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Abstract

In a bilateral trade framework, we examine the impact of tariff reduction on the optimal pollution tax and social welfare when pollution is transboundary. Strategic considerations lead countries to distort their pollution tax in the non-cooperative equilibrium. Trade liberalization changes the distortion, and consequently the pollution tax and welfare, in ways that depend on the extent to which pollution is transboundary. We find that when the pollution damage parameter is sufficiently small (large), bilateral tariff reduction always decreases (increases) the pollution tax, irrespective of the value of the transboundary pollution parameter. However, when the pollution damage parameter takes intermediate values, bilateral tariff reduction decreases the pollution tax if and only if the transboundary pollution parameter is sufficiently large (or even sufficiently small, in certain cases). Moreover, with pollution being transboundary, the impact of trade liberalization on welfare is non-monotonic and concave. The greater the extent to which pollution crosses borders, the more likely is trade liberalization to reduce welfare.

JEL classifications: F18; Q58; H23; D43

Keywords: Transboundary pollution; Strategic trade; Bilateral tariff reduction; Pollution tax

1 Introduction

A continuing concern amongst environmentalists is that expanded international trade may harm the environment. It is feared that competitive pressures generated by freer trade will force governments to relax their environmental policies in a "race to the bottom". The transboundary nature of many pollutants will make it even less likely that globally efficient environmental policies are pursued by individual countries acting non-cooperatively. A growing body of literature has examined these concerns (see, for examples, Krutilla, 1991; Barrett, 1994; Kennedy, 1994; Antweiler, *et al.*, 2001; Copeland and Taylor, 2003).[1] While identifying situations where countries may strategically weaken their environmental regulations in order to capture additional gains from trade (labeled as the "rent capture" effect), the literature has also pointed out other situations where trade can improve environmental quality. The latter can happen, for instance, as a consequence of higher demand for environmental quality that emerges as national income grows with international trade.[2]

For the case where capital is immobile across countries, the rent capture effect has been illustrated by Kennedy (1994a). When firms compete in terms of quantities, reducing domestic firms' environmental costs makes them more competitive internationally, enabling a country to capture additional rents from its trading partners. Equilibrium pollution taxes can be subjected to other distortions as well. A desire to shift polluting production from itself to its trading partners can motivate a country to inefficiently increase its pollution tax. Moreover, to the extent that pollution is transboundary,

[1]Most of the literature on trade and environment has focused on consumption rather than production externalities. Some of the few papers that analyze pollution as a production externality in this context are Copeland and Taylor (1999), and Benarroch and Thille (2001).

[2]Countries may also relax their environmental regulations in order to attract internationally mobile capital (Markusen, *et al.*, 1995). Conversely, strategic behaviour among trading countries can lead to tighter environment policies when imperfectly competitive firms compete in terms of prices (Barrett, 1994).

pollution taxes chosen by individual countries taking into consideration only their own pollution damage (but not that of other countries) will be set too low. Kennedy (1994a) concludes that, in a symmetric equilibrium, the net impact under free trade is a lowering of the pollution tax below its efficient level. In a related paper, Kennedy (1994b) considers two policy instruments – a pollution tax and a production subsidy – and analyzes strategic incentives of trading countries to distort them from their efficient levels.

While Kennedy identifies how the equilibrium pollution tax may be distorted under free trade, Burguet and Sempere (2003) examine how trade liberalization (in the form of bilateral tariff reduction) affects environmental policy and welfare by changing the various distortionary forces.[3] Using a model of bilateral trade with imperfect competition and local pollution, the authors show that trade liberalization can make environmental policy either more or less stringent, depending on various factors such as the convexity of the damage function and the emission intensity of output. On the one hand, by increasing output, trade liberalization increases marginal social cost of output, which tends to tighten environmental policy. On the other hand, lower tariffs imply lower import (export) revenue (cost) which tends to make environmental policy more lax. The net impact on equilibrium environmental policy depends on the relative strength of these counteracting forces. Furthermore, Burguet and Sempere (2003) show that, when the environmental policy instrument is a pollution tax, marginal social cost is always less than price. Consequently, by increasing output, a bilateral tariff reduction always increases welfare of each country.

While Burguet and Sempere consider purely local pollution, the present paper analyzes the impact of trade liberalization on pollution tax and welfare, when pollution is transboundary. Many pollutants (such as SO_2, greenhouse gases, and toxic chemicals) impose detrimental externalities (e.g. acid rain,

[3] Burguet and Sempere (2003) consider various environmental policy instruments such as pollution tax and standard.

global warming, and pollution of the Great Lakes in North America) on countries that are different from the country where the pollutants originated. As a result, even in the absence of international trade, pollution taxes can be set too low when countries set their tax non-cooperatively. Much pollution in the world as such involves two international dimensions – international trade in polluting goods and the cross-boundary nature of the associated pollution. Taking into account both these dimensions, and their interaction, then becomes important for getting a fuller understanding of the impact of freer trade on environmental protection and welfare.

