comparison of different measures. Then, by building conceptual models for each measure under different observability condition, this paper reflects the relationship between producer utility and the adoption of different preventive measures. The results of this research will show how the government can control producer behavior by choosing the appropriate policy to induce disease mitigation. While it is expected that indemnification will be the best course of the action in the beginning stages of infestation and spread, when producers have more direct experience with losses, there may be a positive willingness to pay for insurance. In cases when insuring risk would likely be fraught with moral hazard issues, how to improve observability of producers would be a critical issue.

In the further research, the conceptual model proposed will be used to derive analytical results with respect to the key decision variables. The results of the conceptual model will be used to develop simulation models of END and AI; however, the results can also be used to form specific testable hypotheses about whether existing programs are consistent with derived results for various species in different stage of spread and development. The empirical model will be parameterized using data gathered as described above to investigate the magnitude of the impacts with respect to key variables. The empirical model will also be used to conduct sensitivity analysis when necessary.

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