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

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Selected Paper Prepared for Presentation at the AAEA Meetings July 24-27, 2005, Providence, Rhode Island

Abstract

This Paper designs a political economy model of invasive species management that explores the effectiveness of tariffs in mitigating risks of invasion. The revenue-interests of the government together with the interests of the lobby groups competing with the imported agricultural commodity, that is believed to be the vector of invasive species, are incorporated in a Bargaining game. The government, however, also considers the impact of tariffs on long run risks of invasion and selects optimal tariffs based upon its welfare in the pre and post-invasion scenarios. This study points out that the use of tariffs for mitigating the risk of invasion may not always yield beneficial outcomes and is subject to the multiplicity of objectives that it is brought upon to serve. Along with the size of the lobby group, which is a function of the elasticity 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. Effectiveness of tariffs as a risk mitigation device is compromised when government's revenues in the post-invasion scenario are higher than those in the pre-invasion scenario.

JEL Codes: H23, Q17, Q58

Keywords*: Invasive Species, Political Economy, Tariffs, Bargaining, and Interest Groups*

Introduction

International trade has been argued to be a prominent cause of transportation of invasive species all across the world (OTA 1993). The agricultural sector has been found to be one of the most affected by alien species, with per year damages equaling nearly US$13 billion in crop losses in the US (Pimentel et al. 2000). Recent outbreaks in the US of Bovine Spongiform Encephalopathy (BSE), commonly known as the mad cow disease, have caused widespread concern over the impact on the beef industry from international trade restrictions. It has also simultaneously led to the demand for ban of imports from regions thought to be potential sources of BSE. Besides placing outright ban on commodities that could be vectors of invasives, tariff and non-tariff barriers have also been argued as prevention tools.

The use of tariffs to prevent against invasion is of particular interest to policy makers and is specially advocated by numerous agricultural trade lobbies. Undoubtedly, while such policies help mitigate the risks of invasion, tariffs in the disguise of protection against invasive species, can also be used as tools for protecting the import-competing domestic industries. The role of tariffs in mitigating the risk of invasion cannot be looked upon in isolation of these other roles, as the effectiveness of tariffs in mitigating such risks could be significantly compromised by these multiple, and often conflicting, objectives.

This paper explores the effectiveness of tariffs in mitigating the risk of invasion, when its use is guided by a multiplicity of interests such as protectionism, revenue generation for the government and risk mitigation. The role of interest groups in influencing public policy has been a subject of concern lately, as new incidences of invasive species have led to questionable management strategies. 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. In the past, Fredriksson (1997) and Aidt (1998) have incorporated political economy into environmental models. However, not much has been done so far to apply such political economy models towards understanding the interest-groups' influence on invasive species management. Yet, a lot remains to be explored in terms of understanding the role of interest groups in their interaction with the government, especially over a long term time horizon. Margolis and Shogren (2004) and Margolis et al. (2005) apply the political economy model of Grossman and Helpman's (1994) to understand the influence of interest groups on invasive species related tariffs. In their model, the damages from invasive species form a part of the governmental objectives which also include political contributions. Significantly, they demonstrate that such a tariff must also include the benefits from political contributions alongside the damages from invasion. Only when the components of the governmental objective function are publicly known, will it be possible to delineate the political component of tariffs from the damages related to invasion. While, the paper makes an important point, there are still significant issues related to the use and implications of tariffs that have not been taken up yet. First, policies that rely upon tariffs must incorporate their long-term implications, as the risk of invasion usually gets augmented over time. Second, the pre-invasion scenario may differ significantly from the post-invasion scenario in terms of economic threats and may call for a re-evaluation of societal objectives. This may lead to a shift in the weights that the government places on the various components of its objective function. Once this possibility is acknowledged, the political economy of tariffs turns from a static game into a dynamic game involving inter-temporal bargaining. Third, forward-looking behavior on the part of the lobby groups and the government could lead to unpredictable outcomes. These issues are significant as they can determine the effectiveness of tariffs as a policy tool for invasive species management.