We use a model of bilateral trade with imperfect competition, and represent transboundary pollution by a parameter $\gamma \in [0, 1]$. This "transboundary pollution parameter" γ is the fraction of pollution that spills over from one country to its trading partner. Different values of the parameter allow us to consider a continuum of cases ranging from strictly local pollution to perfectly transboundary pollution. The extent to which pollution is transboundary turns out to be a crucial determinant of the impact of trade liberalization on pollution tax and welfare. This is because the magnitude of the strategic distortions that the pollution tax is subjected to depends on the extent to which pollution crosses borders. In particular, the incentive of each country to increase its tax and shift polluting production to the other country becomes smaller when pollution is more transboundary in nature.

We find that when the pollution damage parameter is sufficiently small (large), liberalizing trade always decreases (increases) the pollution tax, irrespective of the value of the transboundary pollution parameter. In contrast, when the pollution damage parameter takes a low range of intermediate values (defined later), trade liberalization always decreases the optimal pollution tax for strictly local pollution but increases the tax if pollution is moderately transboundary. Alternatively, when the pollution damage parameter takes a high range of intermediate values, trade liberalization always increases the optimal pollution tax for strictly local pollution but decreases the tax if pollution is sufficiently transboundary. Further details of this result are provided in Proposition 1.

The impact of reducing tariff protection on the welfare of each country is also shown to depend on the extent to which pollution is transboundary. When pollution is purely local, we find that a bilateral tariff reduction always increases welfare (as in Burguet and Sempere (2003)). However, when pollution is transboundary, welfare of each country is shown to be non-monotonic and concave in the tariff level. Marginal bilateral tariff reduction then improves welfare if and only if the initial tariff rate exceeds a threshold value, which itself is a positive function of the transboundary pollution parameter. An implication is that the (direction of) change in welfare of a country due to marginal bilateral reductions in the tariff rate may not be the same as that due to a discrete jump in tariff (to free trade, for example).

The rest of this paper is organized as follows. Section 2 presents the model and derives the equilibrium. The effect of bilateral trade liberalization on the optimal pollution tax and on welfare are analyzed in sections 3 and 4 respectively. Section 5 provides two numerical examples in support of our propositions. The last section concludes.

2 The model

Consider two identical countries, Home and Foreign, with segmented markets. There are n firms in each country, with $n \geq 1$. All firms produce a homogeneous good and face a constant marginal cost of production, given by c. Each Home (Foreign) firm sells x (y) units of the good in the Home market and x^* (y^*) units in the Foreign market. Foreign variables are denoted by the superscript "$*$".

In each market, firms compete in quantities, i.e. *à la* Cournot. Demand in each country is identical and given by:

$$p(q) = a - q$$

where $a > c$, and q is total quantity sold in the relevant country. Each country charges a tariff at the same rate of z per unit of import from the other country. The tariff is given exogenously in our model, and trade liberalization takes the form of equal bilateral reduction in the tariff rate. This, for example, reflects the situation subsequent to the signing of free trade agreements (such as CUSTA and NAFTA) between countries.

A by-product of production in this industry is pollution. It is assumed that, for every unit of output produced, the firms emit one unit of pollution.[4] The pollution is transboundary and $\gamma \in [0, 1]$ fraction of pollution generated in one country affects the other country. Different values of the "transboundary pollution parameter", γ, allow us to consider a continuum of cases ranging from strictly local pollution ($\gamma = 0$) to perfectly transboundary pollution ($\gamma = 1$).

The damage from pollution is monotonically increasing and convex in the level of emissions affecting a country. The damage functions in Home and Foreign are given by D and D^* respectively,

$$D = \frac{1}{2}\beta \left(n\left(x + x^*\right) + \gamma n\left(y + y^*\right)\right)^2 \tag{1}$$

$$D^* = \frac{1}{2}\beta \left(n\left(y + y^*\right) + \gamma n\left(x + x^*\right)\right)^2 \tag{2}$$

where $\beta \geq 0$ is the pollution damage parameter. In (1) and (2), $n(x + x^*)$ denotes the total production undertaken in Home and $n(y + y^*)$ the total production undertaken in Foreign. The environmental policy in each country is a tax imposed per unit of emission by domestic firms.[5] The pollution (or

[4]For simplicity, we abstract away from modeling abatement by the firms. Allowing firms to choose their level of abatement will not change our results qualitatively.

[5]Given our assumption of constant emission intensity of output, a tax per unit of

emission) tax is denoted as t and t^* for Home and Foreign, respectively.

