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Strategic environmental policy under free trade with transboundary pollution

Abstract

We analyze the effects of free trade on environmental policies in a strategic setting with transboundary pollution. Trade liberalization can result in a race to the bottom in environmental outcomes, making *both* countries worse off. With command and control policies (quotas), there is no race to the bottom. However, with internationally tradable permits, unless pollution is a pure global public bad, there is a race to the bottom in environmental policy. In our model *carbon leakage alone*, and *not a terms of trade motive*, drives countries to relax domestic environmental policy. Quantity-based tools *strictly* welfare-dominate price-based tools under free trade.

1 Introduction

A serious concern about the relationship between trade and environmental policy is that these two issues have usually been dealt with separately in real-world bilateral or multilateral agreements. When trade agreements forbid the use of trade policies to pursue terms of trade goals, governments may use domestic environmental policies as a second best method of pursuing their terms of trade objectives. Other reasons that might motivate the distortion of domestic environmental policies are the competition to attract more industries (capital) from countries with stricter policies and to capture rents from foreign firms in the presence of imperfect competition. While prior research has shown that when there are no transboundary externalities negotiating tariffs, in conjunction with commitments to market access, can lead to efficiency (see, for example, Bagwell and Staiger (2001)), efficiency will not result from trade agreements alone when there are transboundary externalities. In this paper we explore the effects of trade liberalization on environmental outcomes and welfare, in the presence of transboundary pollution, when environmental policy is set non-cooperatively.

The literature on trade and environmental policy in the presence of an international spillover of emissions is too vast to be adequately surveyed here. Some papers assume the pollution externality affects firm productivity, whereas other papers assume the externality hurts households (an "eyesore" externality). Papers also differ in terms of the policy tools allowed (domestic policies, border policies, or both), the number of policy active countries, and in terms of country size. Since we investigate how, in the presence of an eyesore transboundary externality, the movement from autarky to free trade affects domestic policy and welfare, our literature review focuses on papers with similar structures.

Markusen (1975), one of the first papers to address transboundary pollution, considers one policy active country that uses both tariffs and domestic policy to influence the terms of trade and global pollution output. Rauscher (1997) derives the optimal environmental tax under free trade for a large country that suffers from transboundary pollution. He finds that "carbon leakage" occurs if stricter domestic environmental policy leads to increases in foreign emissions and concludes that with "substantial leakage effects, optimal environmental policies tend to lead to too low emission tax rates" when the pure terms of trade effects are small compared to leakage effects. However, he considers the case in which only one country is policy active. Copeland (1996) considers a small country (A) which suffers transboundary pollution from production of its import good in a neighboring economy (B). Since both countries are small and there are transports costs between the ROW and these two countries, then import tariffs in A will not affect production in B, provided B exports to ROW. However, an import tariff on pollution content can change the way in which B produces output, and hence can reduce the amount of transboundary pollution[1].

Ludema and Wooton (1994) consider strategic policy in a two country asymmetric trade model with transboundary pollution. Foreign production, which is exported to the home country, generates eyesore pollution that affects only the home country. Under a free trade agreement the foreign country - which is not affected by the pollution - implements environmental policies to manipulate its terms of trade, while the home country uses process standards[2] to improve its

[1]If foreign output and pollution were in a one-to-one correspondence, then the tariff on imports and tariff on pollution content would be identical.

[2]As the authors themselves note, such standards would be in violation of WTO rules, so we are not sure if such policies would be viable under free trade.

terms of trade and restrict the incidence of transboundary pollution.

Copeland and Taylor (1995) study a Heckscher-Ohlin two good, two factor model in which eyesore pollution is one of two primary inputs. Assuming pollution is a pure global public good and that there is free trade, they evaluate the welfare implications of trade when countries non-cooperatively choose their environmental policy, pollution permits. They find that, as compared to autarky, emissions in the South rise and emissions in the North fall; aggregate world pollution rises if trade does not lead to factor price equalization (FPE), while under FPE aggregate world pollution is unaffected by trade. Allowing free trade in pollution permits across countries guarantees FPE and hence eliminates the possibility that global emissions increase. While most of the paper assumes countries ignore the effect of their policies on world prices[3], even when countries take into account this effect, the equilibrium coincides with the earlier case because of the pure global public good nature of pollution. We derive a similar result in our model, as a special case, in Section 5.3.

Kiyono and Okuno-Fujiwara (2003) consider strategic interactions between two closed economies with respect to environmental policies. Emissions (a by-product of production) cause global warming that reduces welfare in both countries. They find emission taxes and quotas are equivalent, while emission standards lead to over-production of the polluting good. Ishikawa and Kiyono (2006) compare these policies instruments under free trade, but they use a non-strategic setting in which only one country uses environmental policy. Kiyono and Ishikawa (2004) specify a partial equilibrium model in which two large countries import fuel, an input in the production of a final good. Emissions, a by-product of the use of fuel in production, add to global pollution, which reduces welfare in both importing countries. Regulation of emissions only by the home country leads to carbon leakage, as changes in the world price of fuel affect pollution emissions in the other country. Because of strategic effects, they find world pollution is lower when both countries

[3] In essence, they assume there are a large number of Northern and a large number of Southern countries.

use quotas, rather then taxes, to regulate emissions. In their model the terms of trade and the carbon leakage effect reinforce each other. In general, if these motives work in different directions in any one country, then it is not possible to infer the net effect on pollution and welfare. In our open economy model, with no terms of trade effects in equilibrium, it is purely the carbon leakage effect that drive the results.

We use a two good, two country trade model to analyze the effects of liberalizing trade while leaving domestic policy unconstrained in the presence of transboundary pollution. We assume production of good (X) in either country generates eyesore pollution which reduces welfare in both countries. There are three potential distortions in our model: first, there is a production distortion, a domestic externality that drives a wedge between the private and social costs in one sector. Second, countries are large and hence have incentives to manipulate their terms of trade and lastly, the presence of transboundary pollution implies an efficient allocation cannot be achieved when countries practice free trade but set domestic environmental policies non-cooperatively.