In light of these issues, 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, and applied to invasive species by Margolis et al. (2005), only a single lobby group (the import-competing agricultural sector, in particular) directly affected by invasive species is considered here. In reality, there are multiple lobby groups; however, as long as the interests of this particular lobby group do not clash with the rest, the government can deal with the rest of the lobby groups independently of this particular sector. This allows a more detailed modeling of the 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 any invasive species management problem that needs to be incorporated into 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 through one-shot interactions with the lobby groups.

The paper, first, explores one time interaction between the government and the lobby group by modeling a bargaining game between the two. In this game the underlying assumption is that the government is not concerned about the possibility of invasion, but uses the tariffs entirely as a means to augment its political survival. Though the damages from invasion may constitute a part of the societal welfare, they do not affect the government as long as the government does not expect the post-invasion scenario to influence its objective function. Ideally, the one shot game cannot include the risk of invasion, as the risk of invasion is dynamic in nature. Consequently, the purpose of the one period static game is to derive tariffs that are entirely protectionist in nature.

The model then proceeds to consider the dynamic aspect of the bargaining game, wherein the consequences of an invasion are incorporated into the pre-invasion policies. Several scenarios are considered in the post-invasion situation such as elimination of tariffs or continuation of bargaining. The implication of such situations on optimal tariffs is derived.

Several insights emerge from this modeling approach that may not be so apparent otherwise. The one shot game derives the protectionist element of tariffs and disregards the consequences of invasion on future bargaining situation. The results of the one shot game reveal that the political contributions are increasing and convex in tariffs as long as the bargaining constraints of the players are satisfied and the long-term risks are not considered. The bargaining constraints themselves are functions of the weights on consumer and producer surpluses. However, the dynamic version of the game sheds interesting insights over the decision process affecting tariff allocation, specifically, highlighting the complexity in predicting tariffs when several conflicting interests are involved. The role of risks in influencing tariffs becomes prominent when the post-invasion scenario value function is affected due to invasion. When several conflicting interests such as the lobby group, the government and the rest of the economy are involved, tariffs serve as a poor means of mitigating risk.

In the scenario when tariffs are eliminated after invasion, the role of weights and elasticities on the optimal selection of tariffs is highlighted. While the weights highlight the significance that the government assigns to this particular industry, the slopes (or the elasticities) of the supply and demand curves determine the role the lobby group can play in affecting tariffs. Interestingly, the significance of government weights can be counter balanced by the influence of slopes of demand and supply functions 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 affect the welfare in the post-invasion scenario.

When tariffs are retained after invasion, tariffs in the pre-invasion scenario could be either higher or lower than the tariffs in the post-invasion scenario. Similarly, when there is a change in weights on the producer surplus in the post-invasion scenario, the post-invasion instantaneous benefits function could be higher or lower than the pr-invasion benefits function. Consequently, post invasion tariffs may be higher or lower compared to pre-invasion tariff levels. This highlights the perverse motives present to increase the risks of invasion through reduced tariffs when post-invasion scenarios could bring more revenues.

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) $p = \alpha - \beta q$

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

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

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

The domestic industry producing the commodity 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 may use its revenues and the contributions to increase its prospects for future survival by spending it or by distributing amongst the entire population.

Note that the revenues generated through tariffs and contributions form a separate component in its objective function as these revenues could be used directly to increase its chances of future survival by lump sum payments to the public. The political gains from revenues generated to the producers and the surplus generated to the consumers, whereas, are slightly restrictive in nature, as they impact (and therefore influence the votes of) a limited section of the society. Consequently, the value of these interest groups compared to the rest of the population can by judged by the different weights that the government places on the components of its objective function.

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. These distinctive weights on the consumer and producer surpluses reflect the relative importance of the different lobby groups to the government. For instance, a high weight on the consumer surplus would reflect the heavy influence the consumer group would have on the government through its votes even though it may not be making any monetary contributions. Similarly, a high weight on the producer surplus would indicate the fact that government is better off by pleasing that particular industry group. The idea is that though the revenues are important to the government, it is the weights attached to the source of these revenues that determines the political mileage derived.