The sequence of moves is as follows. In the first stage, (an environmental authority in) each country chooses its pollution tax to maximize the country's own welfare, taking the other country's pollution tax (and tariffs in both countries) as given. In the second stage, each firm takes the policies set by the countries and the output decisions of the $(2n-1)$ other firms as given, and maximizes its profits. To obtain the subgame perfect Nash equilibrium, the model is solved by backward induction.

2.1 Second stage: Output decision of firms

Let the total quantity sold in Home be $Q = n(x+y)$ and that in Foreign be $Q^* = n(x^* + y^*)$. Each Home firm chooses x and x^* to maximize its profit

$$\max_{x,x^*} \quad x(a-Q) + x^*(a-Q^*) - (c+t)(x+x^*) - zx^* \tag{3}$$

Similarly, each Foreign firm chooses y and y^* to maximize its profit

$$\max_{y,y^*} \quad y(a-Q) + y^*(a-Q^*) - (c+t^*)(y+y^*) - zy \tag{4}$$

The Cournot equilibrium quantities for the two markets are computed. The quantities sold in Home and Foreign are given by:

$$x = \frac{a-c-(n+1)t+nt^*+nz}{2n+1} \tag{5}$$

$$y = \frac{a-c+nt-(n+1)t^*-(n+1)z}{2n+1} \tag{6}$$

emission is equivalent to a tax per unit of the polluting good.

$$x^* = \frac{a - c - (n+1)\,t + nt^* - (n+1)\,z}{2n+1} \tag{7}$$

$$y^* = \frac{a - c + nt - (n+1)\,t^* + nz}{2n+1} \tag{8}$$

We assume that parameter values are such that each of the above quantities is positive. Total production in Home is $n\,(x + x^*)$, total consumption in Home is $n\,(x + y)$ and, using (6) and (7), net import of Home is $n\,(y - x^*) = n\,(t - t^*)$. Home's net import thus depends positively on Home's pollution tax and negatively on Foreign's pollution tax. Similarly, net import of Foreign is $n\,(x^* - y) = n\,(t^* - t)$.

2.2 First stage: Optimal environmental policy

In the first stage of the game, each country chooses the pollution tax that maximizes its own welfare (the "optimal pollution tax"), taking as given the tariff level and the other country's pollution tax.[6] Social welfare is taken to be the sum of consumer surplus, producer surplus, tariff revenue and pollution tax revenue less pollution damage. In Home, social welfare, W, is given by

$$W\,(t, t^*) \equiv CS + PS + TR + ER - D \tag{9}$$

where consumer surplus $CS = \frac{1}{2}\,(n\,(x + y))^2$, producer surplus $PS = n\left(x^2 + (x^*)^2\right)$, tariff revenue $TR = zny$, pollution tax revenue $ER = tn\,(x + x^*)$, and pollution damage D is as given by (1).

The first order condition for welfare maximization, $\frac{\partial W(t,t^*)}{\partial t} = 0$, yields an expression for Home's optimal tax, $t\,(t^*)$, which is a function of Foreign's tax, t^*, and the other parameters in our model. The second order condition

[6] In general, the optimal tax chosen by each country in the non-cooperative equilibrium will not be globally efficient (Kennedy, 1994).

for welfare maximization is satisfied since we have the following:

$$\frac{\partial^2 W(t,t^*)}{\partial t^2} = -n^2 \frac{4\beta n^2 (1-\gamma)^2 + 4n(2\beta(1-\gamma)+1) + 4\beta + 3}{(1+2n)^2} < 0$$

In a symmetric equilibrium, where both countries are identical, the pollution tax of each country will be equal. Hence, imposing $t = t^*$ in the expression for Home's optimal tax, $t(t^*)$, gives the Nash equilibrium optimal-tax in each country as

$$\bar{t} = \frac{2n\beta(1+\gamma)(1+n-n\gamma)(2(a-c)-z) - 2(1+n)(a-c-nz) + z}{4n((1+\beta)(1+n)+\beta\gamma(1-n\gamma))} \tag{10}$$

Three sources of market failure that influence the choice of the optimal pollution tax in our model are as follows. First, there is the "transboundary externality effect" that tends to lower $\bar{t}$ (from its globally efficient level), as each country ignores the impact of pollution created within its boundary on welfare in the other country. Second, there is the "rent capture effect" that also works to lower the optimal pollution tax. Since the imperfectly competitive firms enjoy rents, each government has a strategic incentive to provide a competitive advantage to its domestic firms so that they are able to capture more foreign rent. Third, there is a "pollution-shifting effect" (or a NIMBY, not-in-my-backyard, effect) that tends to increase $\bar{t}$, as each country tries to drive polluting production from itself to the other country.

