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International Agricultural Trade and Policy Center

**INVASIVE SPECIES MANAGEMENT THROUGH TARIFFS:
ARE PREVENTION AND PROTECTION SYNONYMOUS?**

By

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WPTC 04-10

December 2004

WORKING PAPER SERIES



**UNIVERSITY OF
FLORIDA**

Institute of Food and Agricultural Sciences

INTERNATIONAL AGRICULTURAL TRADE AND POLICY CENTER

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Invasive Species Management through Tariffs: Are Prevention and Protection Synonymous?

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Abstract

This Paper designs a political economy model of invasive species management in order to explore the effectiveness of tariffs in mitigating the risk of invasion. The revenue-interests of the government together with the interests of the lobby group competing with the imported agricultural commodity, that is believed to be the vector of invasive species, are incorporated in a Nash Bargaining game. The government, however, also considers the impact of tariffs on long run risks of invasion and decides optimal tariffs based upon its welfare in the pre and post-invasion scenarios. Along with the size of the lobby group, which is a function of the slope of the demand and supply curves, the weights assigned to the various components in the government welfare function too play a key role in influencing the extent to which tariffs could be an effective policy tool for invasive species management.

JEL CODES: H23, Q17, Q58

KEYWORDS: Invasive Species, Political Economy, Tariffs, Bargaining, Interest Groups

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Introduction

There options available to manage invasive species comprise prevention, monitoring and control. Recently, there have been some suggestions regarding the use of tariffs as a preventive measure by influencing the import of goods believed to be vectors of invasives. Costello and McAusland (2003) use a trade model to show that while tariffs may lower the rates of invasive species introduction, they may also cause higher damages from infestation due to increased domestic production. Using another trade model, McAusland and Costello (2004) look at the role of tariffs combined with monitoring efforts in managing invasive species. They find that while it is optimal to employ tariffs for managing invasive species, higher infection rate does not necessarily call for higher tariffs.

While it is important to understand the effectiveness of tariffs in preventing against invasion and damages, it must also be recognized that the use of tariff itself is guided by a multiplicity of factors, not all them aimed at invasive species control. Tariffs have primarily been used to protect domestic industries and to generate revenues for the government. The role of tariffs in mitigating risks of invasion cannot be looked upon in isolation of these other roles, as the effectiveness of tariffs in mitigating the risks of invasion could be significantly compromised by these multiple, and often conflicting, objectives.

The role of interest groups in influencing public policy has been a subject of concern lately, as new incidences of invasive species, specially the ones that have potential of harming humans, animals and plant species alike, have led to questionable management strategies. Recent outbreak in the US of Bovine Spongiform

Encephalopathy (BSE), commonly known as the mad cow disease, has caused widespread concerns over its impact on the beef industry from international trade restrictions and subsequent demands for ban of imports from countries thought to potential sources of BSE. Besides causing damages to the domestic beef industry, there are significant risks of the disease passing on to the humans (in the form of BSE-CJD).

When the disease has hosts that span multiple species, potential exists for conflicting interests among groups affected by it. There are similar other cases where import competing domestic agricultural industry may lobby to impose tariffs on imported agricultural products in the disguise of mitigating invasive species threat.

This aspect of influencing public policy has been a subject of intense research in the past, albeit, at a more general level where several domestic lobby groups seek to protect their interests against competition from imports. However, not much has been done so far to apply such political economy models to understand the interest-groups' influence on invasive species management. Yet, a lot remains to explore in terms of understanding the role of interest groups that are directly affected by invasives and their interaction with the government, especially over a long time horizon.

This paper seeks to explore the role played by domestic lobbying in influencing import of certain goods believed to be vectors of invasive species. While the modeling framework follows the lobbying concept as first formalized by Grossman and Helpman, it differs from the existing political economy models in several important regards. Only a single lobby group (the import-competing agricultural sector, in particular) directly affected by invasive species is considered here. While there may exist several other lobby groups, the interests of this particular differ from the rest in that it seeks not only to

protect against imported goods, but also against their hazards, which could even span the rest of the economy. In order to keep the analysis simple, it is assumed that its interests do not conflict with the rest of the existing interest groups, thus allowing the government to deal with them separately. This allows a more detailed modeling of the Nash-bargaining game between the agricultural group and the government. Specifically, the long term impacts of tariffs are explored where the government incorporates the post-invasion scenario in its bargaining objectives. This is an important feature of the invasive species management problem that needs to be incorporated in the political economy framework. Post-invasion scenarios may completely differ from pre-invasion scenarios in terms of the lobby groups interests, their ability to make contributions, the weights that the government assigns to rest of the economy, etc. Consequently, long term interests of the government may lead to policy outcomes that are completely different from those arising from one-shot interactions with the lobby groups. Yet, due to cumulative nature of risks of invasion (accumulating over time and economic activity), if tariffs are imposed for protection against invasives, their long term impacts are the ones that are of particular relevance to the society.

The paper, first, explores one time interaction between government and the lobby group by modeling a Nash bargaining game between the two. Tariffs serve as the control instrument that could affect the risk of invasion by restricting import of foreign goods competing with the lobbying industry's goods. Not any less significantly, tariffs also contribute towards government revenues and producer surplus of the lobby group. However, the flip side of tariffs is the increase in price of the domestic good in consideration, thus causing a reduction in the consumer surplus. Following the literature

on political economy of tariffs, the government is expected to incorporate in its welfare the weighted benefits of the producers and consumers of this commodity, besides its own revenues and the contributions it receives from lobby groups. The rest of the economy in this model is indirectly featured as the reverse of the weights assigned to this particular group of producers and consumers of the commodity. It is therefore reflected in the weights the government assigns to its own revenues as it would eventually use these revenues to affect its chances of survival by spending on the rest of the population (and other interest groups). The model then proceeds to consider the dynamic aspect of the bargaining game, wherein the benefits from optimal policies following an invasion are considered in the pre-invasion policies. Several scenarios are considered in the post-invasion situation that range from elimination of tariffs to continuation of bargaining but with various levels of damages to the producing sectors. The implications of such situations on optimal tariffs are considered. The role of weights assigned to the lobby group and the consumers along with the market strength of the lobbyist is found to be decisive in influencing the level of tariffs and thus the risk of invasion.

Model

Let the demand curve facing an economy for a certain good (q), believed to be a vector of potential invasives, be given by:

$$(1) \quad p = \alpha - \beta q$$

where p is the price of the commodity and q the quantity demanded. The domestic supply of the same commodity is given by:

$$(2) \quad p = \theta + \delta q$$

Assuming the domestic economy to be small so that it is not able to influence the world price of the commodity, p^w , the residual demand for import of the same commodity will be given by the difference between consumer demand and domestic supply as:

$$(3) \quad \frac{\alpha - p^w}{\beta} - \frac{p^w - \theta}{\delta}$$

The domestic industry producing the good lobbies for tariffs on imports by offering a contribution C to the government. The government's welfare function includes producer surplus of this domestic industry, the consumer surplus of the people consuming the good and its own revenues GR besides the contributions C . The government uses its revenues and the contributions to increase its prospects for future survival by spending it directly to improve its popularity or indirectly by distributing amongst the entire population.

