Optimal border policies for invasive species under asymmetric information

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Abstract

This paper analyzes policies to reduce unintentional imports of invasive species. Previous work has typically assumed invasive species risk to be exogenous and constant for a given exporting region. In contrast, we examine cases in which risk may change due to endogenous actions (exporter risk abatement practices). In addition, we allow for unobservable differences in abatement costs across exporters. For these reasons, exporters may have better information regarding their idiosyncratic risk than the importing country's border control agents. We show how the optimal inspection/penalty regime differs in such cases from that derived for a symmetric information setting.

JEL Codes: D82, H23, L51, Q18, Q56

Invasive flora and fauna often arrive via movements of traded goods. Despite formal efforts to mitigate risk through border inspections in the U.S., a fraction of total goods are examined. Such a fact is evident from monthly inspection data of the Animal and Plant Health Inspection Service (APHIS) of the USDA over the period of 1996-2006. For example, for fruits and vegetables over 7 million shipments were inspected at 144 U.S. ports of entry. On average, APHIS agricultural inspectors inspect two percent of all the contents of this volume of traded goods. Given inspection constraints, there is a need for both effectively gathering and using risk information to target the inspections as well as ponder strategies beyond inspections to fully address the invasive species threats.

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It is well recognized that accidental importation of invasive species can radically alter local ecosystems resulting in significant harm to agricultural producers. Bell and Wilen (2003) indicates that 40 percent of the endangered native species are at risk from invasive species. Pimental et al. (2005) estimate total damages to the U.S. economy from non-native invasive plants in natural areas and agriculture at about $35 billion per year. Out of concern for avoiding such damage many countries impose technical barriers to trade, particularly in agricultural commodities. These barriers range from import bans, to product standards (testing to ensure that cargo does not carry unwanted organisms) and process standards (such as treatment of cargo with pesticides) Roberts et al. (1999). The emphasis tends to be on preventing introduction of organisms with only secondary efforts if any for enlisting cooperation from foreign exporters in the private sector. In addition to antagonizing trading partners, such policies may not maximize welfare in the importing country, particularly if individual exporters have better information regarding the presence of an organism in their cargo than does the home country's inspection agency.

Thus far, the economics literature on invasive species has not formally considered information asymmetry problems nor policies to try and address them. Shogren (2000) offers a theoretical look at incorporating economic risk reduction strategies for invasive species where the government, not traders carry out mitigation and adaptation. Shogren (2000) and Kaiser and Roumasset (2002) formulate models that combine action before and after establishment instead of analyzing them separately. Eiswerth and Johnson (2002) apply an optimization model to eradicating an invasive terrestrial weed. Olson and Roy (2002) have explored the optimal control of an invasive species when there are nonconvexities complicating eradication once the species has arrived. Horan et al. (2002) address invasive species with uncertainty in an expected outcome model and conclude more resources should be devoted to high damage events. However, many biologists do not believe eradication can eliminate terrestrial or aquatic invasive species (Ruiz and Carlton, 2003).

In a trade context, Costello and McCausland (2003) explore a theoretical relationship between agricultural imports and invasive species and show how barriers to trade backfire in an effort to prevent damage when import demand is inelastic. McAusland and Costello (2004) analyze the interaction of tariffs and inspection for agricultural imports with hypothetical infection rates of invasive species. This analysis, however, did not evaluate the tradeoff between inspections and sanctions or fines nor did it consider potential avoidance behavior in response to enforcement. If regulators can offer coordination to help solve market failures such as negative externalities of invasive species and asymmetric information, then maybe some objectives of regulation can be obtained ex ante. Preclearance may fall into the category of ex ante enforcement as a quality certification measure at the point of origin (in the country where it is produced prior to export) that has not been well researched.

Articles on invasive species prevention and control do not address the specifics of border enforcement

(Kim et al., 2006; Horan et al., 2002; Jensen, 2002; Olson and Roy, 2005). Horan et al. (2002) address pre-invasion control of invasive species to compare full information and uncertainty with only the government as the decision-maker. Thomas and Randall (2000) look at the role of information and reversibility in invasive species management of intentional releases where there are ways of assigning liability ex ante.