The transboundary externality effect and the pollution-shifting effect depend on the extent to which pollution crosses jurisdictions. As γ increases from 0 to 1, the former effect becomes stronger while the latter effect becomes weaker. Note that when the good is clean (i.e. $\beta = 0$), both these effects are non-existent. Moreover, the rent capture effect disappears when the market becomes competitive (i.e. as $n \to \infty$). The optimal pollution tax (10) in such a case becomes

$$\lim_{n\to\infty} \bar{t}|_{\beta=0} = \frac{1}{2}z \tag{11}$$

As long as there is positive tariff, each country enjoys tariff revenue on imports and has to pay for exports. This gives them an incentive to substitute foreign production for domestic production, and consequently to tax domestic firms (the "tariff effect" on the optimal pollution tax). Only when trade is free (i.e. $z = 0$) as well, will the welfare-maximizing pollution tax rate (11) for each country be zero.

The interaction of the above-mentioned effects determines the choice of the optimal pollution tax. Note that, from (10), we have $\frac{\partial \bar{t}}{\partial \gamma} \geq 0$ if and only if $\gamma \leq \frac{1}{2n}$. Higher values of the transboundary pollution parameter, γ, increases the optimal pollution tax, $\bar{t}$, if and only if γ is sufficiently small.

In a symmetric equilibrium, substituting $t = t^* = \bar{t}$ in (5)-(8), we have total output produced equal to total output consumed in each country, so that its net import is zero. The total output, produced or consumed, in each country is

$$Q = n\left(x + x^*\right) = n\left(x + y\right) = \frac{1}{2} \frac{2\left(n+1\right)\left(a - c - z\right) + z}{\left(1+\beta\right)\left(n+1\right) + \beta\gamma\left(1 - \gamma n\right)}$$

A bilateral tariff reduction leads to an increase in total output as $\frac{\partial Q}{\partial z} < 0$ for $\gamma \in [0, 1]$.

3 Impact of bilateral tariff reduction on optimal pollution tax

The impact of bilateral tariff reduction on the previously mentioned effects determines how reducing protection affects the optimal pollution tax by altering the tradeoff between these effects. As shown below, the extent to which pollution crosses borders plays a pivotal role in the determination of the net impact of these effects.

The impact of bilateral trade liberalization on the optimal pollution tax is given by the sign of the following expression (derived using (10))

$$\frac{\partial \bar{t}}{\partial z} = \frac{1 + 2n(1-\beta)(1+n) - 2\beta n\gamma(1-n\gamma)}{4n(1+n+\beta(1+\gamma)+n\beta(1-\gamma^2))} \tag{12}$$

The denominator of (12) is positive for all $\gamma \in [0,1]$. The sign of $\frac{\partial \bar{t}}{\partial z}$, therefore, is the same as that of the numerator of (12), which is quadratic and convex in the transboundary pollution parameter γ. As such, the two roots in terms of γ that satisfy $\frac{\partial \bar{t}}{\partial z} = 0$ are

$$\gamma^L \equiv \frac{1}{2n}\left(1 - \sqrt{(1+2n)^2 - \frac{2}{\beta}(2n^2+2n+1)}\right) \tag{13}$$

$$\gamma^H \equiv \frac{1}{2n}\left(1 + \sqrt{(1+2n)^2 - \frac{2}{\beta}(2n^2+2n+1)}\right) \tag{14}$$

The above roots are real if and only if

$$\beta \geq 2\frac{2n^2+2n+1}{(2n+1)^2} \equiv \beta_1 \tag{15}$$

Moreover, $\gamma^L \geq 0$ if and only if

$$\beta \leq \frac{2n^2+2n+1}{2n(n+1)} \equiv \beta_2 \tag{16}$$

and $\gamma^H \leq 1$ if and only if

$$\beta \leq \frac{2n^2+2n+1}{4n} \equiv \beta_3 \tag{17}$$

Notice that the above-defined threshold values of the pollution damage parameter are related as follows: $1 < \beta_1 < \beta_2 \leq \beta_3$ for all $n \geq 1$. Proposition 1 follows.

Proposition 1:
(i) Suppose the pollution damage parameter is small, i.e. $\beta < \beta_1$*. Then the roots of* γ*, as given by (13) and (14) are imaginary, and we have* $\frac{\partial \bar{t}}{\partial z} > 0$ *for all* $\gamma \in [0, 1]$*. Bilateral trade liberalization decreases the optimal pollution tax for all values of the transboundary pollution parameter in this case.*
(ii) When $\beta_1 \leq \beta < \beta_2$*, we have* $\frac{\partial \bar{t}}{\partial z} \geq 0$ *if and only if* $\gamma \leq \gamma^L$ *or* $\gamma \geq \gamma^H$*. Bilateral trade liberalization decreases the optimal pollution tax only when the transboundary pollution parameter is sufficiently small or sufficiently large.*
(iii) When $\beta_2 \leq \beta \leq \beta_3$*, we have* $\frac{\partial \bar{t}}{\partial z} \geq 0$ *if and only if* $\gamma \geq \gamma^H$*. Bilateral trade liberalization decreases the optimal pollution tax only when the transboundary pollution parameter is sufficiently large.*
(iv) When the pollution damage parameter is very large, i.e. $\beta_3 < \beta$*, we have* $\frac{\partial \bar{t}}{\partial z} < 0$ *for all* $\gamma \in [0, 1]$*. Bilateral trade liberalization increases the optimal pollution tax for all values of the transboundary pollution parameter in this case.*