The government puts a weight of a on the producer surplus, b on the consumer surplus and $(1-a-b)$ on its own revenues and contributions. Let τ be the tariff imposed on the import of this commodity and p^t the price of the commodity after tariffs. Further, noting that for a small economy tariffs are fully converted into an increase in domestic prices:

$$(4) \quad \tau = p^t - p^w$$

The Producer Surplus in presence of tariffs:

$$(5) \quad PS = \frac{(p^w + \tau - \theta)^2}{2\delta}, \text{ with } \frac{\partial PS}{\partial \tau} = \frac{\partial (p^w + \tau - \theta)^2}{2\delta} = +ve$$

Consumer Surplus in presence of tariffs:

$$(6) \quad CS = \frac{(\alpha - p^w - \tau)^2}{2\beta}, \text{ with } \frac{\partial CS}{\partial \tau} = \frac{\partial (\alpha - p^w - \tau)^2}{2\beta} = -ve$$

Government Revenue in presence of tariffs:

$$(7) \quad GR = \tau \left\{ \left(\frac{\alpha - p^w - \tau}{\beta} \right) - \left(\frac{p^w + \tau - \theta}{\delta} \right) \right\}, \text{ with}$$

$$\frac{\partial GR}{\partial \tau} = \left\{ \left(\frac{\alpha - p^w - \tau}{\beta} \right) - \left(\frac{p^w + \tau - \theta}{\delta} \right) \right\} - \tau \left\{ \frac{1}{\beta} + \frac{1}{\delta} \right\} \pm ve$$

The next step involves sharing the bounties of tariffs between the government and the lobby group through a bargaining game that maximizes the product of their surpluses.

One Time Bargaining Game

In order to share the rewards from tariffs between the lobby groups and the government, a Nash bargaining game is played between the two, which aims at maximizing the joint product of their surpluses. The government's and industry's surpluses are the difference between their welfare before and after tariffs. Government welfare from tariffs is given by:

$$(8) \quad a \frac{(p^t - \theta)^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1 - a - b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta}{\delta} \right) \right\} + C \right\}$$

Bargaining constraint for the government, defined as the gain to government from tariffs compared to no tariffs, is given by:

(9)

$$a \frac{(p^t - \theta)^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1 - a - b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta}{\delta} \right) \right\} + C \right\} - \left\{ a \frac{(p^w - \theta)^2}{2\delta} + b \frac{(\alpha - p^w)^2}{2\beta} \right\}$$

Bargaining constraint for the producers, defined as the gain to producers from tariffs compared to no tariffs, is given by:

$$(10) \quad \left\{ \frac{(p^t - \theta)^2 - (p^w - \theta)^2}{2\delta} \right\} - C$$

The first stage of the Nash bargaining game maximizes the product of the government and producer surpluses with respect to contributions by the industry to the government:

(11)

$$\begin{aligned} & \text{Max}_c \\ & a \frac{(p^t - \theta)^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1-a-b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta}{\delta} \right) \right\} + C \right\} - \left\{ a \frac{(p^w - \theta)^2}{2\delta} + b \frac{(\alpha - p^w)^2}{2\beta} \right\} \\ & * \left\{ \left\{ \frac{(p^t - \theta)^2 - (p^w - \theta)^2}{2\delta} \right\} - C \right\} \end{aligned}$$

Proposition 1:

1.1 For the range of tariffs within which bargaining constraints are satisfied, contributions are increasing and convex in tariffs as long as

$$a > -b \frac{3\beta + 3\delta}{4\beta + 2\delta} + \frac{3\beta + 2\delta}{4\beta + 2\delta}.$$

1.2 Bargaining constraint for the producer surplus is concave in tariffs as long as

$$a < -\frac{3\delta + \beta}{2(\beta + \delta)} b + \frac{2\delta + \beta}{2(\beta + \delta)} \text{ and convex other wise.}$$

1.3 Bargaining constraint for the government is concave in tariffs as long as

$$a < -\frac{3\delta + \beta}{2(\beta + \delta)} b + \frac{2\delta + \beta}{2(\beta + \delta)} \text{ and convex otherwise. However, the bargaining}$$

constraint for the government always lies below that of the producer.

1.4 For a given tariff level, higher the weight on consumer surplus, higher would be the level of contributions.

1.5 For a given level of tariffs, the higher the weight on producer surplus, the higher would be the level of contributions.

Proof 1.1: If the two bargaining constraints are satisfied, first order condition with respect to C would maximize the product of government and producer welfare when:

(12)

$$C = \frac{1}{2(1-a-b)} \left\{ \begin{aligned} &(1-2a-b) \frac{(p^w + \tau - \theta)^2}{2\delta} + (2a+b-1) \frac{(p^w - \theta)^2}{2\delta} - \frac{b(\alpha - p^w - \tau)^2}{2\beta} - \\ &(1-a-b)\tau \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{p^w + \tau - \theta}{\delta} \right\} + \frac{b(\alpha - p^w)^2}{2\beta} \end{aligned} \right\}$$

The contributions vary with the level of tariffs selected by the government as shown by their first and second order partial derivatives below:

(13)

$$\frac{\partial C}{\partial \tau} = \frac{1}{2(1-a-b)} \left\{ \begin{aligned} &(1-2a-b) \frac{(p^w + \tau - \theta)}{\delta} + \frac{b(\alpha - p^w - \tau)}{\beta} - \\ &(1-a-b) \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{p^w + \tau - \theta}{\delta} \right\} + (1-a-b)\tau \left\{ \frac{1}{\beta} + \frac{1}{\delta} \right\} \end{aligned} \right\} \pm ve$$

$$(14) \quad \frac{\partial^2 C}{\partial \tau^2} = \frac{1}{2(1-a-b)} \left\{ \frac{(1-2a-b)}{\delta} - \frac{b}{\beta} \right\} + \left\{ \frac{1}{\beta} + \frac{1}{\delta} \right\} \& +ve$$

if

$$a > -b \frac{3\beta + 3\delta}{4\beta + 2\delta} + \frac{3\beta + 2\delta}{4\beta + 2\delta}$$

The second order partial derivate of the contribution function shows that it will be convex as long as the above relation between the weights is satisfied². But, the first order partial derivative reveals that contributions could be falling in tariffs. However, in order to rule out this possibility, let us look at the contribution function as derived in equation (11). It can be easily deduced that the contribution is zero at a level when the tariffs are zero. This implies that the contribution function passes through the origin on the plane involving contributions and tariffs. As a consequence, only places where the contribution can be falling and still be convex would be when contributions are negative. This would, however, imply that the bargaining constraint for the producer has been violated. Figure below shows the contribution function for a certain combination of parameters.

INSERT FIGURE 1 HERE

Proof 1.2: The bargaining constraint for the producer is usually concave in tariffs. This can be shown by taking the partial derivate of the producer surplus function with respect to tariffs:

$$(15) \quad \frac{\partial^2}{\partial \tau^2} \left\{ \left[\frac{(p^t - \theta)^2 - (p^w - \theta)^2}{2\delta} \right] - C \right\} = \frac{-\beta(-1 + 2a + b) + \delta(2 - 2a - 3b)}{2\beta\delta(a + b - 1)}$$

² The contribution function would be concave only at very high weights on consumer and producer surpluses that are close to 1. Though, not readily apparent from the above condition in (14), this fact can be numerically verified.

Note that concavity of the bargaining constraint implies that the gain to the producer from tariffs initially increases but eventually falls with tariffs. As the weights are increased, the surplus to the producer from bargaining shrinks, eventually turning to zero. Further, it can be verified that the bargaining constraint is zero when tariffs are zero³. From the above, a relation between a and b for concavity could be derived as:

$$(16) \quad a < -\frac{3\delta + \beta}{2(\beta + \delta)}b + \frac{2\delta + \beta}{2(\beta + \delta)}$$

Note that as long as the weights lie within the line specified by the above equation, the bargaining constraint would be concave.