The tradeoffs between the costs and benefits of inspection policies in an invasive species context are considered by Batabyal (2004a,b), Batabyal and Beladi (2004), and Moffit et al. (2005). While Batabyal provides details on how maritime inspections are carried out and accounts for economic losses due to delay, this work primarily presents a queuing theory approach and includes a very simple implicit assumption, less stringent inspections lead to more damages from biological invasions. Batabyal and Belandi conclude that if the costs of regulation are important then port managers should use a less stringent inspection regime while they should use a more stringent regime if reducing the damages from biological invasions is a priority. Moffit et al. focus on dealing with the limited knowledge that policy makers have concerning risks and policies that involve achieving threshold levels of risk. Their results could be interpreted to show that high levels of robustness may be achieved with low levels of inspections due to low inspection costs, or with high levels of inspection given low levels of expected losses. In addition, given expected losses are low and acceptable failure rates are high, high levels of robustness could be achieved with fewer inspections.

With respect to the theoretical economic literature on markets with asymmetric information, modeling whether an exporter's cargo contains an invasive species is similar to modeling in which quality is uncertain as in Akerlof's (1970) seminal "lemons" model. The presence of an invasive species in one of two otherwise identical cargoes is equivalent to modeling that cargo as being of inferior quality that cannot be costlessly observed by the importer. The food safety literature includes some models of asymmetric information. Starbird (2005) addresses one aspect of asymmetric information, moral hazard, but not adverse selection, in a theoretical discussion of pathogen control through sampling inspection. Gramig et al. (2009) assume exogenous inspection for investigating indemnity programs of food safety on animal products where moral hazard and adverse are involved. This article differs from our model as they assume farmers to be ex ante homogeneous and to know the health status of their animals, whereas we assume cargo status to be known imperfectly by heterogeneous exporters and we allow the regulator to choose inspection rates endogenously.

For many types of invasive species, exporters have better information regarding the presence of an invasive species in their cargo than does a government agent from the importing country. Consider the case, for example, in which the invasive species is an insect pest. Pest populations can vary both across time and space with current local environmental conditions leading to risk-reduction costs that may widely vary across producers. As a result, producers may undertake different levels of abatement and thus have better knowledge about the ultimate riskiness of their cargo than the government.

Ideally, the importing country would like exporters voluntarily to disclose the information, and undertake the socially optimal level of abatement. Then only high-risk cargo would be fumigated at the border. Of course, such a disclosure scheme is unlikely to be successful in practice if the only consequence of reporting an invasive species is a loss in exporting profit. It would not be incentive compatible for exporters to reveal the information.

One alternative to this simple voluntary disclosure scheme is to ban imports from countries considered to pose high risks of containing invasive species and to allow imports from those with sufficiently low risk. How to measure these risks is the subject of much research, and an area that we will not address. Similarly, much work has been done in determining an optimal threshold for determining the level of risk that justifies a ban.

Another alternative examined in the literature, but not used in practice, is to borrow policy instruments form the environmental economics literature on optimal pollution, and use taxes (in this case import tariffs) to reduce imports from high-risk areas.

A third policy option is to use inspections of either the product or the process used to produce or package the product to prevent introduction of invasive species. Since such inspections are costly, they tend to be implemented randomly. Inspections are effective at deterring exporters from shipping contaminated goods only inasmuch as there are sufficient penalties for being caught. Limited liability of exporters can limit the effectiveness of such penalties. Thus exporters with contaminated goods may be willing to run the risk of getting caught.

What these alternatives have in common is that they can be designed in a way to help countries manage risk, but they still allow the possibility of introduction of invasive species from low (but not zero) risk countries, or from the reduced, but still positive, trade from countries paying high tariffs, or from exporters of contaminated goods who are not inspected. These policies also have in common the feature that they do not give individual exporters any incentive to disclose their information.

We consider a fourth option that has not received much attention in the literature: compensating exporters for disclosing that their cargo has a high risk of contamination. In the simplest scenario, payments need only be sufficient to cover lost export revenue. It would then be incentive compatible for exporters to disclose the truth and no invasive species would enter the importing country.

Our goal is to open a new line of research into the efficient design of policies to encourage exporters to reveal private information regarding the presence of invasive species. Thus, we fill important gaps in the literature on the economics of invasive species.