Proof: From (12), we have $\frac{\partial}{\partial \gamma}\left(\frac{\partial \bar{t}}{\partial z}\right) \geq 0$ if and only if $\gamma \geq \frac{1}{2n}$, and $\frac{\partial^2}{\partial \gamma^2}\left(\frac{\partial \bar{t}}{\partial z}\right) > 0$ for all $\gamma \in [0, 1]$. Note that $\frac{\partial \bar{t}}{\partial z}|_{\gamma=\frac{1}{2n}} \geq 0$ if and only if $\beta \leq \beta_1$; $\frac{\partial \bar{t}}{\partial z}|_{\gamma=0} \geq 0$ if and only if $\beta \leq \beta_2$; and $\frac{\partial \bar{t}}{\partial z}|_{\gamma=1} \geq 0$ if and only if $\beta \leq \beta_3$.$\blacksquare$

Proposition 1 shows that when the pollution damage parameter is sufficiently small (large), a bilateral tariff reduction always decreases (increases) the optimal pollution tax, irrespective of the value of the transboundary pollution parameter. However, when the pollution damage parameter takes intermediate values, bilateral trade liberalization is likely to reduce (increase) the optimal pollution tax for extreme (intermediate) values of the transboundary pollution parameter. Specifically, when the pollution damage parameter takes a low range of intermediate values ($\beta_1 \leq \beta < \beta_2$), bilateral tariff reduction decreases the optimal pollution tax if and only if the transboundary pollution parameter is sufficiently small ($\gamma < \gamma^L$) or sufficiently large ($\gamma > \gamma^H$). Alternatively, when the pollution damage parameter takes a high range of intermediate values ($\beta_2 \leq \beta \leq \beta_3$), bilateral tariff reduction decreases the tax if and only if pollution is sufficiently transboundary ($\gamma > \gamma^H$).

The above results can be explained as follows. As output increases and price falls with trade liberalization, it increases the generation of and damage from pollution, but decreases rents. Consequently, a country's incentive to raise tax and drive out polluting production increases, but its incentive to lower tax and capture additional rents decreases. These exert an *upward pressure* on the optimal pollution tax. However, a lower tariff also reduces tariff revenues from imports and the cost of exports. This reduces the country's incentive to substitute foreign production for domestic production by increasing the tax. As a result, the optimal pollution tax tends to *decrease*. The net impact on the tax depends on the relative strength of the two counteracting forces.

The incentive for a country to raise its tax and drive out polluting production depends on both the pollution damage parameter as well as the transboundary pollution parameter. For instance, when pollution is largely harmless and/or largely transboundary in nature, each country has little incentive to drive out polluting production (either because pollution damage is too small or because pollution flows back even when production moves out). Consequently, the pollution shifting effect is weak and, with trade liberalization, the upward pressure (mentioned above) on the pollution tax is likely to be dominated by the downward pressure. Trade liberalization tends to lower the optimal pollution tax in such cases.

In the special case when pollution is purely local, using (12) with $\gamma = 0$, we have $\frac{\partial \bar{t}}{\partial z}|_{\gamma=0} \geq 0$ if and only if $\beta \leq \beta_2$. Thus, if the pollution damage parameter took a value such that $\beta_1 < \beta < \beta_2$, trade liberalization would always decrease the optimal pollution tax for strictly local pollution but will increase the tax if pollution is moderately transboundary (i.e. $\gamma^L < \gamma < \gamma^H$). Similarly, when $\beta_2 < \beta < \beta_3$, trade liberalization would always increase the optimal pollution tax for strictly local pollution but will decrease the tax if pollution is sufficiently transboundary (i.e. $\gamma > \gamma^H$). Ignoring the extent to which pollution crosses borders, while analyzing the impact of trade liberalization on optimal environmental policy, is therefore likely to lead to inaccurate conclusions.