Within this framework we compare the effects of environmental taxes and quotas when countries set policy non-cooperatively. We find that, if governments use taxes, the movement from autarky to free trade can result in an equilibrium in which both countries use lower taxes and achieve lower welfare than under autarky. This race to the bottom occurs not because of the terms of trade effect (as there is no trade in equilibrium), but rather because - in a strategic setting in an open economy - the government relaxes environmental taxes to reduce the incidence of transboundary pollution from abroad (i.e., to reduce "carbon leakage" in the free trade equilibrium). This race to the bottom does not occur when (globally nontradable) emission quotas, rather then taxes, are used. However, if international trade in emission permits is allowed, then a race to the bottom will occur if pollution is not a pure global public bad[4]. Thus, we find that in

[4] If the marginal damage in the home country from foreign emissions is positive, but less than that from domestic emissions, then there is transboundary pollution but it is not a pure global public bad.

the symmetric free trade equilibrium, pollution is lowest with internationally nontradable quotas and highest when taxes are used to regulate emissions, and we also find that the emissions quota equilibrium is strictly welfare-superior to the emissions tax equilibrium.

The rest of this paper is organized as follows. The model is presented in Section 2 and Section 3 derives the autarky equilibrium. Section 4 looks at the efficient equilibrium, while Section 5 explores the strategic free trade equilibrium, and compares pollution and welfare under different policy instruments. Section 6 concludes the paper.

2 The Model

We conduct our analysis using a standard two good (X, Y) model of trade between two countries, a home country and a foreign country (denoted by *). The production possibility frontier of the home country is

$$g(x, y) \geq 0; \qquad g_i < 0, \quad i = x, y \tag{1}$$

The foreign production possibility frontier is similar. Emissions are a by-product of the production of X; good Y does not pollute. We assume that production of one unit of X generates α units of emissions in the country of production and, due to transboundary pollution, $\hat{\alpha}$ units of emissions in the other country. Thus, total pollution in the home and foreign countries are, respectively,

$$z = \alpha x + \hat{\alpha} x^*, \quad z^* = \hat{\alpha} x + \alpha x^*; \quad \hat{\alpha} \in (0, \alpha] \tag{2}$$

When $\alpha < \hat{\alpha}$, domestic emissions cause a higher marginal damage in the home country than foreign emissions, while pollution is a pure global public bad if $\alpha = \hat{\alpha}$.

Let c_x and c_y denote consumption of X and Y in the home country. Preferences of the representative agent in the home country are given by a twice differentiable concave utility function

$$U(c_x, c_y, z) = \phi(c_x, c_y) - \delta z; \qquad \phi_{c_x}, \phi_{c_y}, \delta > 0 \tag{3}$$

Foreign country preferences are similar.

3 Autarky

We first solve the domestic social planner's problem. Assuming home and foreign actions are taken simultaneously, the benevolent home government maximizes its own citizen's welfare, which yields the following optimality condition (since in autarky $x = c_x$ and $y = c_y$)

$$\frac{g_x}{g_y} = \frac{\phi_x - \alpha\delta}{\phi_y} \tag{4}$$

i.e., the domestic rate of transformation equals the social marginal rate of substitution, taking into account the effect of emissions on domestic welfare. However, private agents in the economy do not take into account the domestic distortion in their decision making process. Profit maximization implies

$$\frac{p_x^f}{p_y^f} = \frac{g_x}{g_y} \tag{5}$$

where p_x^f and p_y^f are the producer prices of X and Y respectively. Producers equate the domestic rate of transformation to the producer price ratio. Utility maximization by consumers leads to the following optimality condition

$$\frac{p_x^c}{p_y^c} = \frac{\phi_x}{\phi_y} \tag{6}$$

where p_x^c and p_y^c are the consumer prices of X and Y respectively. Consumers equate the marginal rate of substitution to the consumer price ratio. Comparing the optimality conditions of the social planner, producers and consumers, Eq.'s (4), (5) and (6) respectively, it is clear that the best solution is a tax on domestic emissions

$$t_z^a = \frac{\delta}{\phi_y} \tag{7}$$

i.e., a tax on emissions equal to the domestic marginal damage of emissions. Given the one-to-one correspondence between output and emissions, this emission tax is equivalent to a tax on the output of X, which in our case is

$$t^a = \frac{\alpha\delta}{\phi_y} \tag{8}$$

Note that this autarky solution is inefficient from the global perspective as governments do not internalize the transboundary effect of their emissions.

4 Efficient Equilibrium

To obtain Pareto efficient allocations we solve a social planner's problem that maximizes the welfare of the home country subject to meeting a certain utility target for the foreign country. Naturally, the social planner accounts for the domestic and transboundary externalities. The social planner's problem yields the following optimality conditions

$$\frac{\phi_{c_x}}{\phi_{c_y}} = \frac{\phi_{c_x^*}}{\phi_{c_y^*}} \tag{9}$$

$$\frac{g_x}{g_y} = \frac{\phi_{c_x}}{\phi_{c_y}} - \left[\frac{\alpha\delta}{\phi_{c_y}} + \frac{\hat{\alpha}\delta}{\phi_{c_y^*}}\right] \tag{10}$$

$$\frac{g_{x^*}}{g_{y^*}} = \frac{\phi_{c_x^*}}{\phi_{c_y^*}} - \left[\frac{\hat{\alpha}\delta}{\phi_{c_y}} + \frac{\alpha\delta}{\phi_{c_y^*}}\right] \tag{11}$$

The marginal rate of substitution is equated across countries and the domestic rate of transformation in each country is equated to the social marginal rate of substitution, taking into account the effect of emissions on both countries. Hence, the Pareto efficient tax on emissions is

$$t_z^e = \left[\frac{\delta}{\phi_{c_y}} + \frac{\delta}{\phi_{c_y^*}}\right]; \qquad t_z^{e*} = \left[\frac{\delta}{\phi_{c_y^*}} + \frac{\delta}{\phi_{c_y}}\right] \tag{12}$$

i.e., a tax equal to the sum of marginal damages in the two countries. This tax is equivalent to a tax on the production of the polluting good, X

$$t^e = \left[\frac{\delta\alpha}{\phi_{c_y}} + \frac{\delta\hat{\alpha}}{\phi_{c_y^*}}\right]; \qquad t^{e*} = \left[\frac{\delta\alpha}{\phi_{c_y^*}} + \frac{\delta\hat{\alpha}}{\phi_{c_y}}\right] \tag{13}$$

Hence, efficiency need not require equalization of environmental taxes across countries, but it does require that both countries internalize the domestic and transboundary effects of emissions[5].