Tariffs serve as a 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 under consideration, thus causing a reduction in the consumer surplus. 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) $$\tau = p^t - p^w$$

The Producer Surplus (*PS*) in presence of tariffs is given by:

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

The producer surplus is always increasing in tariffs. Consumer Surplus (*CS*), however, is always decreasing in tariffs:

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

Government Revenue (*GR*) in presence of tariffs:

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

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

Consequently, the government revenue may increase or decrease with tariffs depending upon the slopes of the demand and supply curves. 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.

An Entirely Protectionist Tariff

It is possible for the government to augment its coffers by imposing tariffs under the disguise of environmental protectionism, without actually being concerned about the impact of tariffs on risk of invasion. The impact of tariffs on risk of invasion would be just another reason for higher tariffs against imported goods. In this situation, the government is not really bothered about the post-invasion scenario as long as it does not see any potential threats to political contributions or revenues even after the invasives arrive. This may especially be true if the demand for the imported commodity has low price elasticity or if the invasive species affect only the import competing industry.

In order to share the rewards from tariffs between the lobby group and the government, a 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) $$a\frac{(p^t-\theta)^2}{2\delta}+b\frac{(\alpha-p^t)^2}{2\beta}+(1-a-b)\left\{(p^t-p^w)\left\{(\frac{\alpha-p^t}{\beta})-(\frac{p^t-\theta}{\delta}\right\}+C\right\}$$

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

(9)

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

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

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

This bargaining game has two stages. The first stage of the bargaining game maximizes the product of the government and producer surpluses with respect to contributions by the producers to the government[1]:

(11)

$$Max_C$$

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

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

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. Note that in the second stage of the game the government uses tariff to optimize over contributions, its own revenues and the welfare of the producers and the consumers. In a static one-shot game, government maximizes its benefits, say *GB*, with respect to tariffs, where GB is defined as:

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

Taking the first order condition of equation (12), the optimal level of tariffs can be derived as:

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

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, 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 optimal 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 framework. 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.

Tariffs when Risk of Invasion are Considered

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. It is possible for the import competing industry too to have long run objectives, such as optimization of long run contributions. However, for the case of invasive species, the concerned interest groups are mostly agricultural sectors that are more concerned with year-to-year profits than long term plans. In fact, due to the multiplicity of interests, both within and amongst interest groups, it has been found that a large number of agricultural lobbies are not able to influence long run agricultural policies (Browne 1995).

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 until 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 distribution[2]:

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

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:

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

where

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

and

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

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:

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

Let the hazard rate be defined by:

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

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 risks[3]. 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 may either 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 contributions in the presence of risk. Government's long run objective function, which is maximized with respect to tariffs, can be defined as[4]:

(20)

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

Here 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 tariffs[5]. 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:

$$V = \frac{\frac{a}{2\delta}(p^w - \theta')^2 + \frac{b}{2\beta}(\alpha - p^w)^2 - (1-a-b)d}{r} e^{-rt} \qquad (21)$$

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 firms[6]. The government's long run objective function (to be maximized with respect to tariffs), after substituting for the contributions as a function of tariffs from above, can be written as:

(22)

$$Max_{\tau}\int_{o}^{\infty}\left\{\begin{aligned}&(\tau+p^{w}-\theta)^{2}\{\frac{1-b}{4\delta}\}+(\alpha-\tau-p^{w})^{2}\{\frac{b}{4\beta}\}+(p^{w}-\theta)^{2}(\frac{2a+b-1}{4\delta})+(\alpha-p^{w})^{2}\frac{b}{4\beta}+\\&\{\frac{\alpha-p^{w}-\tau}{\beta}-\frac{\tau+p^{w}-\theta}{\delta}\}(\frac{(1-a-b)\tau}{2})+\lambda(t)\frac{\frac{a}{2\delta}(p^{w}-\theta')^{2}+\frac{b}{2\beta}(\alpha-p^{w})^{2}-(1-a-b)d}{r}\end{aligned}\right\}e^{-\mu(t)-rt}dt$$