Proof 1.3: The bargaining constraint for the government is usually concave in tariffs. This can be shown by taking the partial derivate of the consumer surplus function with respect to tariffs at the level when optimal contributions are accounted for as:

$$(17) \quad \frac{\partial^2}{\partial \tau^2} \left[a \frac{(p' - \theta)^2}{2\delta} + b \frac{(\alpha - p')^2}{2\beta} + (1 - a - b) \left\{ (p' - p^w) \left\{ \frac{\alpha - p'}{\beta} - \left(\frac{p' - \theta}{\delta} \right) \right\} + C \right\} - \left\{ a \frac{(p^w - \theta)^2}{2\delta} + b \frac{(\alpha - p^w)^2}{2\beta} \right\} \right]$$

$$= \frac{(-1 + 2a + b)\beta + (-2 + 2a + 3b)\delta}{2\beta\delta}$$

Note from above that the slope of the constraint would be lower, the larger the values of a and b . This would imply that as the weights are increased, the gains from revenue increases, thus increasing the bargaining surplus. Rewriting the above as a relation

³ Therefore, it is possible for the bargaining constraint to be concave and yet be non-positive as weights are increased significantly, even before it becomes convex. Consequently, it is possible that bargaining breaks down even when the constraint function is concave.

between weights on consumer and producer surpluses we get the same relation as the producer's:

$$(18) \quad a < -\frac{3\delta + \beta}{2(\beta + \delta)}b + \frac{2\delta + \beta}{2(\beta + \delta)}$$

Finally, also note that the bargaining constraint for the government always lies beneath that of the producer. That is, the constraint is more binding over the range of weights on consumer and producer surpluses for the government. This can be easily deduced from the fact that the second order derivative of the bargaining constraint, as given by (15) is always higher in magnitude as compared to that of the government, as given by (17). Intuitively, the producer is not directly affected by the weight on the consumer surplus as compared to the government which is directly and indirectly affected by both the weights.

INSERT FIGURE 2 HERE

Proof 1.4 : An increase in weight on consumer surplus would lower the government revenues for any given level of tariffs as weights on government revenues would fall and so would the weighted consumer surplus. Whereas, an increase in weight on consumer surplus, for any given level of tariffs would leave the producer surplus constant. Therefore, maximizing the product of surpluses would require that relatively increased surplus to the producer be shared with the government thus increasing contributions.

Proof 1.5: For any given level of tariffs, an increase in the weight on producer surplus would lower the weighted government revenues as $((1-a-b)$ would fall), but leave the producer surplus intact. This would raise producer surplus relative to government revenues, thus increasing contributions.

Government as the Stackelberg Leader

In the next stage of the game, the government, acting as a Stackelberg leader, selects the level of tariffs in order to maximize its surplus. In a one period game, government maximizes its benefits (*GB*) with respect to tariffs:

$$(19) \quad a \frac{(p^t - \theta)^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1 - a - b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta}{\delta} \right) \right\} + C \right\}$$

Taking the first order condition, the optimal level of tariffs can be derived as:

$$(20) \quad \tau = \frac{-(p^w - \theta) \frac{a}{2\delta} + \frac{(2b + a - 1)}{2\beta} (\alpha - p^w)}{\frac{(1 - b)}{2\delta} + \frac{b}{2\beta} - (1 - a - b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right)}$$

In the above equation, the denominator is the second order partial derivate of the government's benefits, *GB* with respect to tariff. When *a* and *b* are small enough, *GB* will be a concave function. More specifically, it could be verified that as long as the bargaining constraint for the government is satisfied (as given by equation 18), the concavity of *GB* would also hold. A large denominator in the derivate would mean that the *GB* is falling (or rising) fast with respect to tariffs, thus lowering tariffs.

So far the optimal level of tariff selection only involves maximizing the joint profits of interest groups and the government. In order for tariffs to be justifiable on the grounds of mitigating the risk of invasive species, the government must incorporate the consequences of invasion into the bargaining game. However, since risk of invasion is a cumulative process primarily affected by economic activity over a sustained period of

time, any such effort at modeling risks into tariffs must be done in a multiple time frame. In the next section, risks of invasion are explicitly modeled as being affected by the level of imports which in turn are affected by the level of tariffs. The government still plays the bargaining game with the lobby group as a one shot game in each period, however, being the Stackelberg leader it must incorporate the consequences of tariffs on risks over a longer time horizon.

Multiple Periods

We deviate from the literature on political economy models at this stage by making the model dynamic. The government's objectives extend beyond a single period. Therefore, it must keep in mind the consequences of its current actions on future risks of invasion.

Following Clarke and Reed (1994), the risk of invasion is modeled using a survival function $S(t)$ to represent the country's likelihood of surviving an invasion at time period, t . Let T be the moment of invasion. The cumulative probability distribution associated with invasion is denoted $F(t)$, where $F(t) = \Pr(T < t)$. The survivor function captures the probability that an invasion has not yet occurred in time t , and represents the upper tail of the cumulative probability distribution⁴:

$$(21) \quad S(t) = \Pr(T \geq t) = 1 - F(t) .$$

⁴ Even though the risk of a particular invasive species are affected by such broad measures as prevention, and monitoring, here we consider only the incremental risk reduction from tariffs that reduces the import of this particular commodity.

In each time period it is assumed that the country faces a certain probability of transition into the post-invasion state, denoted $\lambda(t)$. This conditional probability, $\lambda(t)$, is also referred to as the hazard rate. The cumulative probability is given by:

$$(22) \quad F(t) = 1 - e^{-\mu(t)},$$

where

$$(23) \quad \mu(t) = \int_0^t \lambda(q(\tau(s))) ds$$

and

$$(24) \quad \dot{\mu}(t) = \lambda(q(\tau(s)))$$

where $\lambda(q(\tau(s)))$ is the hazard rate affected by reduced imports from tariffs. The probability of surviving until any time period t without being invaded is, $e^{-\mu(t)}$. The unconditional probability of invasion in an exact period t is the probability of both being invaded in period t and not having been invaded prior to that period:

$$(25) \quad \lambda(q(\tau(s)))e^{-\mu(t)}.$$

Let the hazard rate be defined by:

$$(26) \quad \lambda(q(\tau)) = \left\{ \frac{\alpha\delta + \beta\theta}{\beta + \delta} - p^w - \gamma\tau \right\}$$

In the above formulation, γ is the factor that affects the effectiveness of tariffs on hazard rate reduction. The first term under brackets is the point of intersection of the demand and the supply curves and implies zero residual demand. Note that when γ is 1, tariffs must equal $\frac{\alpha\delta + \beta\theta}{\beta + \delta} - p^w$ in order for the hazard rate to be completely zero. This would

happen when the residual demand for imports is zero. However, the risk of invasion does not necessarily have to be linearly dependent upon the tariffs and consequently the quantity imported. As mentioned above, in presence of complementary policies aimed at risk reduction, even a marginal reduction of imported quantities from their status quo may lead to significant or complete reduction in risks⁵. This would be made possible by having the value of γ to be more than 1.

In the scenario of an invasion, several situations may arise that would adversely or positively affect government's revenues from tariffs and contributions from lobby groups. A forward looking government would seek to maximize its long run expected benefits from tariffs and bargaining in the presence of risks. Government's long run objective function can be defined as⁶ :

Maximize with respect to tariffs τ :

(27)

$$a \frac{(p^t - \theta)^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1 - a - b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta}{\delta} \right) \right\} + C \right\} + \lambda V$$

⁵ Alternative specification of risk evolution may be where: $\lambda = \{\alpha - p^w - \gamma\tau\}$. This specification would be more applicable when the commodity of concern is the only host to the invasive pest and even if the imports are reduced to zero, significant risks remain in the form of invasives arriving through other means. In that case even the domestic production of the commodity adds to risks and the hazard rate is reduced to zero only when there is no production of that good at all.