5 Free Trade

In this section we analyze the effects of a movement from autarky to free trade and how the choice of the policy instrument governs these effects. We consider each country's optimal non-cooperative environmental policy, given that they have committed to free trade[6] and that they act simultaneously. We consider three cases: i) governments regulate emissions using a tax on domestic emissions (equivalent to a tax on the production of X), ii) emission (or production) quotas are used to regulate pollution, and these quotas are not tradable across countries, and iii) internationally tradable quotas are the environmental policy instruments. Finally, we compare pollution and welfare under these different instruments.

[5] If $\alpha > \hat{\alpha}$, then $t^e > t^{e*}$ if, and only if, $\phi_{c_y^*} > \phi_{c_y}$.

[6] This can be due to trade agreements that restrict the use of trade policies.

5.1 Taxes

The only policy instrument available to each country is a tax on emissions. Given the one-to-one correspondence between output and emissions, this is equivalent to a tax on the production of X, denoted by t and t^*, and we carry out our analysis in the rest of the paper using equivalent production policies. Let p_x and p_y be the (world) consumer prices of X and Y respectively. Let good Y be the numeraire, hence we set $p_y \equiv 1$. The GNP functions for the home and foreign countries are, respectively,

$$R(p_x - t); \qquad R^*(p_x - t^*)$$

The expenditure functions for the home country and the foreign country are[7]

$$e(p_x, u + \delta\{\alpha x + \hat{\alpha} x^*\}); \qquad e^*(p_x, u^* + \delta\{\hat{\alpha} x + \alpha x^*\})$$

Equilibrium is described by the income constraints (balance of trade constraints) for the two countries and a market clearing condition:

$$e(p_x, u + \delta\{\alpha x + \hat{\alpha} x^*\}) = R(p_x - t) + tx \tag{14}$$

$$e^*(p_x, u^* + \delta\{\hat{\alpha} x + \alpha x^*\}) = R^*(p_x - t^*) + t^* x^* \tag{15}$$

$$e_{p_x} + e^*_{p_x} = x + x^* \tag{16a}$$

$$x = R_{p_x - t} \tag{16b}$$

$$x^* = R^*_{p_x - t^*} \tag{16c}$$

[7] Due to the presence of the externality, the expenditure function is given by: $\min_{c_x, c_y}(p_x c_x + c_y)$ s.t. $\phi(c_x, c_y) - \delta z \geq u \Rightarrow \min_{c_x, c_y}(p_x c_x + c_y)$ s.t. $\phi(c_x, c_y) \geq u + \delta z$.

where Eq.'s (14), (15) and (16) are the resource constraints for the home and foreign countries, and the market clearing condition, respectively. We assume that governments simultaneously and non-cooperatively choose their domestic tax to maximize welfare. Also, all tax revenues are redistributed lump-sum to consumers.

Taking the total differential of Eq.'s (14) and (16b), and combining we have

$$e_u du + (e_u \alpha\delta - t)dx + e_u \hat{\alpha}\delta dx^* = (R_p - e_{p_x})dp_x; \qquad dx = S'(dp_x - dt) \tag{17}$$

where we define $R_{p_x - t}$ as R_p, and R_{pp} as S'. Similarly totally differentiating Eq.'s (15) and (16b), we have

$$e^*_{u^*} du^* + (e^*_{u^*} \alpha\delta - t^*)dx^* + e^*_{u^*} \hat{\alpha}\delta dx = (R^*_{p^*} - e^*_{p_x})dp_x; \qquad dx^* = S^{*'}(dp_x - dt^*) \tag{18}$$

where we define $R^*_{p_x - t^*}$ as $R^*_{p^*}$, and $R^*_{p^*p^*}$ as $S^{*'}$.

Differentiating Eq. (14) with respect to t we get the home country's best response function as a function of the foreign country's tax

$$e_u \frac{du}{dt} = (R_p - e_{p_x})\frac{dp_x}{dt} + (t - e_u \alpha\delta)\frac{dx}{dt} - e_u \hat{\alpha}\delta \frac{dx^*}{dt} \tag{19}$$

The first term, the terms of trade effect, depends on whether the country is a net importer of X. The second term is the effect of changes in t on domestic pollution: as t increases, domestic emissions decline. An increase in the domestic environmental tax reduces domestic production of the polluting good resulting, under trade, in an increase in p_x, which increases foreign production and emissions. Thus, the last term reflects the carbon leakage effect.

Similarly the best response function of the foreign country is given by

$$e^*_{u^*}\frac{du^*}{dt^*} = (R^*_{p^*} - e^*_{p_x})\frac{dp_x}{dt^*} + (t^* - e^*_{u^*}\alpha\delta)\frac{dx^*}{dt^*} - e^*_{u^*}\hat{\alpha}\delta\frac{dx}{dt^*} \tag{20}$$

