AARES National Conference 2010

Strategic environmental policy under free trade with transboundary pollution

Harvey E. Lapan

Iowa State University

Shiva Sikdar

Yonsei University

Strategic environmental policy under free trade with transboundary pollution*

Harvey E. Lapan†
Iowa State University

Shiva Sikdar‡
Yonsei University

January 2010

Abstract

We analyze the effects of trade liberalization on environmental policies in a strategic setting when there is transboundary pollution. Trade liberalization can result in a race to the bottom in environmental taxes, which makes ***both*** countries worse off. This is ***not due to the terms of trade motive***, but rather the incentive, in a strategic setting, to reduce the incidence of transboundary pollution. With command and control policies (emission quotas), countries are unable to influence foreign emissions by strategic choice of domestic policy; hence, there is ***no*** race to the bottom. However, with internationally tradable quotas, unless pollution is a pure global public bad, there is a race to the bottom in environmental policy. Under free trade, internationally nontradable quotas result in the lowest pollution level and ***strictly*** welfare-dominate taxes. The ordering of internationally tradable quotas and pollution taxes depends, among other things, on the degree of international pollution spillovers.

JEL classification codes: F18, Q56, H23, D62.
Key words: Free trade; Transboundary pollution; Strategic environmental policy; Carbon leakage; Race to the bottom.

*Acknowledgements to be added.
†Lapan: Department of Economics, Iowa State University, 283 Heady Hall, Ames, IA 50011, USA; Tel: +1 (515) 294-5917; FAX: +1 (515) 294-0221; E-mail address: hlapan@iastate.edu.
‡Sikdar: EIC, Yonsei University, Jeongui Gwan 338, 234 Maeji, Heungup, Wonju, Gangwondo, Korea 220-710; Tel: +82 (33) 760 2716; FAX: +82 (33) 760-2712; E-mail address: shivasikdar@gmail.com.

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. We compare and provide welfare rankings of different pollution policy instruments.

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. In contrast to these papers, we consider a game in which both countries are policy-active and compare different policy instruments.

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[1] to improve its terms of trade and restrict the incidence of transboundary pollution. We, on the other hand, use a more general structure where there is two-way flow of pollution between two policy-active countries and the only policy instrument is an emission policy. We also compare different policy instruments.

Copeland and Taylor (1995) study a Heckscher-Ohlin 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. While most of the paper assumes countries ignore the effect of their policies on world prices[2], even when countries take into account this effect, the equilibrium coincides with the earlier case[3] because of the pure global public good nature of pollution. We, on the other hand, consider a strategic game and compare different policy instruments. However, we derive a similar result in our model, as a special case, in Section 5.3, when pollution is a pure global public bad.

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. Although, in our model, there is no trade in equilibrium, the opportunity to trade and affect world prices breaks the equivalence of taxes and quotas.

Kiyono and Ishikawa (2004) look at carbon leakage through trade in fossil fuel by specifying a partial equilibrium model in which two large countries import fuel, an input in the production of a final good. Regulation of emissions, a by-product of the use of fuel in production, only by the home country leads to carbon leakage, as changes in the world price of fuel affect pollution

[1] 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.

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

[3] With factor price equalization, under free trade, as compared to autarky, emissions rise in the South and fall in the North, while aggregate world pollution is unaffected.

emissions in the other country. Because of strategic effects, they find world pollution is lower when both countries use quotas, rather then taxes, to regulate emissions. We model different sources of generation of pollution, possibility of abatement and also of trade between two countries. Furthermore, we compare and rank taxes, quotas and internationally tradable quotas.

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. Our model nests a number of different scenarios: pollution may be generated as a by-product of the production of either or both goods. It also allows for substitutability between inputs that can reduce emissions, the possibility of abatement and having polluting as well as non-polluting inputs. Hence, our model covers various possible sources of generation of pollution. We assume that pollution causes an "eyesore" transboundary externality, in the sense that it 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. 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 different policy instruments, environmental taxes and quotas, and rank welfare under these instruments when countries strategically set domestic policy. 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 the symmetric free trade equilibrium, pollution is lowest with internationally nontradable quotas and the internationally nontradable emissions quota equilibrium is ***strictly*** welfare-superior to the emissions tax equilibrium. When pollution is not a pure global public bad, the internationally tradable quota equilibrium welfare dominates

[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 tax equilibrium only under certain conditions; however, the former strictly dominates the latter if pollution is a pure global public bad.

In general there is a consensus that price-based policies are superior to quantity instruments. We show that this is not necessarily true in the presence of an international transboundary externality in a strategic setting. Apart from deriving the non-equivalence of taxes and quotas, we also provide welfare-rankings of different policy instruments. This has important policy implications regarding international negotiations; as will be shown, when countries negotiate on trade liberalization, it might be beneficial to negotiate on the environmental policy instrument also.