4 Impact of bilateral tariff reduction on welfare

The maximized welfare of each country, denoted as $\overline{W}$, can be derived by substituting $t = t^* = \bar{t}$ into $W(t, t^*)$, where $\bar{t}$ is the optimal pollution tax given by (10) and $W(t, t^*)$ is given by (9). Resultantly, we get

$$\overline{W} = \frac{\begin{array}{c}[2(a-c)(n+1) - z(2n+1)] \\ \left[z(2n+1)\left(\beta(\gamma+1)^2+1\right) + 2(a-c)\left((1+n)(\beta+1-\beta\gamma^2) - 2n\beta\gamma(1+\gamma)\right)\right]\end{array}}{8\left(\beta(\gamma+1)(n+1-n\gamma)+n+1\right)^2}$$

The effect of bilateral trade liberalization on welfare is given by

$$\frac{\partial\overline{W}}{\partial z} = \frac{(2n+1)^2\left(2\gamma\beta(a-c)(\gamma+1) - z\left(\beta(\gamma+1)^2+1\right)\right)}{4\left(\beta(\gamma+1)(n\gamma-n-1)-1-n\right)^2} \tag{18}$$

The following result holds.

Proposition 2: *In the presence of transboundary pollution, a marginal bilateral tariff reduction leads to an increase in the welfare of each country (i.e.* $\frac{\partial\overline{W}}{\partial z} \leq 0$*) if and only if the initial tariff rate* z *is sufficiently large (specifically* $z \geq \frac{2\beta\gamma(1+\gamma)(a-c)}{\beta(1+\gamma)^2+1} \equiv z_1$*).*

Proof: Follows from (18). ■

By increasing output, tariff reduction increases marginal social cost and reduces price. Whether this increases welfare of a country, or not, depends on whether initially price exceeds marginal social cost of output, or not, in that country. When pollution is cross-boundary (i.e. $\gamma > 0$), Proposition 2 indicates that welfare is non-monotonic and concave in z. The turning point corresponds to the threshold value of tariff, z_1. It is only when tariff is sufficiently high ($z > z_1$), and the associated output sufficiently low, that price exceeds marginal social cost. An increase in output, that emerges as a result of bilateral tariff reduction, then increases welfare. The opposite result holds when $z < z_1$.

Notice that the threshold value of tariff, z_1, is an increasing function of the transboundary pollution parameter γ (i.e. $\frac{\partial z_1}{\partial \gamma} > 0$). An important policy implication arises: the more transboundary is pollution, the less likely it is that trade liberalization will improve welfare. In contrast, when pollution is purely local (i.e. $\gamma = 0$), trade liberalization always improves welfare as (18) implies $\frac{\partial \overline{W}}{\partial z}|_{\gamma=0} = -\frac{z(2n+1)^2}{4(\beta+1)(n+1)^2} < 0$.[7]

5 Numerical analyses

In this section, we provide two numerical examples in support of our analytical results.

Example 1: Suppose the previously-defined parameters in our model take the following values:

$$a = 100,\ c = 0,\ n = 2,\ z = 1$$

Then from (15), (16), and (17) we have the threshold values of the pollution damage parameter as $\beta_1 = 1.04$, $\beta_2 = 1.08$, and $\beta_3 = 1.62$. Figure 1

[7] Burguet and Sempere (2003), who assumed local pollution, found a similar result (Proposition, p. 31): "If the environmental instrument is a tax (either on output, input, or emissions), a bilateral reduction in tariffs increases welfare."

plots $\frac{\partial \bar{t}}{\partial z}$, as given by (12), for various values of the transboundary pollution parameter $\gamma \in [0,1]$. The four U-shaped lines in Figure 1 correspond to four different values of the pollution damage parameter: $\beta = 1$, $\beta = 1.06$, $\beta = 1.3$, and $\beta = 1.7$ (these choices of β-values are dictated by the above threshold values). The sign of $\frac{\partial \bar{t}}{\partial z}$ for different values of β and γ in Figure 1 provide validation for Proposition 1. It is interesting to note that, when $\beta = 1.06$, reducing tariff protection decreases the optimal pollution tax if and only if the transboundary pollution parameter is sufficiently small (i.e. $\gamma < 0.08$) or sufficiently large (i.e. $\gamma > 0.42$).

In our symmetric equilibrium, when $t = t^* = \bar{t}$, we have $x = y^*$ and $x^* = y$ (i.e. quantity sold by a Home firm at Home equals quantity sold by a Foreign firm at Foreign, and quantity sold by a Home firm at Foreign equals quantity sold by a Foreign firm at Home). These quantities are plotted in Figures 2 and 3 for the above mentioned parameter values. It is seen that all the quantities are positive, as required.

Example 2: This example is in support of Proposition 2. Suppose the parameter values are

$$a = 100,\ c = 0,\ n = 2,\ \beta = 1,\ \gamma = 0.1$$

Then the threshold value of the tariff, as defined in Proposition 2, is $z_1 = 9.95$.

Suppose the prevailing tariff rate is $z = 1$. Then the optimal pollution tax is $\bar{t} = 38.37$, quantities are $x = y^* = 12.73$ and $x^* = y = 11.73$, and welfare is $\overline{W} = 2247.5$. Moreover, from (18), we have $\frac{\partial \overline{W}}{\partial z} = 3.35 > 0$. Thus a marginal bilateral tariff reduction causes welfare of each country to *decrease* in this case. For instance when tariff falls to $z = 0$, welfare decreases to $\overline{W} = 2243.9$.