Note that Eq.'s (19) and (20) can also be solved for the optimal autarky production taxes. In autarky domestic production equals domestic consumption, i.e., $R_p(.) = e_{p_x}(.)$, and foreign output is independent of domestic policy, i.e., $\frac{dx^*}{dt} = 0$; hence, from Eq. (17) we have $e_u\frac{du}{dt} = (t - e_u\alpha\delta)\frac{dx}{dt}$. Since $\frac{dx}{dt} < 0$ and $e_u > 0$, it follows that the optimal autarky tax for the home country is

$$t^a = e_u\alpha\delta \tag{21}$$

Similarly the optimal autarky tax in the foreign country is

$$t^{a*} = e^*_u\alpha\delta \tag{22}$$

However, with free trade both x and x^* are affected by the environmental policy in the other country. Totally differentiating Eq. (16) yields, after simplification:

$$e_{p_xu}du + e^*_{p_xu^*}du^* + [(\beta + \beta^*) + S'(e_{p_xu}\alpha\delta + e^*_{p_xu^*}\hat{\alpha}\delta) + S^{*'}(e_{p_xu}\hat{\alpha}\delta + e^*_{p_xu^*}\alpha\delta)]dp_x$$

$$= [S'(e_{p_xu}\alpha\delta + e^*_{p_xu^*}\hat{\alpha}\delta) - S']dt + [S^{*'}(e_{p_xu}\hat{\alpha}\delta + e^*_{p_xu^*}\alpha\delta) - S^{*'}]dt^* \tag{23}$$

where we define $\beta \equiv e_{p_xp_x} - S' < 0$ and $\beta^* \equiv e^*_{p_xp_x} - S^{*'} < 0$.

Eq.'s (17), (18) and (23) can be written in matrix form as

$$\begin{bmatrix} e_u & 0 & S'(e_u\alpha\delta - t) + S^{*'} e_u\hat{\alpha}\delta + M_x \\ 0 & e_u^* & S^{*'}(e_{u^*}^*\alpha\delta - t^*) + S' e_{u^*}^*\hat{\alpha}\delta + M_x^* \\ e_{p_x u} & e_{p_x u^*}^* & (\beta+\beta^*) + S'(e_{p_x u}\alpha\delta + e_{p_x u^*}^*\hat{\alpha}\delta) + S^{*'}(e_{p_x u}\hat{\alpha}\delta + e_{p_x u^*}^*\alpha\delta) \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dp_x \end{bmatrix}$$

$$= \begin{bmatrix} S'(e_u\alpha\delta - t)dt + S^{*'} e_u\hat{\alpha}\delta dt^* \\ S^{*'}(e_{u^*}^*\alpha\delta - t^*)dt^* + S' e_{u^*}^*\hat{\alpha}\delta dt \\ [S'(e_{p_x u}\alpha\delta + e_{p_x u^*}^*\hat{\alpha}\delta) - S']dt + [S^{*'}(e_{p_x u}\hat{\alpha}\delta + e_{p_x u^*}^*\alpha\delta) - S^{*'}]dt^* \end{bmatrix} \tag{24}$$

where $M_x = e_{p_x} - R_p$ is the imports of the home country. In equilibrium we have $M_x + M_x^* = 0$. The above system can be inverted and solved. However, to simplify the calculations, we assume quasi-linear preferences (so that the income effect on demand for X is zero, i.e., $e_{p_x u} = e_{p_x u^*}^* = 0$) in the rest of the paper. Hence, from the third equation in the above system we have

$$\frac{dp_x}{dt} = -\frac{S'}{\beta + \beta^*} > 0$$

Substituting this into the first equation in the above system we have

$$\frac{du}{dt} = \frac{1}{e_u} S'(e_u\alpha\delta - t) + \frac{1}{e_u}\left[S'(e_u\alpha\delta - t) + S^{*'} e_u\hat{\alpha}\delta + M_x\right]\left[\frac{S'}{\beta + \beta^*}\right] \tag{25}$$

Note that our model nests the case of no externality, i.e., when $\delta = 0$, and also the case of no transboundary pollution, i.e., $\hat{\alpha} = 0$. In the case of no externality, the sign of the above expression depends on M_x. If the country is an importer of X, then $M_x > 0$ implying $\left(\frac{du}{dt}\right)_{t=0} < 0$. Thus the standard terms of trade argument applies, whereby a large country should subsidize domestic production of the importable if the use of commercial policies is prohibited.

Now suppose that the home and foreign countries are identical. Hence, if $t = t^*$ then $M_x = 0$.

Evaluating Eq. (25) at the autarky solution, $t^a = e_u \alpha \delta$, we have

$$\left(\frac{du}{dt}\right)_{t=t^a} = S^{*'} \hat{\alpha} \delta \left[\frac{S'}{\beta + \beta^*}\right] < 0 \tag{26}$$

Intuitively, the result in Eq. (26) follows because increases in domestic taxes increase foreign output and hence foreign pollution, i.e., $\frac{dx^*}{dt} > 0$. Thus, carbon leakage, in our symmetric model, leads to lower environmental taxes for *both* countries under free trade. We summarize our results in the following proposition

Proposition 1. *If two countries have identical preferences and technology, and t^a is the optimal autarky tax in each country, then under free trade each country's optimal response is to choose a tax rate less than t^a.*

This policy is optimal for both countries. Hence, assuming identical solutions and uniqueness, we have

Proposition 2. *With identical countries, if countries set environmental taxes non-cooperatively but otherwise pursue free trade, then*

1. *there is a race to the bottom in environmental taxes, and*
2. *both countries are worse off under free trade relative to autarky.*

Note that even if the countries are not identical, by continuity, if they are *sufficiently* similar then the above results hold. Thus,

Corollary 1. *If countries are sufficiently similar then a move from autarky to free trade will make both countries worse off if environmental taxes are set non-cooperatively.*

An important implication of this is that the more similar countries are, the more likely it is that trade liberalization will lead to higher pollution and lower welfare in *both* countries. The primary role of environmental policies should be regulation of pollution. However, in the absence of tariffs large countries have an incentive to use environmental policies as a secondary trade barrier to manipulate the terms of trade. There is another role for environmental policies in the presence of transboundary pollution; change in world prices due to domestic environmental regulations can increase foreign emissions via carbon leakage, which reduces the benefits from tighter domestic policies. The motive behind the under-regulation of the polluting sector is to reduce transboundary pollution from abroad, which partly offsets the benefits of tighter domestic pollution policies. In equilibrium, in our symmetric model, there is *no terms of trade motive*; it is purely the incentive to *reduce carbon leakage* that leads countries to lower domestic environmental tax, resulting in a race to the bottom in environmental policy.