The above maximization is subject to the equation of motion for the hazard rate as given above by (19). The current value Hamiltonian is given by[7]:

(23)

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

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

(24)
$$\tau\left\{\frac{1-b}{2\delta}+\frac{b}{2\beta}-(1-a-b)(\frac{1}{\beta}+\frac{1}{\delta})\right\}+(p^{w}-\theta)(\frac{1-b}{2\delta})-\frac{(\alpha-p^{w})b}{2\beta}+\frac{1-a-b}{2}(\frac{(\alpha-p^{w})}{\beta}-\frac{(p^{w}-\theta)}{\delta})$$
$$-\gamma\frac{\frac{a}{2\delta}(p^{w}-\theta')^{2}+\frac{b}{2\beta}(\alpha-p^{w})^{2}-(1-a-b)d}{r}=\gamma le^{\mu}$$

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 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 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 condition derived below:

(25)

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

Let $m = le^{\mu}$, where m can be thought of as the conditional shadow value of cumulative risks[8]. Then

(26) $\dot{m} = \dot{l}e^{\mu} + le^{\mu}\lambda$

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

(27)

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

Rewriting the above we get:

(28)

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

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

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:

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

The term inside brackets is nothing but the curvature (or the second order derivative) of the instantaneous benefits function, where the instantaneous function is the same as the government benefit function *GB* derived before in the one shot game, except with a time argument (see equation 12). 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. 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.

Steady State Analysis

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 $\tau = \dfrac{\dfrac{\alpha\delta + \beta\theta}{\beta + \delta} - p^w}{\gamma}$. Note that when γ is more than one, it is possible for $\dot{\mu} = \lambda(\tau)$ to be zero even before the tariff reaches the 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.

When the government is faced with the possibility of losing tariff revenues after invasion, its emphasis is on higher tariffs in the pre-invasion scenario. However its ability to raise tariffs in the pre-invasion scenario would be guided by several factors. As the weight on consumer surplus increases, the government would be obliged to reduce tariffs in order to raise the consumer surplus. Contributions from the producers would increase in order to influence an increase in tariffs. However, the producer must be able to compensate the government for the loss in consumer surplus that is accompanied by an increase in tariffs. Consequently, as the weight on consumer surplus keeps increasing, the producer may not find it profitable to offer contributions, thus reducing contributions to zero. Therefore it is the relative weight on the consumer and producer surpluses that would determine the level of tariffs and contributions. However, the relative differences in elasticities of demand and supply too would play a crucial role in determining the level of contributions and tariffs. Tariffs would be lower when the elasticities of demand and supply are relatively higher (given by lower slopes of the demand and supply curves). This is because a higher elasticity of demand and supply would increase both the producer and consumer surpluses for any given level of tariff. When the slope of the demand curve is relatively higher than that of the supply curve, for a given level of tariffs, the residual demand would be lower. Consequently, it may happen that for a high enough difference in their elasticities, the optimal tariff is set at the maximum possible level, the one that leads to zero residual demand. 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 effect 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 weights on the consumer and producer surpluses. Further, if the damages to the rest of the economy from invasion increase significantly, even the previous cases where the difference between the slopes of the demand and supply curves is not very significant may force optimal 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, when the slope of the supply curve is much higher than that of the demand curve, tariffs may still reach their maximum possible levels. This could happen despite the consumer surplus being significantly larger than the producer surplus. The relative differences in the slopes of the demand and supply curves pushes 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.

The example highlights the role of weights and elasticities in 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 affect the welfare in the post-invasion scenario.