In practice we observe some alternative ways that regulatory agricultural inspection agencies in North America deal with invasive species. We draw on several real world cases to set up models that investigate the economic incentives amidst asymmetric information occurring in these cases. For example, one alternative is a program of preclearance that involves inspectors from each of the three NAFTA countries carrying out inspection in Holland for the bulb industry to prevent soil born invasive insects (nematodes) in bulbs exported for planting in North America. A second alternative is a program that involves an international standard for any exports involving wood packaging. The standard requires any shipment have a label indicating the required treatment to prevent woodboring invasive species has taken place prior to export. The treatment involves some technology that has been disseminated with the help of some importing countries such as Canada for heat treatment. A third alternative is a program that involves technical assistance to horticultural exporters that has value depending on how much abatement is undertaken in the exporting country to prevent invasive species for the importing North American market.

Our research analyzes optimal use of border protection policy instruments under conditions of asymmetric information regarding the riskiness of an exporter's cargo. The border protection policy can apply to two scales, one single country in North America or for North America as a whole (three NAFTA countries) in the context of the North American Plant Protection Organizations coordination between national agricultural inspection operations of the three countries.

We assume that a shipment is either clean or infected. The shipment can be any traded good imported to North America (largely agricultural for reference to cases relevant to the NAPPO) that originates in the rest of the world (not North America). The exporter then refers to a trading entity from the rest of the world shipping to North America. The probability that a shipment is infected is a function of an abatement effort undertaken by the exporter to reduce the probability of infection, and technical assistance provided by the importing country (eg, training on management practices). Abatement effort is privately known by the exporter, but endogenously chosen as a function of the exporter's privately known abatement cost.

We refer to the PPQ280 database for past inspection records related to cases of interest to NAPPO. The inspection records offer some information, but not all related to episodic events. For example, with a shipment for a crop, the disposition code of action taken does not offer comments related to which type of invasive species might be found, or how long the inspection took.

The importing country's border protection agency (the regulator) assigns an inspection intensity level (probability that an infected shipment is rejected at the border) to all importers. In addition transfers (positive or negative) are made to each exporter as a function of his type. The inspections take place at the border of the importing trade group (NAFTA). The transfer can be thought of as an information provision by the importing trade group regarding inspection. One form of information provision is preclearance where inspection by the importing trade group is carried out in the exporting country. A preclearance program from the bulb industry in Holland, has been in existence since the 1950s. In this case, North American inspectors (from Canada, U.S. and Mexico) inspect bulbs in Holland to prevent any soil-bearing insects (nematodes) from being shipped into North America, in order to avoid a risk for any soils the bulbs might be planted in. The reason the transfer may be positive or negative is that the preclearance inspection information can be paid for in part by the bulb industry (exporter) and importing trade group regulator.

The goal is to maximize social welfare which includes consumer surplus from imports less damage from invasives that are not caught and cost of inspection, transfers, and technical assistance. We also allow for perishable goods. Inspections take time, so increasing inspection intensity causes the value of the good (for both the importer and exporter) to depreciate.

1 Model

We model the interaction between an importing country's border protection agency, referred to as the regulator, and exporters (all parties risk neutral) as a non-repeated Stackelberg game in which the regulator is the first mover. We obtain the Perfect Bayesian Equilibrium through backwards induction. We first derive the exporter's best response to any set of policy instruments proposed by the regulator, then use this information to derive the regulator's optimal set of policy instruments.

Our model has a fixed population (normalized to one) of exporters each with a single shipment of a perishable good. A shipment's status is binary (clean or infected), with a baseline risk of infection B. Exporters can undertake two levels of abatement, a^ℓ and a^h, where $a^\ell < a^h < B$, to reduce this risk to $B - a$.

Producers are heterogeneous in terms of abatement costs. In some regions, for example, the same effort may reduce risk more than in others. For simplicity, we assume two types of exporters. A low-cost (type 1) exporter achieves the two abatement levels by incurring θc^ℓ and θc^h (with $c^\ell < c^h$ and $\theta \in (0,1)$), while a high-cost (type 2) exporter incurs c^ℓ and c^h, with $c^\ell < \theta c^h$. Exporters are otherwise equivalent, with an opportunity cost of providing the good normalized to zero. Type and abatement are assumed to be privately known by the exporter, while the ex post status of the shipment is unknown to both parties in the absence of an inspection. The regulator and exporters share common beliefs regarding the distribution of types: The probability that an exporter is type 1 is g.