5.2 Quotas

Now suppose both governments use command and control policies, such as upper bounds on emissions (or output), instead of taxes. Hence $x \leq L$ and $x^* \leq L^*$, where L and L^* are the production limits in the home and foreign countries, respectively. Governments simultaneously and non-cooperatively choose their quota levels to maximize welfare. Define the (shadow) value of a quota in the home and foreign countries as $\hat{\tau} \equiv p_x - p$ and $\hat{\tau}^* \equiv p_x - p^*$, respectively, where p (p^*) is the producer price of X in the home (foreign) country. If the quotas are auctioned off or traded domestically then $\hat{\tau}$ and $\hat{\tau}^*$ are the market prices of the quotas in the home and foreign countries, respectively. The home and foreign GNP functions are, respectively,

$$R(p_x - \hat{\tau}), \quad \text{with} \quad R_p(p_x - \hat{\tau}) \equiv L; \qquad R^*(p_x - \hat{\tau}^*), \quad \text{with} \quad R^*_{p^*}(p_x - \hat{\tau}^*) \equiv L^*$$

Equilibrium is described by

$$e(p_x, u + \delta\{\alpha x + \hat{\alpha} x^*\}) = R(p_x - \hat{\tau}) + \hat{\tau} L \tag{27}$$

$$e^*(p_x, u^* + \delta\{\hat{\alpha} x + \alpha x^*\}) = R^*(p_x - \hat{\tau}^*) + \hat{\tau}^* L^* \tag{28}$$

$$e_{p_x} + e^*_{p_x} = x + x^* \tag{29a}$$

$$x = R_{p_x - \hat{\tau}} \leq L \tag{29b}$$

$$x^* = R^*_{p_x - \hat{\tau}^*} \leq L^* \tag{29c}$$

where Eq.'s (27), (28) and (29) are the income constraints for the home and foreign countries, and the market clearing conditions, respectively. The quota rents (revenues) are rebated lump-sum to consumers. We assume that the quotas bind; hence, $\hat{\tau}, \hat{\tau}^* > 0$, and Eq.'s (29b) and (29c) hold with equality.

Taking the total differential of Eq. (27) we have

$$e_{p_x} dp_x + e_u du + e_u \alpha \delta dx + e_u \hat{\alpha} \delta dx^* = R_p(dp_x - d\hat{\tau}) + L d\hat{\tau} + \hat{\tau} dL;$$

$$dx = dL, \quad \text{and} \qquad R_p(p_x - \hat{\tau}) = L \tag{30}$$

Similarly totally differentiating Eq. (28) we have

$$e^*_{p_x} dp_x + e^*_{u^*} du^* + e^*_{u^*} \alpha \delta dx^* + e^*_{u^*} \hat{\alpha} \delta dx = R^*_{p^*}(dp_x - d\hat{\tau}^*) + L^* d\hat{\tau}^* + \hat{\tau}^* dL^*;$$

$$dx^* = dL^*, \quad \text{and} \quad R^*_{p^*}(p_x - \hat{\tau}^*) = L^* \tag{31}$$

Differentiating Eq. (27) with respect to L gives the home country's best response function as a function of the foreign country's quota

$$e_u \frac{du}{dL} = (R_p - e_{p_x}) \frac{dp_x}{dL} + (\hat{\tau} - e_u \alpha \delta) \frac{dx}{dL} - e_u \hat{\alpha} \delta \frac{dx^*}{dL} \tag{32}$$

The first and second terms are the terms of trade and domestic pollution effects, respectively, while the last term is the effect of changes in the incidence of transboundary pollution on domestic welfare. The terms of trade effect depends on whether the polluting good is an import of the home country. Issuing an additional permit, given that the quota binds, increases domestic production and domestic emissions. If foreign production changes following changes in domestic quotas, then it affects domestic welfare via a change in the incidence of transboundary pollution.

The foreign country's best response function is given by

$$e^*_{u^*} \frac{du^*}{dL^*} = (R^*_{p^*} - e^*_{p_x}) \frac{dp_x}{dL^*} + (\hat{\tau}^* - e^*_{u^*} \alpha \delta) \frac{dx^*}{dL^*} - e^*_{u^*} \hat{\alpha} \delta \frac{dx}{dL^*} \tag{33}$$

Eq.'s (32) and (33) can be solved for the optimal autarky production quotas. In autarky domestic consumption equals domestic production and the quota binds, i.e., $e_{p_x}(.) = R_p(.) = L$, and foreign output is independent of domestic policy, i.e., $\frac{dx^*}{dL} = 0$; hence, from Eq. (30), we have $e_u \frac{du}{dL} = \hat{\tau} - e_u \alpha \delta$. Since $e_u > 0$, the domestic production tax equivalent of the optimal autarky production quota for the home country is

$$\hat{\tau}^a = e_u \alpha \delta \tag{34}$$

Similarly the production tax equivalent of the optimal autarky output quota for the foreign country is

$$\hat{\tau}^{a*} = e^*_{u^*} \alpha \delta \tag{35}$$

Now consider each country's optimal non-cooperative environmental policy, given a commitment to free trade. Let x^a and x^{a*} be the autarky output (quota) levels in the home and foreign countries, respectively. Further, suppose that the countries are identical. Hence, if $\hat{\tau}, \hat{\tau}^* > 0$, $L = x^a = x^{a*} = L^*$, then $\exists N(x^a)$ such that, for $L \in N[x^a]$, L^* binds. Hence

$$\left(\frac{dx^*}{dL}\right)_{L=x^a} = 0 \tag{36}$$

If $L^* = x^{a*} = x^a = L$, then at $L = x^a$, $x(L, L^*) = x^a = e_{p_x}$, i.e., $L = R_p(.) = e_{p_x}(.)$. Evaluating Eq. (32) at the autarky solution, $L = x^a$, we have

$$\left(\frac{du}{dL}\right)_{L=x^a} = 0 \tag{37}$$

Hence, for our symmetric specification, the optimal domestic output and the equivalent output tax are the same in the free trade equilibrium as in the autarky equilibrium. We summarize our result in the following proposition