While the above 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[9]. Now, in the post-invasion scenario, the government maximizes its objective function with respect to tariffs:

$$(30) \qquad a\frac{(p^t-\theta')^2}{2\delta}+b\frac{(\alpha-p^t)^2}{2\beta}+(1-a-b)\left\{(p^t-p^w)\left\{(\frac{\alpha-p^t}{\beta})-(\frac{p^t-\theta'}{\delta})\right\}+C'\right\}$$

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 (30) with respect to tariffs we get:

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

Note that, since the post-invasion scenario does not involve any further threats of invasion, there is no state variable involved thereafter. As a consequence τ^* would be the optimal tariff in each period following an invasion. Without any loss of generality, we ignore damages (*d*) to the rest of the economy following 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*:

(32)

$$V = \int_t^\infty \left\{ a\frac{(p^w + \tau^* - \theta')^2}{2\delta} + b\frac{(\alpha - p^w - \tau^*)^2}{2\beta} + (1-a-b)\left\{\tau^*\left\{(\frac{\alpha - p^w - \tau^*}{\beta}) - (\frac{p^w + \tau^* - \theta'}{\delta})\right\} + C'\right\}\right\} e^{-rt} dt$$

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

(33)

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

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

(34)

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

where

(35)

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

is the instantaneous benefits (say, *IB-post*) in the post-invasion scenario[10]. Similarly,

(36)

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

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 1**: For any given tariff level, post-invasion per period benefits (IB-post) would be lower than the pre-invasion per period benefits (IB-Pre) by a factor f, from a marginal increase in θ. Consequently, tariffs in the pre-invasion scenario would always be higher than those in the post-invasion scenario.*

Proof: 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 (36) and differentiating we get:

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

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 (37). Substituting (37) into the current value Hamiltonian (*cvh*), the *cvh* can be written as:

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

In the above, the second term under brackets is *IB-post* which is some fraction of the *IB*-pre, evaluated at τ^*. From equation (37) 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 (38) 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 $(IB - pre)\frac{(1+f)}{r}$ 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 (37), 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 (13) that the tariff level in a one shot game is a function of θ too and is given by:

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

From concavity condition of the instantaneous benefit function, we know that the denominator would be negative, thus making the partial in equation (39) negative. So, under this situation we get $\tau(\theta')<\tau(\theta)$. 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.

This proposition throws interesting insights over the nature of tariff structure when the government considers long term impacts of its tariff policies. When, revenues in the post-invasion scenario are reduced as compared to the pre-invasion scenario, the government imposes higher tariffs in order to avoid the possibility of invasion. Notice that for this to happen, two key factors are important; one the impact on post-invasion utility from an increase in the fixed cost of production and two, the impact on tariffs from an increase in the same. It turns out that both these effects are negative, thus leading to lower-post invasion tariffs. In the case when damages in the post-invasion scenario are significant there is an added incentive to raise the level of tariffs in the pre-invasion scenario. Thus far, the incentives for the government are not at cross roads with the incentives that would minimize the risk of invasion. However, invasive species can significantly alter the productive capacity of the affected industries by increasing both their marginal and fixed costs of production.

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 cots intact as before. Under such a situation following proposition is made:

***Proposition**:*

2.1 *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.*

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

2.3 *Pre-invasion tariff could be lower or higher than the post-invasion tariff when* $a < \frac{1}{2} - \frac{b}{2}$ *and g is positive. When* $a > \frac{1}{2} - \frac{b}{2}$ *and g is positive, post-invasion tariffs could be higher than the pre-invasion tariffs thus leading to perverse incentives.*

Proof 2.1: Following similar marginal derivation of the instantaneous benefit function as above with respect to δ the value of *g* is derived to be:

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

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

Proofs 2.2: The current value Hamiltonian can now be re-written as:

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

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

(42)

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

From equation (13) 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 (42) would be determined by terms under the fourth bracket in the numerator as:

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

Now, when g is negative, proposition 2.2 would follow from similar logic as in proposition 1.2.