If a shipment containing an invasive enters the importing country's market it causes damage d. The regulator decides the terms under which shipments can enter the country. Any shipment can be fumigated at the importing country's port at cost f to eliminate invasive risk. Fumigation indicates a treatment that can present chemical, heat or other form of preparing the shipment for market access upon inspection approval. In the PPQ280 database of the U.S. APHIS/Customs and Border Protection Agency such treatment is referred to as a disposition code (action code) that refers to how the shipment is categorized by the inspection effort to deal with how the shipment may enter the market. The location of the fumigation at first is at the border of the importing trade bloc. However, there can be a modification to consider this taking place in the exporting country prior to the border.

In addition, a random border inspection can reveal the presence of an invasive in a shipment. The inspection intensity, $I \in [0,1]$ is the probability of finding an invasive (if present). The cost of inspection intensity is $k(I)$ where $k' \geq 0$, $k'' > 0$, $k'(0) = 0$, and $\lim_{I \to 1} k'(I) = \infty$. Inspections take time, and depreciate the value of the good by discount factor $\delta(I) \in [0,1]$, where $\delta(0) = 1$, $\delta' < 0$, and $\delta'' < 0$.

Let $p(\cdot)$ denote the importing country's inverse demand curve, with $p'(\cdot) < 0$. Consumer surplus is $\int_0^{\delta(I)} p(q)\mathrm{d}q - p(\delta(I))\delta(I)$. An exporter's expected market return from shipping the good is $\delta(I)p(\delta(I))$. We assume the total market surplus provided by the good, $\int_0^{\delta(I)} p(q)\mathrm{d}q$, is greater than the fumigation cost (otherwise the regulator would rather reject the good at the border than fumigate), as is the environmental harm caused by an invasive (else the regulator would prefer to let an infected good pass rather than fumigate). We further assume that fumigation cost is sufficiently greater than the expected damage from a shipment with a high level of abatement, $[B - a^h]d$, that it is not worthwhile to simply fumigate all incoming shipments without inspection.

We model the interaction between the regulator and exporters as a principal-agent problem. The regulator first announces the inspection intensity, then assigns a contract to each type exporter. Each contract consists of a transfer, t, and a fumigation fee ϕ incurred only if the shipment is found to contain an invasive.

Let $\langle t_i, \phi_i \rangle$ denote a contract assignment to type $i = 1, 2$. Equilibrium exporter expected profit is

$$\pi_1 = t_1 - \theta c_1 - I\phi_1(B - a_1) + \delta(I)p(\delta(I)); \tag{1}$$

$$\pi_2 = t_2 - c_2 - I\phi_2(B - a_2) + \delta(I)p(\delta(I)); \tag{2}$$

$$c_i = c^j \text{ if } a_i = a^j, \text{ for } i = 1, 2 \text{ and } j = h, \ell. \tag{3}$$

The regulator seeks to maximize the importing country's consumer surplus, less damage caused by invasives and net transfers abroad:

$$W(a_1, a_2, I) - [g\pi_1 + [1 - g]\pi_2], \tag{4}$$

where

$$\begin{aligned} W(a_1, a_2, I) = \int_0^{\delta(I)} p(z)\mathrm{d}z - k(I) - g\left\{[B - a_1]\left[[1-I]d + If\right] - \theta c_1\right\} \\ -[1-g]\left\{[B - a_2]\left[[1-I]d + If\right] - c_2\right]\right\}. \end{aligned} \tag{5}$$

Suppose abatement and type are observed by the regulator and thus directly contractible. The only constraints the regulator faces are that exporter profit be non-negative (or else they would refuse to ship their product). The regulator has no need to impose fumigation charges, since she can simply dictate the desired abatement level. Since transfers are costly, she reduces them as far as possible, leaving exporters with zero expected profit. The optimal inspection rate solves first-order condition

$$\delta'(I)p(\delta(I)) - k'(I) + [h - f][B - ga_1 - [1-g]a_2] = 0. \tag{6}$$

Abatement levels are chosen simultaneously with I as follows:

$$a_1 = \begin{cases} a^h & \text{if } I \le \frac{\theta[c^h - c^\ell] - d[a^h - a^\ell]}{[a^h - a^\ell][f - d]} \\ a^\ell & \text{otherwise.} \end{cases} \tag{7}$$

$$a_2 = \begin{cases} a^h & \text{if } I \le \frac{[c^h - c^\ell] - d[a^h - a^\ell]}{[a^h - a^\ell][f - d]} \\ a^\ell & \text{otherwise.} \end{cases} \tag{8}$$

Let a_1^*, a_2^*, I^* denote the values of abatement and inspection that solve this problem. For the rest of the paper, we focus on the interesting case in which the regulator would prefer that the low-cost type undertake a high level of abatement, and the high-cost type undertake a low level of abatement. Under symmetric information regarding type and abatement, the regulator's maximum welfare is then $W(a^h, a^\ell, I^*)$.