Proposition 3. *Suppose governments use production (or pollution) limits, rather than taxes to regulate pollution. Then, in the symmetric equilibrium, the autarky and free trade equilibria will be the same and there is no race to the bottom in environmental policy.*

To see why this result follows, suppose the foreign government imposes an upper bound on output (emissions) equal to the autarky level, i.e., it regulates output such that $x^* \leq L^* = x^{a^*}$. For any domestic output $x < x^a$, the reduced world output of good x (compared to the autarky situation) results in higher consumer (hence, producer) prices than in the (symmetric) autarky equilibrium and so the foreign output upper bound will bind. As the home country increases its permissible output limit, L, in the domain $L < x^a$, the foreign production limit continues to bind and thus $\frac{dx^*}{dL} = 0$ in the domain $L < x^a$. Furthermore, at $L = x^a$, a (small) increase in L leads to a (small) decline in world consumer prices (to below autarkic levels) but foreign output is still not affected because the consumer price is above the producer price[8]. Hence, in the neighborhood of $L = x^a$, we have $\frac{dx^*}{dL} = 0$, i.e., changes in the domestic quota level do not affect foreign output (hence, foreign emissions). Recall that the driving force behind the race to the bottom in taxes was the motive to reduce the incidence of transboundary pollution. Since changes in domestic policy do not influence foreign emissions, countries follow the same policies as in autarky. Thus, although typically there is a presumption that price-based policies are superior to command and control policies, in a strategic setting that need not be the case, and the equivalence between the two in closed economies breaks down with the possibility of trade between countries.

5.3 Tradable Quotas

We analyze the interaction between goods trade and permit trade, and consider the situation in which governments regulate emissions using quotas but, following Copeland and Taylor (1995), these quotas are tradable across the countries, i.e., countries practice free trade not only in goods, but also in permits. Thus, producer prices of goods and market values of quotas are equalized across countries, i.e., $p = p^* = p_x - \tau$, where τ is the market price of production quotas. Governments simultaneously and non-cooperatively choose quota limits to maximize welfare. Equilibrium is now described by

$$e(p_x, u + \delta\{\alpha x + \hat{\alpha} x^*\}) = R(p_x - \tau) + \tau L \tag{38}$$

$$e^*(p_x, u^* + \delta\{\hat{\alpha} x + \alpha x^*\}) = R^*(p_x - \tau) + \tau L^* \tag{39}$$

[8] The market value of the foreign production quota, if tradable, will fall but remain positive, as the increase in domestic output of x lowers the gap between the demand and supply price. However, this has no impact on the home economy and, due to symmetry, the terms of trade effect around $L = x^a$ are zero.

$$e_{p_x} + e^*_{p_x} = x + x^* \tag{40a}$$

$$x + x^* = R_{p_x-\tau} + R^*_{p_x-\tau} \leq L + L^* \tag{40b}$$

where Eq.'s (38), (39) and (40) are the balance of trade constraints for the home and foreign countries, and the market clearing conditions, respectively. We assume that the quotas bind; hence, $\tau > 0$ and

$$e_{p_x} + e^*_{p_x} = R_{p_x-\tau} + R^*_{p_x-\tau} = L + L^* \tag{41}$$

Note that, as shown in the previous section, the production tax equivalent of the optimal autarky quota in the home and foreign countries are, respectively, $\tau^a = e_u\alpha\delta$ and $\tau^{a*} = e^*_{u^*}\alpha\delta$.

Taking total differential of Eq. (38) we have

$$e_{p_x}dp_x + e_u du + e_u\alpha\delta dx + e_u\hat{\alpha}\delta dx^* = R_p(dp_x - d\tau) + Ld\tau + \tau dL;$$

$$dx + dx^* = dL + dL^*, \quad \text{and} \quad R_p(p_x - \tau) + R^*_p(p_x - \tau) = L + L^* \tag{42}$$

Totally differentiating Eq. (39) we get

$$e^*_{p_x}dp_x + e^*_{u^*}du^* + e^*_{u^*}\alpha\delta dx^* + e^*_{u^*}\hat{\alpha}\delta dx = R^*_p(dp_x - d\tau) + L^*d\tau + \tau dL^*;$$

$$dx + dx^* = dL + dL^*, \quad \text{and} \quad R_p(p_x - \tau) + R^*_p(p_x - \tau) = L + L^* \tag{43}$$

The best response function of the home country in terms of the foreign country's quota is derived by differentiating Eq. (38) with respect to L

$$e_u\frac{du}{dL} = (R_p - e_{p_x})\frac{dp_x}{dL} + (L - R_p)\frac{d\tau}{dL} + (\tau - e_u\alpha\delta)\frac{dx}{dL} + (\tau - e_u\hat{\alpha}\delta)\frac{dx^*}{dL} \tag{44}$$

The net domestic welfare effect of issuing an additional quota depends on a number of different effects. The first term, the terms of trade effect, depends on the pattern of trade, while the second term is the quota revenue effect. The third term is the effect on domestic welfare through changes in domestic emissions: if some of the new quotas are used domestically, then domestic emissions increase. The last term, the transboundary pollution effect, depends on whether foreign production increases with an increase in domestic quotas and on the public bad characteristic of pollution.