⁶ Note that all the variables in the objective function would have a time argument but are ignored for purposes of simplicity.

where V is the discounted sum of value derived from optimal policies in the aftermath of an invasion. This value function would depend upon specific scenarios that follow an invasion. We discuss some of these scenarios below.

Scenario I: Elimination of Tariffs upon Invasion

In the simplest case consider that the post-invasion scenario leads to elimination of tariffs⁷. Let V be the discounted and weighted sum of consumer and producer surpluses in the aftermath of invasive species establishment. The value function in the post establishment scenario can be derived as:

$$(28) \quad V = \frac{\frac{a}{2\delta}(p^w - \theta')^2 + \frac{b}{2\beta}(\alpha - p^w)^2 - (1 - a - b)d}{r} e^{-rt}$$

where d is the per period damages from species establishment to the rest of the economy, r is the rate of discount and θ' is the new intercept of the domestic supply curve, assuming pest infestation leads to an increase in private fixed costs to the domestic firms⁸. The government's long run objective function, after substituting for the contributions as a function of tariffs from above, can be written as:

$$(29)$$

⁷ International Sanitary and Phytosanitary regulations may call for tariff elimination if the pest has already been established.

⁸ It is also possible that the supply curve is shifted to the right causing changes in both its slope and intercept. Implications of such a possibility are considered later.

$$\text{Max}_{\tau} \int_0^{\infty} \left\{ (\tau + p^w - \theta)^2 \left\{ \frac{1-b}{4\delta} \right\} + (\alpha - \tau - p^w)^2 \left\{ \frac{b}{4\beta} \right\} + (p^w - \theta)^2 \left(\frac{2a+b-1}{4\delta} \right) + (\alpha - p^w)^2 \frac{b}{4\beta} + \right. \\ \left. \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right\} \left(\frac{(1-a-b)\tau}{2} \right) + \lambda(t) \frac{\frac{a}{2\delta} (p^w - \theta')^2 + \frac{b}{2\beta} (\alpha - p^w)^2 - (1-a-b)d}{r} \right\} e^{-\mu(t)-rt} dt$$

Subject to the equation of motion for the hazard rate as given above by (26). The current value Hamiltonian is given by⁹:

(30)

$$\left\{ (\tau + p^w - \theta)^2 \left\{ \frac{1-b}{4\delta} \right\} + (\alpha - \tau - p^w)^2 \left\{ \frac{b}{4\beta} \right\} + (p^w - \theta)^2 \left(\frac{2a+b-1}{4\delta} \right) + (\alpha - p^w)^2 \frac{b}{4\beta} + \right. \\ \left. \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right\} \left(\frac{(1-a-b)\tau}{2} \right) + \lambda \frac{\frac{a}{2\delta} (p^w - \theta')^2 + \frac{b}{2\beta} (\alpha - p^w)^2 - (1-a-b)d}{r} \right\} e^{-\mu} + \\ l \left(\frac{\alpha\delta + \beta\theta}{\beta + \delta} - p^w - \gamma\tau \right)$$

where l is the shadow price of cumulative risks, μ , and refers to the cost of decreasing the cumulative risks marginally by an increase in tariffs. First order condition with respect to tariff leads to:

$$(31) \quad \tau \left\{ \frac{1-b}{2\delta} + \frac{b}{2\beta} - (1-a-b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right) \right\} + (p^w - \theta) \left(\frac{1-b}{2\delta} \right) - \frac{(\alpha - p^w)b}{2\beta} + \frac{1-a-b}{2} \left(\frac{\alpha - p^w}{\beta} - \frac{(p^w - \theta)}{\delta} \right) \\ - \gamma \frac{\frac{a}{2\delta} (p^w - \theta')^2 + \frac{b}{2\beta} (\alpha - p^w)^2 - (1-a-b)d}{r} e^{-rt} = \lambda e^{\mu}$$

Notice that reducing the cumulative risks reduces the chance of invasion and thereby pushes farther into the future the gains to be had in the post-invasion scenario. Post-invasion value could either be positive or negative depending upon whether the damages

⁹ The current value Hamiltonian would be concave in tariffs, thus ensuring a maximum, as long as the government's benefit function is concave. It was shown earlier that concavity would hold as long as the weights on consumer and producer surpluses do not exceed a certain threshold as defined by equation (18).

to the rest of the economy d (which are assigned a weight $(1-a-b)$) exceed the combined sum of gains to the producers, consumers and the government. In the case when the invasive species of concern may have significant economy wide impacts, the post-invasion value would be negative, implying that the shadow price of cumulative risks be negative. When the post-invasion value is positive, an increase in tariffs would still be warranted as long as the pre-invasion value exceeds the post-invasion value. The optimal path of tariffs would be decided by the no-arbitrage conditions derived below:

(32)

$$\dot{l} = \left\{ \begin{aligned} & (\tau + p^w - \theta)^2 \left\{ \frac{1-b}{4\delta} \right\} + (\alpha - \tau - p^w)^2 \left\{ \frac{b}{4\beta} \right\} + (p^w - \theta)^2 \left(\frac{2a+b-1}{4\delta} \right) + (\alpha - p^w)^2 \frac{b}{4\beta} + \\ & \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right\} \left(\frac{(1-a-b)\tau}{2} \right) + \lambda \frac{\frac{a}{2\delta} (p^w - \theta')^2 + \frac{b}{2\beta} (\alpha - p^w)^2 - (1-a-b)d}{r} \end{aligned} \right\} e^{-\mu} + r l$$

Let $m = l e^{\mu}$, where m can be thought of as the conditional shadow value of cumulative risks¹⁰. Then

$$(33) \quad \dot{m} = \dot{l} e^{\mu} + l e^{\mu} \lambda$$

Substituting for \dot{l} from above we get:

(34)

¹⁰ Clarke and Reed (1994) define this manipulation as the shadow price conditional on the fact that the event associated with risk has not yet occurred.

$$\dot{m} = \left\{ \begin{aligned} &(\tau + p^w - \theta)^2 \left\{ \frac{1-b}{4\delta} \right\} + (\alpha - \tau - p^w)^2 \left\{ \frac{b}{4\beta} \right\} + (p^w - \theta)^2 \left(\frac{2a+b-1}{4\delta} \right) + (\alpha - p^w)^2 \frac{b}{4\beta} + \\ &\left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right\} \left(\frac{(1-a-b)\tau}{2} \right) + \lambda \frac{\frac{a}{2\delta}(p^w - \theta')^2 + \frac{b}{2\beta}(\alpha - p^w)^2 - (1-a-b)d}{r} e^{-rt} \end{aligned} \right\} e^{-\mu} +$$

$$+ rle^{\mu} + le^{\mu} \lambda$$

Rewriting the above we get:

(35)

$$\dot{m} = \left\{ \begin{aligned} &(\tau + p^w - \theta)^2 \left\{ \frac{1-b}{4\delta} \right\} + (\alpha - \tau - p^w)^2 \left\{ \frac{b}{4\beta} \right\} + (p^w - \theta)^2 \left(\frac{2a+b-1}{4\delta} \right) + (\alpha - p^w)^2 \frac{b}{4\beta} + \\ &\left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right\} \left(\frac{(1-a-b)\tau}{2} \right) + \lambda \frac{\frac{a}{2\delta}(p^w - \theta')^2 + \frac{b}{2\beta}(\alpha - p^w)^2 - (1-a-b)d}{r} e^{-rt} \end{aligned} \right\} +$$

$$+ \frac{r + \lambda}{\gamma} \left\{ \begin{aligned} &\tau \left\{ \frac{1-b}{2\delta} + \frac{b}{2\beta} - (1-a-b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right) \right\} + (p^w - \theta) \left(\frac{1-b}{2\delta} \right) - \frac{(\alpha - p^w)b}{2\beta} + \frac{1-a-b}{2} \left(\frac{(\alpha - p^w)}{\beta} - \frac{(p^w - \theta)}{\delta} \right) \\ &- \gamma \frac{\frac{a}{2\delta}(p^w - \theta')^2 + \frac{b}{2\beta}(\alpha - p^w)^2 - (1-a-b)d}{r} e^{-rt} \end{aligned} \right\}$$