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

$$g(x, y, z; \overrightarrow{V}) \geq 0; \qquad g_x, g_y < 0 < g_z, g_{v_i} \tag{1}$$

where z is pollution and $\overrightarrow{V}$ is the vector of inputs[5]. The production possibility function nests the case in which pollution is generated as a by-product of production of either[6] or both goods. It also allows for substitutability between inputs that can reduce emissions, the possibility of abatement and having polluting as well as non-polluting inputs. The foreign country's production possibility frontier is similar

$$g(x^*, y^*, z^*; \overrightarrow{V}^*) \geq 0; \qquad g_{x^*}, g_{y^*} < 0 < g_{z^*}, g_{v_i^*} \tag{2}$$

[5]If there are a number of domestic firms, f, each with production sets defined by $g^f(x_f, y_f, z_f, \overrightarrow{V_f}) \geq 0$, and with aggregate resource constraint $\sum_f \overrightarrow{V_f} \leq \overrightarrow{V}$, there is no guarantee that, in the presence of an externality, individual (profit-maximizing) decisions will lead to production on the societal production possibility frontier. However, if all producers face the same prices for all goods and factors, including the externality, z_f, then individual profit maximization will lead to production on the aggregate production possibility frontier. If pollution is regulated domestically by quotas rather than taxes, then these quotas must be traded internally. Hereafter we assume that domestic policies lead to production on the societal production possibility frontier.

[6]This specification subsumes the case in which pollution and output of good X (for example) are in fixed proportion.

Total pollution in the home and foreign countries are, respectively,

$$Z = z + \lambda z^*, \quad Z^* = \lambda z + z^*; \quad \lambda \in (0, 1] \tag{3}$$

i.e., total pollution in the home (foreign) country consists of two components: domestic emissions, z (z^*), and the inflow of transboundary pollution, λz^* (λz), from the other country. When $\lambda < 1$, domestic emissions cause a higher marginal damage in the home country than foreign emissions, while pollution is a pure global public bad if $\lambda = 1$.

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

$$U(c_x, c_y, Z) = \phi(c_x, c_y) - \eta Z; \qquad \phi_{c_x}, \phi_{c_y}, \eta > 0 \tag{4}$$

Foreign country preferences are similar

$$U(c_x^*, c_y^*, Z^*) = \phi(c_x^*, c_y^*) - \eta Z^*; \qquad \phi_{c_x^*}, \phi_{c_y^*}, \eta > 0 \tag{5}$$

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 $y = c_y$)

$$\frac{g_x}{g_y} = \frac{\phi_{c_x}}{\phi_{c_y}} \tag{6}$$

$$\frac{g_z}{g_y} = \frac{-\eta}{\phi_{c_y}} \tag{7}$$

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

$$\frac{g_x}{g_y} = \frac{p_x^f}{p_y^f} \tag{8}$$

$$\frac{g_z}{g_y} = \frac{-t_z}{p_y^f} \tag{9}$$

where p_x^f and p_y^f are the producer prices of X and Y respectively; t_z is the market price of pollution, i.e., tax on pollution. Producers equate the domestic rate of transformation to the producer price ratio. Utility maximization by consumers leads to the following optimality condition

$$\frac{p_x^c}{p_y^c} = \frac{\phi_{c_x}}{\phi_{c_y}} \tag{10}$$

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, eqs. (7), (9) and (10) respectively, it is clear that the best solution is a tax on domestic emissions

$$t_z^a = \frac{\eta}{\phi_{c_y}} \tag{11}$$

i.e., a tax on emissions equal to the domestic marginal damage of emissions. Note that this autarky solution, although optimal from each country's perspective, 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

$$\frac{\phi_{c_x}}{\phi_{c_y}} = \frac{\phi_{c_x^*}}{\phi_{c_y^*}} \tag{12}$$

$$\frac{g_x}{g_y} = \frac{\phi_{c_x}}{\phi_{c_y}} \tag{13}$$

$$\frac{g_z}{g_y} = -\frac{\eta}{\phi_{c_y}} - \frac{\lambda\eta}{\phi_{c_y^*}} \tag{14}$$

$$\frac{g_{x^*}}{g_{y^*}} = \frac{\phi_{c_x^*}}{\phi_{c_y^*}} \tag{15}$$

$$\frac{g_{z^*}}{g_{y^*}} = -\frac{\eta}{\phi_{c_y^*}} - \frac{\lambda\eta}{\phi_{c_y}} \tag{16}$$

The marginal rate of substitution is equated across countries and the domestic rate of transformation in each country is equated to the marginal rate of substitution, taking into account the effect of emissions on both country's welfare. Hence, the Pareto efficient emissions taxes in the home and foreign countries are, respectively,

$$t_z^e = \frac{\eta}{\phi_{c_y}} + \frac{\lambda\eta}{\phi_{c_y^*}}; \qquad t_z^{e*} = \frac{\eta}{\phi_{c_y^*}} + \frac{\lambda\eta}{\phi_{c_y}} \tag{17}$$

i.e., the efficient tax is equal to the sum of marginal damages in the two countries. 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[7].

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[8] and that they act simultaneously. We consider three cases: i) governments regulate emissions using a tax on domestic emissions, ii) emission 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.