The foreign country's best response function is

$$e^*_{u^*}\frac{du^*}{dL^*} = (R^*_p - e^*_{p_x})\frac{dp_x}{dL^*} + (L^* - R^*_p)\frac{d\tau}{dL^*} + (\tau - e^*_{u^*}\alpha\delta)\frac{dx^*}{dL^*} + (\tau - e^*_{u^*}\hat{\alpha}\delta)\frac{dx}{dL^*} \tag{45}$$

Differentiating Eq. (41) with respect to L we have[9]

$$\frac{dp_x}{dL} = \frac{dp_x}{dL^*} = \frac{1}{e_{p_xp_x} + e^*_{p_xp_x}} < 0 \tag{46}$$

and

$$\frac{dp_x}{dL} - \frac{d\tau}{dL} = \frac{1}{S' + S^{*\prime}} \tag{47}$$

Furthermore, $x^* = R^*_p(p_x - \tau)$ implies (using Eq. (47))

$$\frac{dx^*}{dL} = S^{*\prime}(\frac{dp_x}{dL} - \frac{d\tau}{dL}) = \frac{S^{*\prime}}{S' + S^{*\prime}} \in (0,1) \tag{48}$$

Suppose, as before, that the countries are identical; hence, if $L = x^a = x^{a*} = L^*$, then $e_{p_x}(.) = R_p(.) = L$. Evaluating Eq. (44) at the autarky solution, $L = x^a$, we have

$$\left(e_u\frac{du}{dL}\right)_{L=x^a} = (\tau^a - e_u\hat{\alpha}\delta)\frac{dx^*}{dL} \tag{49}$$

[9]Recall that we assume quasi-linear preferences, so $e_{p_xu} = e^*_{p_xu^*} = 0$.

$(\tau^a - e_u\hat{\alpha}\delta) > 0$ if $\alpha > \hat{\alpha}$, and Eq. (48) $\Rightarrow \frac{dx^*}{dL} > 0$; thus, Eq. (49) implies (since $e_u > 0$)

$$\left(\frac{du}{dL}\right)_{L=x^a} > 0 \quad \text{if} \quad \alpha > \hat{\alpha} \tag{50}$$

We summarize our result in the following proposition

Proposition 4. *If two countries have identical preferences and technology, and if domestic emissions result in a higher marginal damage than transboundary pollution, i.e., $\alpha > \hat{\alpha}$, then under free trade in both goods and production (or emission) permits, each country's optimal response is to choose a quota level higher than the equilibrium autarky level, L^a.*

As this policy is optimal for both countries, assuming identical solutions and uniqueness, we have the following

Proposition 5. *With identical countries, if the marginal damage from domestic emissions is higher than that from transboundary pollution, i.e., $\alpha > \hat{\alpha}$, and countries set production (or emission) quotas non-cooperatively but otherwise pursue free trade in goods and permits, then*

1. *there is a race to the bottom in environmental policy, and*

2. *both countries are worse off under free trade relative to autarky.*

If the countries are not identical, as long as they are *sufficiently* similar, then, by continuity, the above results hold.

Corollary 2. *If countries are sufficiently similar and production (or emission) quotas are set non-cooperatively, then a move from autarky to free trade in both goods and quotas will make both countries worse off if the marginal damage from domestic emissions is higher than that from transboundary pollution, i.e., if $\alpha > \hat{\alpha}$.*

Thus, the more similar countries are, the more likely it is that *both* countries will relax their environmental policies and *both* will lose from trade liberalization, if $\alpha > \hat{\alpha}$. Note that with identical countries, assuming identical and unique solutions, Eq. (49) implies

$$\left(\frac{du}{dL}\right)_{L=x^a} = 0 \quad \text{if} \quad \alpha = \hat{\alpha} \tag{51}$$

Thus, we have

Proposition 6. *If pollution is a pure global public bad, i.e., if $\alpha = \hat{\alpha}$, then, in the symmetric equilibrium of this model, the free trade equilibrium with tradable permits is the same as the autarky and nontradable permit equilibria and there is no race to the bottom in environmental policy.*

Proposition 6 reflects the result in Copeland and Taylor (1995) where, due to the pure global public bad nature of pollution, the strategic and non-strategic free trade equilibria coincide. In autarky issuing an additional permit results in an accompanying increase in pollution by α units, given that the quota binds. However, with free trade in goods and permits, issuing an additional quota leads to a less than proportional increase in domestic production as some of the additional quotas are used in the foreign country; now pollution increases by $\alpha - \frac{S^{*\prime}}{S'+S^{*\prime}}(\alpha - \hat{\alpha}) < \alpha$ if $\alpha > \hat{\alpha}$. This leads to a race to the bottom in pollution policies. However, when pollution is a pure global public bad, i.e., $\alpha = \hat{\alpha}$, the source of emissions does not matter as the marginal damage is the same irrespective of the origin of pollution. Hence, there is no incentive to shift emissions to the other country and there is no race to the bottom.

In Kiyono and Okuno-Fujiwara (2003) countries, by assumption, do not trade and taxes and quotas are found to be equivalent. However, this equivalence breaks down in open economies, even if there is no trade in equilibrium, due to carbon leakage and the strategic interaction among countries. This highlights how results that hold in a closed economy setting do not necessarily hold in an open economy setting even if there is no trade in equilibrium. Furthermore, in our model the only driving force is the carbon leakage effect. In previous models, including Kiyono and Ishikawa (2004), there have been other motives at play in equilibrium, but we have isolated the pure effects of carbon leakage and how the choice of policy instrument affects the outcome of a strategic game.

5.4 Pollution and Welfare

In this section we derive the optimal (equivalent) taxes and compare welfare under different policy instruments. The optimal production tax under autarky is $t^a = e_u \alpha \delta$, while the Pareto efficient tax is

$$t^e = e_u \alpha \delta + e^*_{u*} \hat{\alpha} \delta > t^a \tag{52}$$

In autarky taxes and quotas are equivalent, i.e.,

$$t^a = \hat{\tau}^a = \tau^a = e_u \alpha \delta \tag{53}$$

Hence, we have

Proposition 7. *Under autarky the choice of policy instrument to regulate pollution does not matter, i.e., environmental taxes and quotas are equivalent.*

This result is similar to Kiyono and Okuno-Fujiwara (2003), who find that in closed economies, emission taxes and quotas are equivalent. When the policy instrument is an environmental tax, the optimal production tax for the home country can be calculated using Eq. (25). Setting $\frac{du}{dt} = 0$, we have the optimal free trade production tax

$$t = e_u \alpha \delta + \frac{S^{*'} e_u \hat{\alpha} \delta + M_x}{e_{p_x p_x} + \beta^*}$$