The shadow price of conditional risks is a function of tariffs and also of key parameters such as the weights a and b . In order to understand how the shadow price of cumulative risks varies with tariffs we derive its partial as:

$$(36) \quad \frac{\partial \dot{m}}{\partial \tau} = \frac{r + \lambda}{\gamma} \left\{ \left\{ \frac{1-b}{2\delta} + \frac{b}{2\beta} - (1-a-b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right) \right\} \right\}$$

The term inside brackets is nothing but the curvature (or the second order derivative) of the instantaneous benefits function. From the above equation, it is evident that the derivative would be negative when the curvature of the instantaneous benefit function is

concave. This would happen when weights on the consumer and producer surplus are not too high and therefore satisfy the concavity constraint as derived before. The expected value in the post- invasion scenario in absence of revenues is lower than the benefits in the pre-invasion scenario. Therefore, it pays to lower the chance of getting into that state by raising tariffs. As a consequence, shadow price of cumulative risks would be falling as tariff increases, because as tariff increase, the expected post-invasion value falls due to reduced risks. Figure below shows the graph of $\frac{\partial \dot{m}}{\partial \tau}$ for a low combinations of the weights on consumer and producer surpluses¹¹.

INSERT FIGURE 3 HERE

Steady State

Steady state implies $\dot{l}=0$, which would happen when the hazard rate is zero. Solving

which, one can derive the steady state level of tariffs as $\tau = \frac{\frac{\alpha\delta + \beta\theta}{\beta + \delta} - p^w}{\gamma}$. Note that

when γ is more than one, it is possible for $\dot{\mu} = \lambda(\tau)$ to be zero even before the tariff levels reach their maximum possible level at which the residual demand for imported goods is zero. While the existence of such a steady state is a possibility, it would happen under extreme scenarios where very high costs from invasion or very low gains to consumer surplus prompt maximum possible tariffs. Consequently, further steady state

¹¹ The time path of tariffs could be derived from equations (32) and (35), however, they get too complex for a qualitative analysis.

analysis is ignored here. Instead, we do a brief numerical simulation to explore the role of parameters in shaping optimal tariffs.

A Numerical Example

In table 1 we present the results of numerical simulation of the above dynamic game using various combinations of elasticities of demand and supply and weights on consumer and producer surpluses. Besides presenting the optimal tariffs and contributions, we also present the consumer and producer surpluses before and after tariffs¹². In table 1 below, the first case involves high slopes (low elasticities) for demand and supply curves. For this case, notice that as the weight on consumer surplus increases from .1 to .3, tariff falls. This is obvious as consumer surplus is significantly higher than the producer surplus (given the choice of this parameter set) and a relatively small increase in weights on consumer surplus leads to an increase in its weighted value. Contributions do not necessarily increase with an increase in weight on the producer surplus. In fact, the highest contributions are when $a=.1$, $b=.2$ and the producer is obliged to contribute more to maintain a tariff level of 5.3, as the government increases its weights on the consumer surplus. However, as weights on consumer surplus increase

¹² The simulations were performed in GAMS. In all of the above cases the tariff and contribution levels stabilized right from the first time period, hence only the first period results are presented. Fixed Parameters: $r = .1, \alpha = 10, \theta = .1, d = 1, \gamma = 1, \theta' = .15, p^w = 1$. Figures in brackets after the tariff in the first column depict the price at which the residual demand for imports is zero.

to .3, contributions fall to zero as the producer is no more able to compensate the government for the loss of higher consumer surplus concomitant with higher tariffs.

In the next case, when both the slopes of demand and supply curves are low, tariffs fall significantly compared to the first case. Note that the increase in consumer surplus far outweighs the increase in producer surplus from this change in slopes. Contributions are zero all throughout as the producer is unable to influence the government's welfare function due to its own meager surpluses. Change in tariffs in this case is solely dictated by the change in weights on the consumer surplus. The third case, depicts a situation where slope of demand curve is relatively higher. Note that compared to the previous cases, tariffs are significantly lower. However, this is solely because of a reduction in the price at which the residual demand becomes zero. That is, the government in fact, raises tariffs to its maximum possible level. Note that this policy would also lead to a zero hazard rate, thus stabilizing the risks of invasion. Risk of invasion plays a role in affecting tariffs in the previous cases too, through its affect on the post-invasion value function. It is interesting to note that since there are no revenues in the post-invasion scenario, the post-invasion value function is heavily influenced by the weight on the consumer surplus. However, the post-invasion value is never significant enough to enforce a higher tariff thus causing corner solution as in this case. Further, it was found that as the damages to the rest of the economy from invasion increased significantly, even the previous cases showed corner solutions, forcing tariffs at their maximum possible levels. This is because if the damages significantly outweigh the gains in the post-invasion scenario, higher tariffs can help mitigate the risks of falling in that state.

Finally, in the last case, when the slope of the supply curve is much higher than that of the demand curve, tariffs reach their maximum levels. This happens despite the fact that the consumer surplus is significantly larger than the producer surplus. The relative differences in the slopes of the demand and supply curves push the point of zero residual demand higher, enabling higher tariffs, and therefore increasing residual demand of imported goods (thus increasing revenues) and producer surplus. Their combined effect outweighs the loss in consumer surplus when assigned lower weights.

Though it is possible to get a different set of results from a combination of a different set of parameters that assign higher producer surplus than consumer surplus, the direction movement of tariffs should be fairly intuitive by now. The example highlights the role of weights and elasticities on the optimal selection of tariffs. While the weights highlight the significance that the government assigns to this particular industry and also the rest of the economy (through weights on its own revenues), the slopes of the supply and demand curves determine the role the lobby group can play in affecting tariffs. A higher producer surplus also means a higher ability to contribute. Interestingly, the influence of government weights can be counter balanced by the influence of slopes of demand and supply as they both directly and indirectly affect government welfare. The significance of risk of invasion too is dependent upon these weights and slopes as they affected the welfare in the post-invasion scenario.

While the above simulation analysis is based upon the scenario of no tariffs after invasion, several other possibilities exist. In the next sections we explore such possibilities.