Proof 2.3: When g is positive, and $\frac{\partial \tau}{\partial \delta}$ negative as before, the results could go either way. When $a < \frac{1}{2} - \frac{b}{2}$, $\tau^*(\delta') < \tau^*(\delta)$, 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 for 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 1 below.

INSERT FIGURE 1 BELOW

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

There are two key factors that play a role in the derivation of the above proposition. First is the impact on the post-invasion value function for the government from an increase in the marginal costs (given by g) and the second is the change in the post-invasion tariffs from a change in the marginal costs. Note that, both g and $\frac{\partial \tau}{\partial \delta}$ could be either positive or negative depending upon the weights assigned and the slopes of the demand and supply curves. The condition for g to be positive is that an increase in marginal cost of production substantially raises government revenues without reducing its political contributions. The condition for $\frac{\partial \tau}{\partial \delta}$ to be positive is that the government assigns a higher weight to the producer surplus, which is possible when $a > \frac{1}{2} - \frac{b}{2}$. So when both these conditions are satisfied, opportunities arise for perverse incentives as the government would disregard the use of tariffs for risk mitigation in favor of attaining higher post-invasion utility.

This scenario highlights the fact that the interests of the government may not always be in sync with societal interests, thus leading to selection of tariffs that in fact increase the risk of invasion.

Finally, when both fixed and variable costs change due to invasion, instantaneous benefit functions may intersect, making any unambiguous result 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 may also readjust the weights downwards after invasion, if the prospects from other lobby groups become relatively brighter. Under this situation the following proposition can be made.

Proposition 3*: 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 3: By taking the partial derivative of the instantaneous benefits function with respect to a , the value of *h* could be derived as:

$$(44) \qquad h = \frac{(p^w - \theta)^2}{2\delta} - \frac{\tau}{2}\left(\frac{\alpha - p^w - \tau}{\beta} - \frac{\tau + p^w - \theta}{\delta}\right)$$

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 impacts of a change in weights and in supply function are considered. As before, the *cvh* can de derived as:

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

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. 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. The government, using the contribution function, plays the role of a 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 and 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 an 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 then full transformation into an increase in domestic prices.