As before, assuming identical countries, and identical and unique solutions, we have $M_x = 0$ and

$$t = e_u \alpha \delta + \frac{S^{*'} e_u \hat{\alpha} \delta}{e_{p_x p_x} + \beta^*} < t^a \tag{54}$$

With internationally nontradable permits, assuming identical countries, the autarky and free trade equilibria coincide, and the production tax equivalent of the optimal free trade quota is

$$\hat{\tau} = e_u \alpha \delta = t^a \tag{55}$$

Finally, with internationally tradable permits, the production tax equivalent of the optimal free trade quota can be found by equating $\frac{du}{dL}$ to zero in Eq. (44)

$$\tau = e_u \alpha \delta + \frac{e_{p_x} - R_p}{e_{p_x p_x} + e^*_{p_x p_x}} + \frac{(L - R_p)(\beta + \beta^*)}{(e_{p_x p_x} + e^*_{p_x p_x})(S' + S^{*'})} + \frac{S^{*'}}{S' + S^{*'}} (e_u \hat{\alpha} \delta - e_u \alpha \delta)$$

Again, assuming identical countries, and identical and unique solutions, we have $e_{p_x}(.) = R_p(.) = L$, which implies that the production tax equivalent of the optimal free trade quota is

$$\tau = e_u \alpha \delta + \frac{S^{*'}}{S' + S^{*'}} (e_u \hat{\alpha} \delta - e_u \alpha \delta) \tag{56}$$

If $\alpha > \hat{\alpha}$, i.e., if pollution is not a pure global public bad, then $\tau < t^a$, while $\tau = t^a$ if $\alpha = \hat{\alpha}$. Furthermore, it is straightforward to verify that $\tau > t$.

The optimal (equivalent) environmental taxes in the different cases are related as follows

$$t^e > t^a = \hat{\tau} \geq \tau > t \tag{57}$$

Note that $t^a = \hat{\tau} = \tau$ if $\alpha = \hat{\alpha}$. We summarize our results in the following proposition

Proposition 8. *If identical countries simultaneously and non-cooperatively choose pollution policies but otherwise pursue free trade, and the marginal damage from domestic emissions is higher than that form transboundary pollution, i.e.,* $\alpha > \hat{\alpha}$*, then*

1. *the (equivalent) environmental tax rate is the highest (equal to the autarkic level) when internationally nontradable quotas are the policy instruments, followed by the case when internationally tradable quotas are used, and it is the lowest when taxes are used to regulate pollution;*

2. *pollution is the highest when the policy instrument is an environmental tax, followed by the case when internationally tradable quotas are used, and is the lowest (equal to the autarkic level) when internationally nontradable quotas are the policy instruments.*

Given our symmetric specification, and that no trade takes place in equilibrium, it follows that welfare (W) under the different policy instruments can be ranked as follows

$$W^{\text{efficient}} > W^{\text{autarky}} = W^{\text{quota}} \geq W^{\text{tradable quota}} > W^{\text{tax}} \tag{58}$$

Hence,

Proposition 9. *If identical countries simultaneously and non-cooperatively choose pollution policies but otherwise pursue free trade, then*

1. *the internationally nontradable quota equilibrium is equivalent to the autarky equilibrium and strictly welfare-superior to the internationally tradable quota equilibrium, which is, in turn, strictly welfare-superior to the tax equilibrium if the marginal damage from domestic emissions is higher than that from transboundary pollution, i.e., if* $\alpha > \hat{\alpha}$*;*

2. *the internationally nontradable and tradable quota equilibria are equivalent to the autarky*

equilibrium, and strictly welfare-dominate the tax equilibrium if pollution is a pure global public bad, i.e., if $\alpha = \hat{\alpha}$.

6 Concluding Remarks

We have used a very simple model to highlight the effect of trade liberalization in the presence of transboundary pollution. The autarky equilibrium is inefficient because countries do not internalize the transboundary effects of domestic emissions. The Pareto efficient equilibrium requires both countries to internalize the effects of transboundary pollution and is, naturally, welfare improving. The movement from autarky to free trade can be welfare reducing. If countries are identical and environmental taxes are set non-cooperatively, then carbon leakage, by increasing foreign emissions under trade, reduces the benefits of tighter domestic environmental policy. Although, in equilibrium, there is no trade in our symmetric model, the possibility of trade provides the opportunity to influence world prices and influence foreign production and emissions, thereby leading to a race to the bottom in environmental taxes, which makes *both* countries worse off relative to autarky.

When quotas are the policy instruments, changes in domestic policy do not affect foreign production (hence, foreign emissions) and there is no incentive to distort domestic policy. Even when the quotas are tradable across countries, if pollution is a pure global public bad, then there is no race to the bottom. However, if pollution is not a pure global public bad, then there is a race to the bottom in environmental policy with internationally tradable permits, which, again, makes *both* countries worse off as compared to autarky. Here the lower marginal damage from increased issue of pollution permits under free trade as compared to autarky is the driving force behind the race to the bottom.

The nontradable quota equilibrium welfare-dominates the tradable quota equilibrium, which, in turn, strictly welfare-dominates the tax equilibrium. Pollution is the highest when taxes are the strategic variables and the lowest when internationally nontradable quotas are the policy instruments. Although we have used identical countries to isolate the role of carbon leakage, it should be clear that, by continuity, our results hold even if countries are not identical, provided they are *sufficiently* similar. We find that quantity based tools are welfare-superior to price based tools. Other factors, such as imperfect competition or imperfect information, might favor price-based policies. Hence, this warrants a more careful analysis of the choice and restriction of policy instruments in the presence of transboundary externalities and non-cooperative policy settings. The importance of the proper choice of policy instruments becomes more crucial the more similar countries are, because certain instruments may result in *both* countries being worse off with trade liberalization, while others do not.

We have assumed that pollution causes disutility, but does not affect the production possibility set. Allowing for the latter might result in some interesting insights with respect to the equivalence between policy instruments. Another possible avenue of future research is to allow for imperfect information between countries, and verify if the welfare rankings of policy instruments derived in this paper hold in a sequential game, where countries try to infer about the preference or technology of each other from their choice of policy instrument.

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