Scenario II: Bargaining Continues after invasion

While elimination of tariffs in the post-invasion scenario is one possibility, another possibility is that the government retains the tariff structure purely for revenue purposes. Now, in the post-invasion scenario, the government maximizes its objective function with respect to tariffs:

$$(37) \quad a \frac{(p^t - \theta')^2}{2\delta} + b \frac{(\alpha - p^t)^2}{2\beta} + (1 - a - b) \left\{ (p^t - p^w) \left\{ \left(\frac{\alpha - p^t}{\beta} \right) - \left(\frac{p^t - \theta'}{\delta} \right) \right\} + C' \right\}$$

where θ' is the new intercept of the supply curve for the producers assuming that an invasion causes their fixed cost of operation to go up. C' is the contribution in the post-invasion scenario. Taking the first order condition of (37) with respect to tariffs we get:

$$(38) \quad \tau^* = \frac{-(p^w - \theta') \frac{a}{2\delta} + \frac{(2b + a - 1)}{2\beta} (\alpha - p^w)}{\frac{(1 - b)}{2\delta} + \frac{b}{2\beta} - (1 - a - b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right)}$$

Note that, since the post-invasion scenario does not involve any further threats of invasion, there is no state variable involved there. As a consequence τ^* would be the optimal tariff in each period following an invasion. For the sake of simplicity, we ignore damages (d) to the rest of the economy from an invasion. Value function in the post-invasion scenario can be derived as the sum of discounted profits in the long run from the time of invasion t :

(39)

$$V = \int_t^{\infty} \left\{ a \frac{(p^w + \tau^* - \theta')^2}{2\delta} + b \frac{(\alpha - p^w - \tau^*)^2}{2\beta} + (1-a-b) \left\{ \tau^* \left\{ \left(\frac{\alpha - p^w - \tau^*}{\beta} \right) - \left(\frac{p^w + \tau^* - \theta'}{\delta} \right) \right\} + C' \right\} \right\} e^{-\pi t} dt$$

where the contributions are a function of the tariffs as before:

(40)

$$C' = \frac{1}{2(1-a-b)} \left\{ \begin{aligned} & (1-2a-b) \frac{(p^w + \tau - \theta')^2}{2\delta} + (2a+b-1) \frac{(p^w - \theta')^2}{2\delta} - \frac{b(\alpha - p^w - \tau)^2}{2\beta} - \\ & (1-a-b) \tau \left\{ \frac{\alpha - p^w - \tau}{\beta} - \frac{p^w + \tau - \theta'}{\delta} \right\} + \frac{b(\alpha - p^w)^2}{2\beta} \end{aligned} \right\}$$

The current value Hamiltonian for maximization of profits in the pre and post-invasion scenarios is given by:

(41)

$$\left\{ \begin{aligned} & a \frac{(p^w + \tau - \theta)^2}{2\delta} + b \frac{(\alpha - p^w - \tau)^2}{2\beta} + (1-a-b) \left\{ \tau \left\{ \left(\frac{\alpha - p^w - \tau}{\beta} \right) - \left(\frac{p^w + \tau - \theta}{\delta} \right) \right\} + C \right\} + \\ & \frac{\lambda e^{-\pi t}}{r} \left\{ a \frac{(p^w + \tau^* - \theta')^2}{2\delta} + b \frac{(\alpha - p^w - \tau^*)^2}{2\beta} + (1-a-b) \left\{ \tau \left\{ \left(\frac{\alpha - p^w - \tau^*}{\beta} \right) - \left(\frac{p^w + \tau^* - \theta'}{\delta} \right) \right\} + C' \right\} \right\} \end{aligned} \right\} e^{-\mu(t)} + l\lambda$$

where

(42)

$$\left\{ a \frac{(p^w + \tau^* - \theta')^2}{2\delta} + b \frac{(\alpha - p^w - \tau^*)^2}{2\beta} + (1-a-b) \left\{ \tau \left\{ \left(\frac{\alpha - p^w - \tau^*}{\beta} \right) - \left(\frac{p^w + \tau^* - \theta'}{\delta} \right) \right\} + C' \right\} \right\}$$

is the instantaneous benefits (say, *IB-post*) in the post-invasion scenario¹³. Similarly,

(43)

$$a \frac{(p^w + \tau - \theta)^2}{2\delta} + b \frac{(\alpha - p^w - \tau)^2}{2\beta} + (1 - a - b) \left\{ \tau \left\{ \left(\frac{\alpha - p^w - \tau}{\beta} \right) - \left(\frac{p^w + \tau - \theta}{\delta} \right) \right\} + C \right\}$$

is the instantaneous benefits (say, *IB-pre*) in the pre-invasion scenario. Note that the difference in these benefits is caused due to an increase in the fixed costs of production, θ , for the private sector.

Proposition 2:

2.1 For any given tariff level, IB-POST would differ from IB-Pre by a factor f , from a marginal increase in θ .

2.2 Pre-invasion tariff level would always be higher than the post-invasion tariff level.

Proof 2.1: In order to see this, let's look at the impact on *IB-post* from a marginal change in θ . This change is derived by taking the partial derivative of *IB-pre* with respect to θ .

Substituting the value of C from above into (43) and differentiating we get:

$$(44) \quad \frac{\partial (IB - pre)}{\partial \theta} = \frac{-a(2(p^w - \theta) + \tau)}{2\delta} < 0$$

Then, for small enough changes in θ , *IB-post* can be written as:

$IB-post = IB-pre + (IB - pre)f$, where f represents the marginal change derived above in equation (44).

¹³ The instantaneous function *IB* is the same as the government benefit function *GB* derived before in the one shot game, except with a time argument.

Proof 2.2: Substituting (44) into the current value Hamiltonian (*cvh*), the *cvh* can be written as:

$$(45) \quad cvh = \left\{ IB - PRE(\tau) + (IB - PRE(\tau^*)) \frac{(1+f)\lambda e^{-rt}}{r} \right\} e^{-\mu(t)} + l\lambda$$

In the above, the second term under brackets is *IB-post* which is some fraction of the *IB-pre*, evaluated at τ^* . From equation (44) we also know that f is a negative term. That is, small changes in θ would invariably lower *IB-pre*. The two terms under bracket in (45) denote a trade-off between the pre and post-invasion instantaneous values, as $\lambda e^{-\mu(t)}$ denotes the chances of invasion exactly at the instant t , thus yielding $(IB - pre) \frac{(1+f)e^{-rt}}{r}$ at the time of invasion in discounted sum of future benefits and $e^{-\mu(t)}$ denotes the chance of the system surviving until time t , yielding *IB-pre* in each period until invasion. That is, as long as the system is un-invaded, the government receives, *IB-pre*(τ) in each period and after invasion it receives *IB-pre*(τ^*)(1+f) in each period. Now, we know that the instantaneous benefit is falling in θ from (44), thus suggesting *IB-pre*(θ', τ^*) < *IB-pre*(θ, τ^*). That is, if the government imposed a tariff level of τ^* in the pre-invasion scenario too, its per period profits would be higher than those in the post-invasion scenario. But we also know from equation (20) that the tariff level in a one shot game is a function of θ too and is given by :

$$(46) \quad \frac{\partial \tau}{\partial \theta} = \frac{\frac{a}{2\delta}}{\frac{(1-b)}{2\delta} + \frac{b}{2\beta} - (1-a-b)(\frac{1}{\beta} + \frac{1}{\delta})}$$

From concavity condition of the instantaneous benefit function we know that the denominator would be negative, thus making the partial in (46) negative. So $\tau(\theta') < \tau(\theta)$. Now when the instantaneous benefits function is increasing but concave in tariffs, tariffs in the pre-invasion situation would always be higher than that in the post-invasion situation, *ceteris paribus*. When an infinite horizon as above is concerned, it would pay to raise pre-invasion tariffs even higher as it reduces the chances of invasion.

Next let us look at a case when invasion leads to an alteration in the shape of the supply curve, altering its marginal costs, however, leaving the fixed costs intact as before. Under such a situation following proposition is made:

Proposition 3:

3.1 When there is a change in the slope of the cost curve for private producers following an invasion, IB-post differs from IB-pre by a factor g .

3.2 Pre-invasion tariff would always be higher than the post-invasion tariff when g is negative and $a > 1 - \frac{b}{2}$.

3.3 Pre-invasion tariff could be lower or higher than the post-invasion tariff when $a > 1 - \frac{b}{2}$ and g is positive.