If type and abatement are private information for the exporter, the regulator faces problems of both adverse selection and moral hazard in determining the optimal policy. For a contract allocation to be feasible, it must satisfy both individual rationality and incentive compatibility. Since trade is voluntary, exporters only send shipments if their expected profit is positive. These two (one for each type) individual rationality, or participation, constraints are

$$t_1 - \theta c_1 - I\phi_1(B - a_1) + \delta(I)p(\delta(I)) \ge 0; \tag{9}$$

$$t_2 - c_2 - I\phi_2(B - a_2) + \delta(I)p(\delta(I)) \ge 0. \tag{10}$$

Incentive compatibility constraints reflect the fact that the regulator can observe neither type nor abatement. Thus, for a contract allocation to be feasible, an exporter's assigned contract must maximize his profit relative to the contract on offer to the other type. In addition, the exporter must maximize profit by choosing the abatement level intended by the regulator versus the undesired abatement level, denoted $\tilde{a}_i$ at cost $\tilde{c}_i$. There are thus three incentive compatibility constraints for each exporter: Profit from the assigned contract and desired abatement level must be no lower than that obtainable from the assigned contract and the undesired abatement level, the unassigned contract and the desired abatement level, and the unassigned contract and the undesired abatement level. Together, these six incentive compatibility constraints are:

$$
\begin{aligned}
&(11) & t_1 - \theta c_1 - I\phi_1(B - a_1) + \delta(I)p(\delta(I)) &\geq t_1 - \theta \tilde{c}_1 - I\phi_1(B - \tilde{a}_1) + \delta(I)p(\delta(I));\\
&(12) & t_1 - \theta c_1 - I\phi_1(B - a_1) + \delta(I)p(\delta(I)) &\geq t_2 - \theta c_1 - I\phi_2(B - a_1) + \delta(I)p(\delta(I));\\
&(13) & t_1 - \theta c_1 - I\phi_1(B - a_1) + \delta(I)p(\delta(I)) &\geq t_2 - \theta \tilde{c}_1 - I\phi_2(B - \tilde{a}_1) + \delta(I)p(\delta(I));\\
&(14) & t_2 - c_2 - I\phi_2(B - a_2) + \delta(I)p(\delta(I)) &\geq t_2 - \tilde{c}_2 - I\phi_2(B - \tilde{a}_2) + \delta(I)p(\delta(I));\\
&(15) & t_2 - c_2 - I\phi_2(B - a_2) + \delta(I)p(\delta(I)) &\geq t_1 - \tilde{c}_2 - I\phi_1(B - \tilde{a}_2) + \delta(I)p(\delta(I));\\
&(16) & t_2 - c_2 - I\phi_2(B - a_2) + \delta(I)p(\delta(I)) &\geq t_1 - c_2 - I\phi_1(B - a_2) + \delta(I)p(\delta(I)).
\end{aligned}
$$

Since this problem exhibits both adverse selection and moral hazard, there are more incentive compatibility conditions than in the standard models that only have one type of asymmetric information (see, for example, Salanié, 2005). Nonetheless, we are able to simplify the problem by showing that at the optimum, at least four of these eight constraints are inactive. We derive these constraints for the four possible abatement allocations: $a_1 > a_2$, $a_1 = a_2 = a^h$, $a_1 = a_2 = a^\ell$, and $a_1 < a_2$.

We can discard the last case since it violates incentive compatibility. Summing up constraints (13) and (15) for this case requires $\theta[c^h - c^\ell] \geq c^h - c^\ell$, which violates the assumption that $\theta \in (0, 1)$.