Alternatively, suppose $z = 12$. Then $\bar{t} = 38.49$, $x = y^* = 17.1$, $x^* = y = 5.1$, and $\overline{W} = 2261.7$. Moreover, from (18), we have $\frac{\partial \overline{W}}{\partial z} = -0.76 < 0$. Thus

a marginal bilateral tariff reduction leads to an *increase* in welfare in this case. For instance when tariff falls to $z = 11$, welfare increases to $\overline{W} = 2262.$
$2.$

6 Conclusion

This paper examines the impact of bilateral trade liberalization on the optimal pollution tax and welfare, when pollution is transboundary. Accounting for the cross-boundary nature of pollution is important because much of worldwide pollution exhibits such a characteristic. This tends to make non-cooperatively set pollution taxes inefficient from a global perspective. Within such a second-best world, we analyze how changing (reducing) one policy instrument, the tariff rate, changes the optimal value of another policy instrument, the pollution tax, and the associated welfare in symmetric countries. Such an analysis is topical in a world where the move towards freer trade has left countries with less control over their tariff policy. The latter, in turn, has motivated some countries to use environmental policy instruments in order to achieve trade policy objectives (Ederington and Minier, 2003).

The extent to which pollution is transboundary affects the magnitude of the pollution shifting effect and the tradeoff between this effect, the rent capture effect, and the tariff effect. Liberalizing trade changes the tradeoff, and is shown in the paper to affect optimal pollution tax and welfare in ways that depend on the transboundary pollution parameter. We find that when the pollution damage parameter takes lower intermediate values, bilateral tariff reduction increases the pollution tax if and only if pollution is moderately transboundary. On the other hand, when the pollution damage parameter takes higher intermediate values, bilateral tariff reduction decreases the tax if and only if pollution is sufficiently transboundary (Proposition 1).

Further, when pollution is transboundary, we find that the impact of bilateral trade liberalization on welfare is non-monotonic and concave (Proposition 2). Marginal tariff reduction then improves welfare if and only if the initial tariff rate exceeds a threshold value. The more transboundary is pollution, the higher is this threshold value and the less likely it is that trade liberalization will improve welfare. Another implication for policy is that welfare changes due to marginal bilateral changes in the tariff may be an inaccurate predictor of welfare changes due to discrete jumps in tariff (to free trade, for example). For purely local pollution, however, trade liberalization always improves welfare.

Our paper examines the analytically simpler case of symmetric countries with linear demand. Nevertheless, the role of transboundary pollution in the determination of the impact of trade liberalization should remain crucial and qualitatively similar even when these simplifying assumptions are relaxed.