Proof 3.1: Following similar marginal derivation of the instantaneous function with respect to δ we derive the value of g to be:

(47)

$$g = \frac{1}{4\delta^2} \left\{ -(1-b)(\tau + p^w - \theta)^2 - (2a+b-1)(p^w - \theta)^2 + 2(\tau + p^w - \theta)(1-a-b)\tau \right\}$$

Contrary to the case of a fixed costs change before, g could be negative or positive.

Proofs 3.2: The current value Hamiltonian can now be rewritten as:

$$(48) \quad cvh = \left\{ IB - PRE(\tau) + (IB - PRE(\tau^*)) \frac{(1+g)\lambda e^{-rt}}{r} \right\} e^{-\mu(t)} + l\lambda$$

Taking the partial of tariffs with respect to the slope of the supply curve we get:

(49)

$$\frac{\partial \tau}{\partial \delta} = \frac{\left\{ (p^w - \theta) \frac{a}{2\delta^2} \right\} \left\{ \frac{(1-b)}{2\delta} + \frac{b}{2\beta} - (1-a-b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right) \right\} - \left\{ - (p^w - \theta) \frac{a}{2\delta} + \frac{(2b+a-1)}{2\beta} (\alpha - p^w) \right\} \left\{ \frac{1-b-2a}{2\delta^2} \right\}}{\left\{ \frac{(1-b)}{2\delta} + \frac{b}{2\beta} - (1-a-b) \left(\frac{1}{\beta} + \frac{1}{\delta} \right) \right\}^2}$$

From equation (20) we know that the terms under second and third brackets in the numerator must be negative for any positive tariff level. Therefore the sign of equation (49) would be determined by terms under the fourth bracket in the numerator as:

$$(50) \quad \frac{\partial \tau}{\partial \delta} < 0 \text{ if } a > 1 - \frac{b}{2} \text{ and indeterminate if } a < 1 - \frac{b}{2}$$

Now, when g is negative, proposition 3.2 follows from similar logic as in propositions 2.2

Proof 3.3 : When g is positive, and $\frac{\partial \tau}{\partial \delta}$ negative as before, the results could go either

way. When $a > 1 - \frac{b}{2}$, $\tau^*(\delta') < \tau^*(\delta)$, i.e., tariffs in the post-invasion scenario would be

lower. However, if the fall in instantaneous profits from a fall in tariffs in the post

invasion scenario is more than compensated by the rise in instantaneous benefits from a positive g , pre-invasion tariffs would be lower than the post-invasion tariffs, as lower tariffs increase the risks of invasion and make it possible to reap higher post-invasion rewards. When the magnitude of positive g does not compensate for the fall in IB from lower tariffs, tariffs in the pre-invasion scenario would be higher. This situation is depicted in figure 4 below.

INSERT FIGURE 4 BELOW

Point Y leads to unambiguously lower instantaneous benefits from an increase in δ , whereas point X and Z lead to a lower and higher benefits respectively.

INSERT FIGURE 4 HERE

Finally, when both the fixed and variable costs change due to invasion, instantaneous benefit functions may intersect, thus making any unambiguous results difficult to predict.

In the end, let us also look at a situation where government readjusts its priorities with respect to the lobby group by changing the weights on the producer surplus in the post-invasion scenario. This may happen for several reasons. For one, a seriously damaging pest invasion may change the way rest of the country views the role played by the government in combating it. That is, the government may increase the weights on either the consumer or producer surpluses, as it may add to its vote prospects from people outside the affected industry. This might be inferred as a further subjective weighing of the monetary rewards to the government from consumer and producer surpluses accruing from this particular industry. The government, on the other hand, may readjust the weights downwards after invasion, if the prospects from other lobby groups become relatively more bright. Under this situation the following proposition can be made.

Proposition 4: When there is a change in weights on the producer surplus in the post-invasion scenario, the post-invasion instantaneous benefits function would differ from IB-pre by a factor h . Post invasion tariffs may be higher or lower compared to pre-invasion tariff levels.

Proof 4 : By taking the partial derivative of the instantaneous benefits function with respect to a , the value of h could be derived as:

$$(51) \quad h = \frac{(p^w - \theta)^2}{2\delta} - \frac{\tau}{2} \left(\frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta} \right)$$

Notice that h could be either positive or negative depending upon whether the third term is lower or higher than the first term in the expression for h above. Further notice that the second term encompasses the revenue aspect in government's instantaneous benefits function, where as the first term is the producer surplus. When the slope of the demand curve is low, (low β), h could be negative implying a fall in the post-invasion IB from an increase in government weights on producer surplus. This happens as the revenue lost from such an increase in weights outweighs the gain in weighted producer surplus to the government. This may also happen when the slope of the supply curve is high enough.

When the instantaneous benefits function is concave, optimality would require the pre-invasion tariffs to be higher than post-invasion tariffs when h is negative. However, if the weights assigned to producer surplus in the post-invasion scenario cause h to be positive, the post-invasion instantaneous benefits would exceed the pre-invasion instantaneous benefits for any given level of tariffs. This would require lowering of tariffs in the pre-invasion scenario below those in the post-invasion scenario so that risks

of invasion are raised. However, ambiguities arise when the joint impact of a change in weights and in supply function is considered. As before, the cvh can be derived as:

$$(52) \quad cvh = \left\{ IB - PRE + (IB - PRE) \frac{(1+h)\lambda e^{-rt}}{r} \right\} e^{-\mu(t)} + l\lambda$$

In the above analysis we have assumed that the post-invasion weights are exogenously affected. However, these weights could be endogenously determined too by the government, when multiple lobby groups are considered.

Conclusion

Though important to invasive species management, the political economy aspect of public policies aimed at their control has not deserved much attention in the literature so far. In this paper an effort is made to explore the role of interest groups affected by invasive species in affecting import tariffs, thus influencing their effectiveness. The paper borrows from the existing political economy models in the literature to analyze the role of lobbyists and policy makers, which are often conflicting to a certain extent, in influencing tariffs on particular imported goods. First, a one period bargaining game is designed between the lobby group and the government to derive the relation between tariffs and contributions as a function of key parameters such as the weights on the consumer and producer surpluses, slopes of demands and supply curves, etc. While the nature of the demand and supply curves highlight the capacity of market in influencing public policy, the weights on consumer and producer surpluses highlight the importance the government assigns to that particular lobby group and industry. All key results are found to be dependent upon these weights, which signify the role of market size and

lobby power in influencing public policy. It is shown that the contributions are increasing and convex in tariffs as long as the bargaining constraints are satisfied and weights are not extremely high. The bargaining constraints themselves are functions of the weights on consumer and producer surpluses. It is shown that the bargaining constraints are less binding for the producers as their objective function has fewer arguments. The government, using the contribution function, plays the role of Stackelberg leader in deciding the optimal level of tariffs. Tariffs, in a one shot bargaining game, cannot include the risk of invasion appropriately, as the risk of invasion is a cumulative process. In order to incorporate the risk of invasion and its impact on the welfare of the lobby groups and the government, the model is made dynamic, with an infinite time horizon. This extension is important to incorporate the cumulative nature of risk-evolution with trade. Most risks of invasion accrue over time and with economic activity. In order to model these characteristics of threats of invasion, the risk of invasion is modeled as a Poisson process. The post-invasion value function is solved for different post-invasion scenarios and incorporated into the pre-invasion optimal policy problem. Numerical simulations throw interesting insights into the decision process affecting tariff allocation and specifically, highlight the complexity in predicting tariffs when several conflicting interests are involved. The role of risks in influencing tariffs is made prominent when the post-invasion scenario value function is affected. This is shown through extension of the model involving different post-invasion scenarios. Finally, tariff levels in the pre-invasion scenario are compared to tariffs in the post-invasion scenarios for various cases and key results derived.