We now consider the case $a_1 > a_2$. First, note that the right-hand side (RHS) of (13) minus the left-hand side (LHS) of (10) is $[1 - \theta]c^\ell > 0$. Thus, holding all else equal, t_2 can be reduced until (10) holds as an equality, without violating (13). This adjustment reduces π_2, improving the principal's welfare. Similarly, t_1 can be reduced until (13) holds as an equality without violating condition (9). In fact, satisfaction of (13) implies (9) is satisfied and can be safely ignored. We must still verify that no other constraints are being violated.

With (10) and (13) binding, the LHS of (13) minus the RHS of (15) is $[1 - \theta]c^h$. Since the LHS of (13) is $[1 - \theta]c^\ell$, which is less than $[1 - \theta]c^h$, it must be the case that the RHS of (15) is less than zero. Thus, satisfaction of (10) implies satisfaction of (15), and this constraint can be safely ignored.

From (11), $-I\phi_1(B - a^\ell) \leq -\theta[c^h - c^\ell] - I\phi_1(B - a^h)$. With (13) binding, the RHS of (16) is less than or equal to zero. Satisfaction of (10) therefore implies satisfaction of (16), and this constraint is inactive.

With (10) binding, (12) requires $\phi_2 \leq [\theta c^h - c^\ell]/[I[a^h - a^\ell]]$. Since satisfaction of (14) requires $\phi_2 \leq [c^h - c^\ell]/[I[a^h - a^\ell]]$, this latter constraint is also inactive. Finally, note that condition (11) implies $\phi_1 \geq \frac{\theta[c^h - c^\ell]}{I[a^h - a^l]}$.

To summarize, a contract inducing type 1 to undertake a^h and type 2 to undertake a^ℓ is feasible if only the following constraints are satisfied:

$$
\begin{aligned}
t_1 &= [1-\theta]c^\ell + \theta c^h + I\phi_1(B - a^h) - \delta(I)p(\delta(I)); && (17)\\
t_2 &= c^\ell + I\phi_2(B - a^\ell) - \delta(I)p(\delta(I)); && (18)\\
\phi_1 &\geq \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]}; && (19)\\
\phi_2 &\leq \frac{\theta c_h - c_l}{I[a^h - a^\ell]}. && (20)
\end{aligned}
$$

Since both the regulator and exporters are risk neutral, they are indifferent to the values of ϕ_i: Any reductions in ϕ_i are offset by increases in t_i required by Eqs. (27) and (28). Without loss of generality, we simplify the exposition by setting the fumigation fees equal to their minimum values, $\phi_1 = \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]}$ and $\phi_2 = 0$. The regulator's optimization problem can then be restated:

$$
\max_I W(a^h, a^\ell, I) - g[1-\theta]c^\ell = W(a^h, a^\ell, I^*) - g[1-\theta]c^\ell. \tag{21}
$$

We next consider the case $a_1 = a_2 = a^h$. Note that RHS of (12) minus LHS of (10) is $[1-\theta]c^h > 0$. Thus, holding all else equal, t_2 can be reduced until (10) holds as an equality, without violating (12), and t_1 can be reduced until (12) holds as an equality without violating condition (9). Since (12) implies (9), this individual rationality constraint may be safely ignored.

With (10) and (12) binding, the LHS of (12) minus the RHS of (16) is $[1-\theta]c^h$. Since the LHS of (13) is $[1-\theta]c^h$, it must be the case that the RHS of (15) is zero and (15) may be safely ignored since it is implied by (10).

From (11), $-I\phi_1(B - a^\ell) \leq -\theta[c^h - c^\ell] - I\phi_1(B - a^h)$. With (12) binding, the RHS of (15) is less than or equal to zero. Satisfaction of (10) therefore implies satisfaction of (16), and this constraint is inactive.

Note that condition (11) implies $\phi_1 \geq \frac{\theta[c^h - c^\ell]}{I[a^h - a^l]}$, and (14) implies $\phi_2 \geq \frac{c^h - c^\ell}{I[a^h - a^\ell]}$. RHS of (12) minus RHS of (13) is positive since $\phi_2 > \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]}$. Consequently, (13) is inactive.