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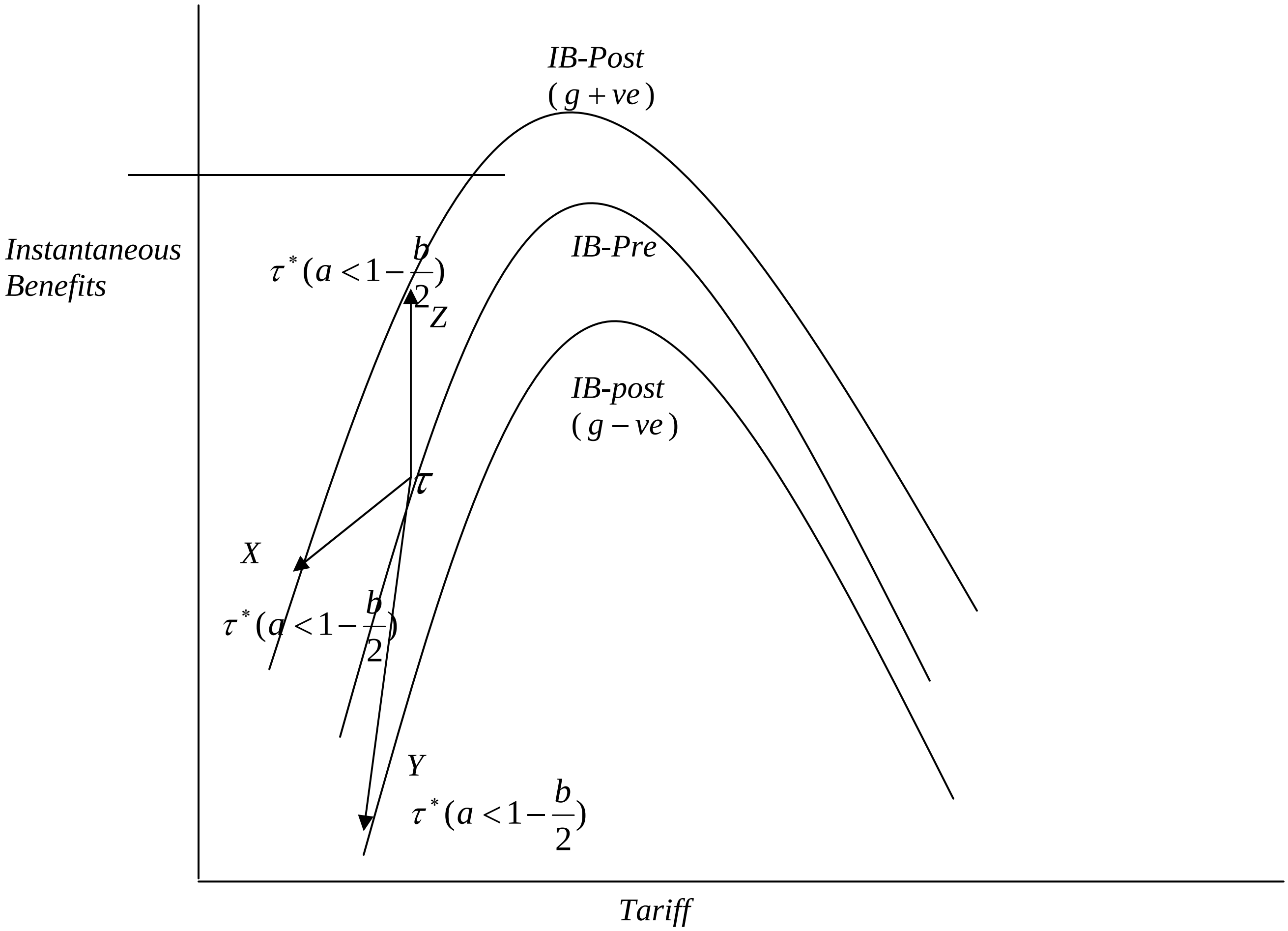
Figure 1: Optimal Tariffs before and after Invasion



1 It can be shown that for the range of tariffs within which bargaining constraints are satisfied, contributions are increasing and convex in tariffs as long as $a > -b\frac{3\beta + 3\delta}{4\beta + 2\delta} + \frac{3\beta + 2\delta}{4\beta + 2\delta}$. Bargaining constraint for the producer surplus is concave in tariffs as long as $a < -\frac{3\delta + \beta}{2(\beta + \delta)}b + \frac{2\delta + \beta}{2(\beta + \delta)}$ and convex other wise. Bargaining constraint for the government is concave in tariffs as long as $a < -\frac{3\delta + \beta}{2(\beta + \delta)}b + \frac{2\delta + \beta}{2(\beta + \delta)}$ and convex otherwise. These properties can be verified by taking the first and second order partials of the producer's and the government's surpluses with respect to tariff.

2 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.

3 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.

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

5 International Sanitary and Phytosanitary regulations may call for tariff elimination if the pest has already been established. The regulations of the WTO have been increasingly becoming sensitive towards protectionist tariffs and therefore, the government may have to justify its choice of keeping tariffs in the post-invasion scenario if the tariffs were meant to prevent the invasion only and not reduce the inflow of invasives.

6 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.

7 Notice that in order to ensure that the necessary conditions for maximum are also the sufficient conditions; one needs to check for semi-definiteness of the Hessian matrix of the Hamiltonian. This would require that the principal minors of the Hessian containing one state and one control variable are all negative in sign. The current value Hamiltonian would be concave in tariffs, thus ensuring a maximum, as long as the government's benefit function and the hazard function are 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 the static game above.

[8] 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.

[9] Tariffs in the post-invasion scenario can be justified if the level of economic damages depends upon the extent of invasion. While some species become endemic in an alien environment at a much faster pace, others may need repeated invasions to establish.

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