When several conflicting interests such as the lobby group, the government and the rest of the economy are involved, the impact of tariffs on risk could be compromised by such conflicting considerations. Further, it is no longer straightforward to predict the level of tariffs over time. This is especially evident from the comparison of pre and post-invasion tariff levels in the second scenario where pre-invasion tariffs may be lowered if the weights on consumer and producer surpluses are not the same after invasion. Tariffs in the pre-invasion scenario could also be higher or lower depending upon the weights on producer and consumer surpluses when an invasion leads to a change in the supply function for the producer.

In the first scenario, when the government does not get revenues in the post-invasion period, tariffs may be increased to avoid invasion. Tariffs are also increased when high damages are expected to the rest of the economy in the post-invasion situation. However, when damages occur only to the interest groups concerned, the net impact on tariffs would be a function of the weights assigned.

While the above model assumes the case of an open economy, thus leading to a one-to-one relation between tariffs and an increase in domestic prices, it is possible that in the case of a large economy such a relationship would not hold. That is, an increase in tariffs would lead to a less than full transformation into an increase in domestic prices. Under such a scenario, the government may have a higher flexibility in its tariff policies as it can increase tariffs without significantly affecting its revenues, as an increase in tariffs would not necessarily reduce import demand significantly. However, the net effect, including the effect on contributions would be subject to the mix of key parameters analyzed above.

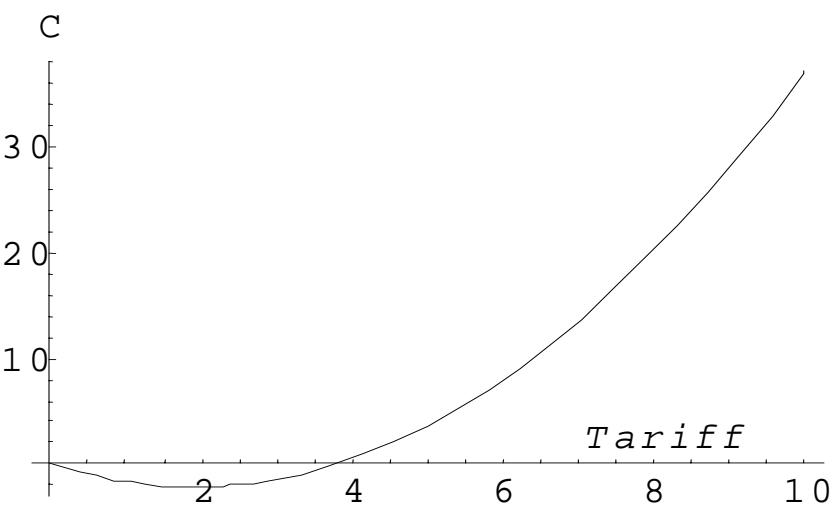
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Table 1: Results of Numerical Simulation using various Weights and Elasticities

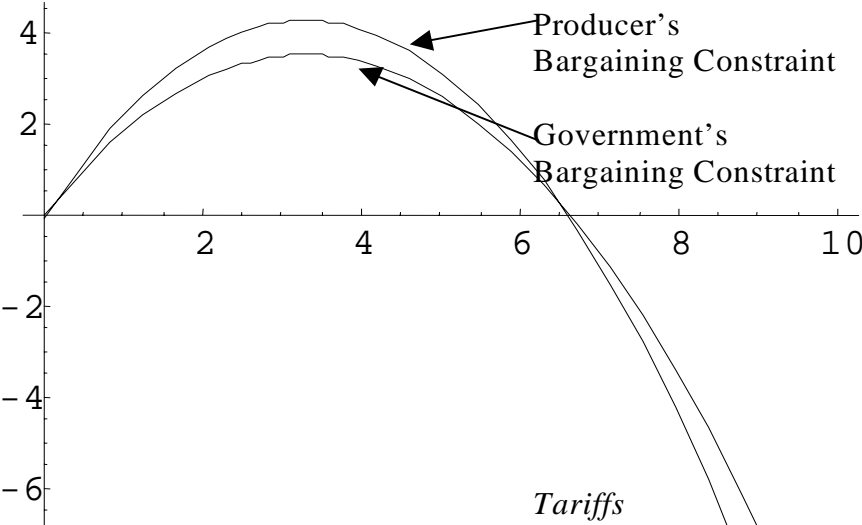
$\beta=1.5, \delta=2.5$	$a=.1, b=.1$	$a=.1, b=.2$	$a=.2, b=.1$	$a=.1, b=.3$
τ (6.3)	5.3	5.3	5.3	2.2
c	4.7	6.4	4.3	0
csb, csa	(27,4.6)	(27,4.6)	(27,4.6)	(27,15)
psb, psa	(.16,7.7)	(.16,7.7)	(.16,7.7)	(.16,1.9)
$\beta=.5, \delta=.5$				
τ (5.1)	2.6	2.1	2.7	1.3
c	0	0	0	0
csb, csa	(81,41)	(81,48)	(81,40)	(81,59)
psb, psa	(.81,12.3)	(.81,8.9)	(.81,13)	(.81,4.9)
$\beta=1.5, \delta=.5$				
τ (2.58)	1.58	1.58	1.58	
c	2.9	3.5	2.51	
csb, csa	(27,18)	(27,18)	(27,18)	
psb, psa	(.81,6.1)	(.81,6.1)	(.81,6.1)	
$\beta=.5, \delta=2.5$				
τ (8.4)	6.2	5.3	6.2	4
c	0	0	0	0
csb, csa	(81,8.1)	(81,13)	(81,8)	(81,25)
psb, psa	(.2,10)	(.2,8)	(.2,10)	(.2,5)

Figure 1: Contributions as a Function of Tariffs



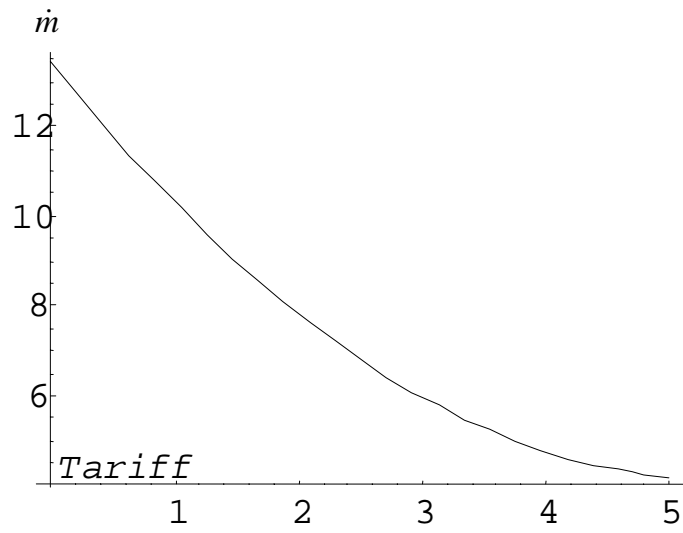
$\alpha=10; \beta=1.5; \delta=2.5; a=.1; b=.1;$

Figure 2: Producer and Government bargaining Constraints as a Function of Tariffs



$\alpha=10; \beta=1.5; \theta=.1; \delta=2.5; pw=1; a=.1; b=.1$

Figure 3: Time Path of Conditional Shadow Price of Cumulative Risk of Invasion



$$\alpha=10; \beta=1.5; \theta=.1; \delta=2.5; p^w=1; \gamma=1; a=.1; b=.1; r=.1; \theta'=.15; d=1; t=10;$$

Figure 4: Optimal Tariffs before and after Invasion