To summarize, a contract inducing both types to undertake a^h is feasible if only the following constraints are satisfied:

$$
\begin{aligned}
&(22) \qquad & t_1 &= c^h + I\phi_1[B - a^h] - \delta(I)p(\delta(I));\\
&(23) \qquad & t_2 &= c^h + I\phi_2[B - a^h] - \delta(I)p(\delta(I));\\
&(24) \qquad & \phi_1 &\geq \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]};\\
&(25) \qquad & \phi_2 &\geq \frac{c_h - c_l}{I[a^h - a^\ell]}.
\end{aligned}
$$

We simplify the exposition by setting the fumigation fees equal to their minimum values, $\phi_1 = \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]}$ and $\phi_2 = \frac{c_h - c_l}{I[a^h - a^\ell]}$. The regulator's optimization problem can then be restated:

$$(26) \qquad \max_I W(a^h, a^h, I) - [1 - \theta]c^h.$$

Finally, consider the case $a_1 = a_2 = a^\ell$. Note that RHS of (12) minus LHS of (10) is $[1 - \theta]c^\ell > 0$. Thus, holding all else equal, t_2 can be reduced until (10) holds as an equality, without violating (12), and t_1 can be reduced until (12) holds as an equality without violating condition (9). Since (12) implies (9), this individual rationality constraint may be safely ignored.

With (10) and (12) binding, the LHS of (12) minus the RHS of (16) is $[1 - \theta]c^\ell$. Since the LHS of (13) is also $[1 - \theta]c^\ell$, it must be the case that the RHS of (16) is zero and (16) may be safely ignored since it is implied by (10).

From (11), $-I\phi_1(B - a^\ell) \leq -\theta[c^h - c^\ell] - I\phi_1(B - a^h)$. With (12) binding, the RHS of (15) is less than or equal to zero. Satisfaction of (10) therefore implies satisfaction of (15), and this constraint is inactive.

Note that condition (11) implies $\phi_1 \leq \frac{\theta[c^h - c^\ell]}{I[a^h - a^l]}$, and (14) implies $\phi_2 \leq \frac{c^h - c^\ell}{I[a^h - a^\ell]}$. Note that (12) is inactive if $\phi_2 > frac\theta[c^h - c^\ell]I[a^h - a^l]$, otherwise (13) is inactive.

To summarize, a contract inducing both types to undertake a^ℓ is feasible if only the following constraints are satisfied:

$$
\begin{aligned}
&(27) \qquad & t_1 &= c^h + I\phi_1[B - a^\ell] - \delta(I)p(\delta(I));\\
&(28) \qquad & t_2 &= c^h + I\phi_2[B - a^\ell] - \delta(I)p(\delta(I));\\
&(29) \qquad & \phi_1 &\leq \frac{\theta[c^h - c^\ell]}{I[a^h - a^\ell]};\\
&(30) \qquad & \phi_2 &\leq \frac{c_h - c_l}{I[a^h - a^\ell]}.
\end{aligned}
$$

We simplify the exposition by setting the fumigation fees equal to their minimum values, $\phi_1 = \phi_2 = 0$. The regulator's optimization problem can then be restated:

$$\max_{I} W(a^{\ell}, a^{\ell}) - g[1-\theta]c^{\ell}. \tag{31}$$

In comparing the three contracts discussed above, it is useful to evaluate the losses asymmetric information imposes on the regulator relative to the full information outcome. Asymmetric information causes two types of loss. The regulator must give positive profit (information rent) to the type 1 exporter. In addition, there is a possible efficiency loss if the regulator induces a different abatement level than under symmetric information. This efficiency loss is captured by the difference between the value of $W(\cdot)$ under symmetric information and under the various asymmetric information contract options. The information rents are captured by the excess profit given to the type 1 exporter (zero under symmetric information). Comparing expressions (21), (26), and (31) with $W(a^h, a^{\ell}, I^*)$ it is straightforward to see that the optimal contract under asymmetric information is that which induces abatement levels $a_1 = a^h$ and $a_2 = a^{\ell}$. Only with this contract is there no efficiency loss. Moreover the information rents in this contract are less than or equal to those provided by the other two.

2 Conclusion and Extensions

Implementation of border control to reduce the risk of unintentional entry of invasive species policy is likely characterized by both moral hazard and adverse selection. Moral hazard exists if exporters can undertake unobservable (to the importing country's border protection agency) actions that reduce the risk of an invasive being on their shipment. Adverse selection can exist if exporters are heterogeneous in their cost of undertaking such actions.