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Figure 1

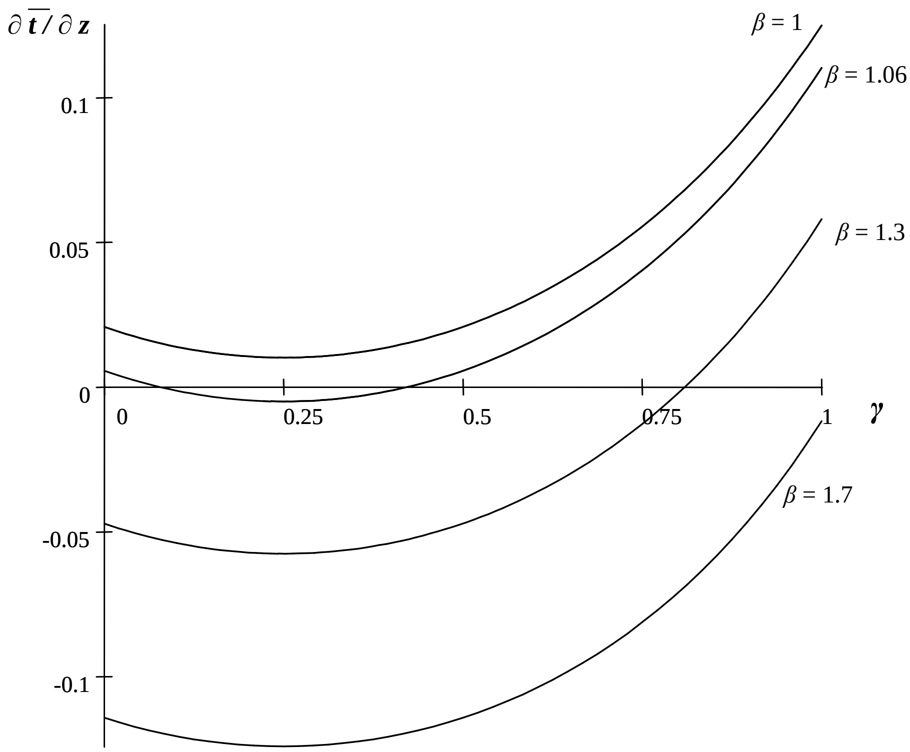


Figure 2

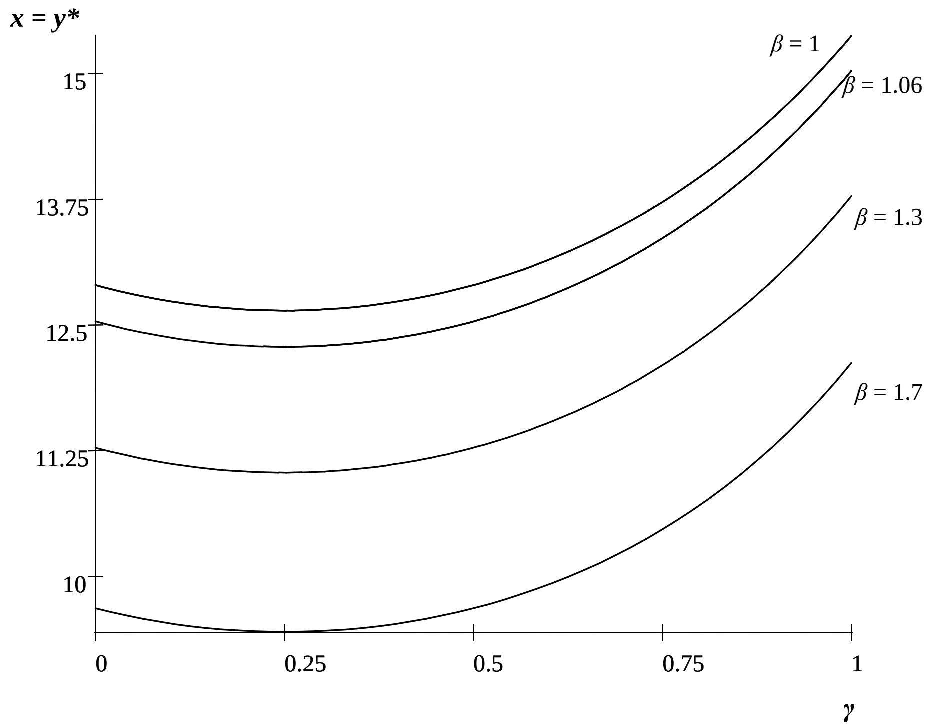
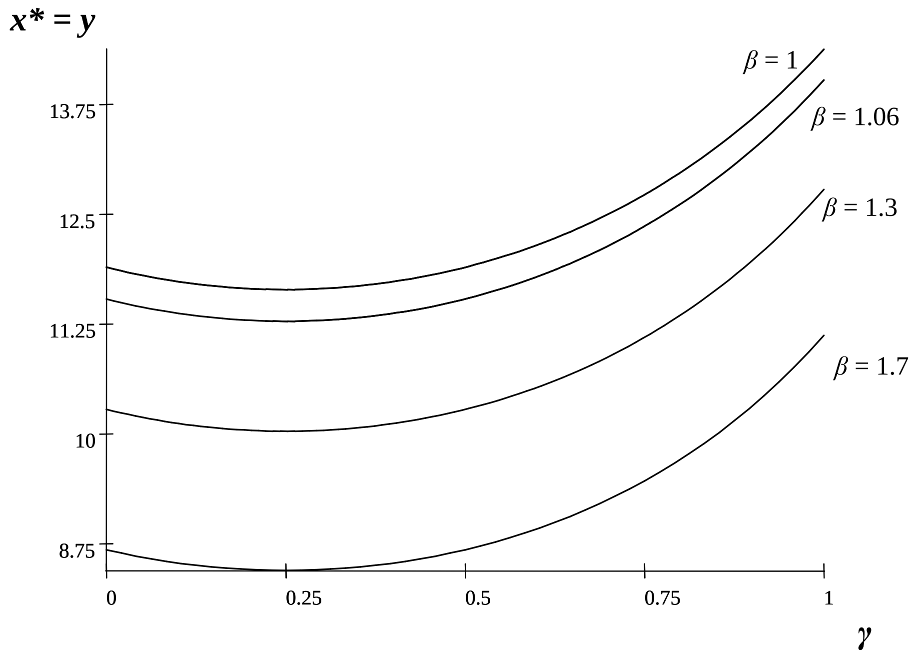


Figure 3



$x^* = y$
13.75
12.5
11.25
10
8.75
0
0.25
0.5
0.75
1
γ
$\beta = 1$
$\beta = 1.06$
$\beta = 1.3$
$\beta = 1.7$