In this paper we have characterized an optimal border control strategy under such conditions of moral hazard and adverse selection and compared the welfare impact with an optimal policy under symmetric information. The border control strategy consists of an inspection intensity, a fumigation surcharge levied if inspections reveal the presence of an invasive, and a transfer.

With symmetric information, high cost producers would undertake low levels of abatement, while low-cost producers would undertake high levels. Inspections would take place, but there would be no need for fumigation charges. Transfers would leave producers with zero profit.

Under conditions of asymmetric information, it is optimal for the regulator to induce the same abatement levels as under symmetric information. To do so, however, it is necessary to couple inspections with fumigation surcharges. No surcharge is necessary for the high-cost exporter, but a positive fumigation charge is necessary for low-cost exporters. The surcharge must be set such that the reduction in the expected payment caused by undertaking the higher level of abatement is at least as large as the additional abatement cost. In order to induce low-cost exporters to voluntarily expose themselves to the possibility of paying a fumigation fee, transfers must leave them with strictly positive expected profit. High-cost exporters are left with zero expected profit.

In this model, asymmetric information does not cause any loss in economic efficiency since there is no distortion in abatement levels. This result stems in part from the assumption of risk neutral exporters. It is similar to the standard result in the moral hazard literature that under such risk preferences the principal can effectively overcome moral hazard by "selling the firm" to the agent, i.e., making the agent absorb the risk of his actions. In the present context, this is the effect of the fumigation charges. Nonetheless, adverse selection still results in a welfare loss to the principal.

The simple model presented here provides a starting point for future research efforts to provide practical policy advice for border protection agencies in reducing the risk of trade-borne invasive species. A few areas in which we are actively engaged include extensions to cover issues of limited liability, optimal fumigation rates, and technical assistance.

Limited liability is important since it affects the maximum amount of the fumigation charge. If a charge is too high, exporters may simply opt to redirect or destroy their shipment rather than pay the fee. In such cases, explored in the context of financial contracts by Innes (1990), the regulator may be unable to achieve the optimal abatement levels.

In the current model, the regulator offers the same inspection regime to all exporters, only payments differ. An interesting extension would be to allow the regulator to take advantage of information revealed in the contracts by offering different inspection regimes to different types. Specifically, it may be in the regulator's interest to inspect only low-cost types and offer high-cost types the opportunity to avoid inspections and have their shipments fumigated with certainty.

In practice, it is unlikely that regulators can provide cash transfers to exporters. We do, however, observe large importers such as the United States providing technical assistance to exporters to help reduce abatement costs. We are examining how the model can be extended to accommodate these kinds of activities.

The activities relate to the examples we draw upon for North America. The cases range from a preclearance program in place since the 1950s to a more recent effort elevated to an international standard. In all cases, three countries in North America act as one unified importer receiving exports from the rest of the world that must be regulated for invasive species protection. The reason that wood packaging and plants for planting are of interest as well as food and fiber crops is that they pose a direct threat to the environment from exposure, including soil borne insects on plants for planting such as bulbs from Holland or root stocks from Costa Rica. Our case studies addressing those imports to North America, will draw details from the existing programs in place that are relevant for inspection, preclearance, clean stock and technical assistance components. The model includes mechanisms designed help the exporters take into account the costs of accidental introduction of invasive species (soil borne or otherwise).

The preclearance program involving bulbs from Holland is the oldest one for North America, where inspectors from Canada, U.S. and Mexico conduct invasive species inspections in Holland, paid for by the Dutch bulb industry prior to export to North America. Having preclearance can speed the processing upon entry to the importing country (or North American Continent).

The wood packaging program that began in North America between Canada and the U.S. is now elevated to an International Plant Protection Standard #15 involves inspecting for a label of certification of internationally agreed upon treatment (fumigation, heat) as well as inspecting for physical evidence. Technical assistance has been offered from North America to guide exporting countries through treatment and certification so as to insure the standard is met.

Another horticulture product case study involves Dracaena, a cornlike stalk that has sparked significant technical assistance interaction between the exporting country, Costa Rica and the importing regulatory agency (APHIS). The plant has been plagued with invasive grasshoppers, cycadelits, scales, snails. Aiming for a Clean Stock Program that entails a comprehensive systems approach of preventing invasive species at each stage up through arrival into an importing country. As part of the effort, APHIS specialists from the Port of Miami have been involved in technical assistance to train and implement the program at each stage.

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