5.1 Taxes

The only policy instrument available to each country is a tax on emissions. Let good Y be the numeraire, hence we set the world price of Y, $p_y \equiv 1$. Let p be the (world) price of X. Further, suppose that t_z and t_z^* denote the pollution taxes in the home and foreign countries, respectively. The GNP functions[9] for the home and foreign countries are, respectively,

$$R(p, t_z); \qquad R^*(p, t_z^*)$$

[7]If $\lambda < 1$, then $t_z^e > t_z^{e*}$ if, and only if, $\phi_{c_y^*} > \phi_{c_y}$.

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

[9]The revenue function is given by: $\max_{x,y,z}(px + y - t_z z)$ s.t. $g(x, y, z, \overrightarrow{V}) \geq 0$. If all firms face the same prices (p_x, p_y, t_z) for goods and for the factors, V, then individual profit maximization, together with factor market equilibrium, will lead to GNP maximization, or the revenue function as defined above. See footnote 5 for more details.

The expenditure functions for the home country and the foreign country are[10], respectively,

$$e(p, u + \eta\{z + \lambda z^*\}); \qquad e^*(p, u^* + \eta\{\lambda z + z^*\})$$

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

$$e(p, u + \eta\{z + \lambda z^*\}) = R(p, t_z) + t_z z \tag{18}$$

$$e^*(p, u^* + \eta\{\lambda z + z^*\}) = R^*(p, t_z^*) + t_z^* z^* \tag{19}$$

$$e_p + e_p^* = x + x^* \tag{20a}$$

$$x = R_p, \quad x^* = R_p^* \tag{20b}$$

$$z = -R_{t_z}, \quad z^* = -R_{t_z^*}^* \tag{20c}$$

where eqs. (18), (19) and (20) are the resource constraints for the home and foreign countries, and the market clearing conditions, respectively; t_z (t_z^*) is the pollution tax in the home (foreign) country. 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 eqs. (18) and (20c), we have

$$e_u du + (e_u \eta - t_z) dz + e_u \eta \lambda dz^* = (R_p - e_p) dp; \qquad dz = -R_{t_z t_z} dt_z - R_{p t_z} dp \tag{21}$$

Similarly, totally differentiating eqs. (19) and (20c), we have

$$e_{u^*}^* du^* + (e_{u^*}^* \eta - t_z^*) dz^* + e_{u^*}^* \eta \lambda dz = (R_p^* - e_p^*) dp; \qquad dz^* = -R_{t_z^* t_z^*}^* dt_z^* - R_{p t_z^*}^* dp \tag{22}$$

Differentiating eq. (18) with respect to t_z, we get the home country's best response function

[10] 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. $\phi(c_x, c_y) - \eta Z \geq u \Rightarrow \min_{c_x, c_y}(p_x c_x + c_y)$ s.t. $\phi(c_x, c_y) \geq u + \eta Z$.

as a function of the foreign country's tax

$$e_u \frac{du}{dt_z} = (R_p - e_p)\frac{dp}{dt_z} + (t_z - e_u\eta)\frac{dz}{dt_z} - e_u\eta\lambda\frac{dz^*}{dt_z} \tag{23}$$

The first term, the terms of trade effect, depends on whether the country is a net importer of X and the pollution intensity of X which, in turn, determines the direction of change in the price of X due to a change in the pollution tax, t_z. The second term is the effect of changes in t_z on domestic pollution: as t_z increases, domestic emissions decline. An increase in the domestic environmental tax reduces domestic production of the pollution intensive good resulting, under trade, in an increase in the world price of that good, which increases foreign production and emissions. Thus, the last term is the transboundary pollution effect and reflects the role of carbon leakage.

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

$$e^*_{u^*} \frac{du^*}{dt^*_z} = (R^*_p - e^*_p)\frac{dp}{dt^*_z} + (t^*_z - e^*_{u^*}\eta)\frac{dz^*}{dt^*_z} - e^*_{u^*}\eta\lambda\frac{dz}{dt^*_z} \tag{24}$$

Note that eqs. (23) and (24) can also be solved for the optimal autarky pollution taxes. In autarky domestic production equals domestic consumption, i.e., $R_p(.) = e_p(.)$, and foreign pollution is independent of domestic policy, i.e., $\frac{dz^*}{dt_z} = 0$; hence, from eq. (23) we have $e_u \frac{du}{dt_z} = (t_z - e_u\eta)\frac{dz}{dt_z}$. Since $\frac{dz}{dt_z} < 0$ and $e_u > 0$, it follows that the optimal autarky pollution tax for the home country is

$$t^a_z = e_u\eta \tag{25}$$

Similarly, the optimal autarky tax in the foreign country is

$$t^{a*}_z = e^*_{u^*}\eta \tag{26}$$

However, with free trade both z and z^* are affected by the environmental policy in the other country. Totally differentiating eq. (20) yields, after simplification:

$$e_{pu}du + e^*_{pu^*}du^* + [(\beta + \beta^*) - R_{pt_z}(e_{pu}\eta + e^*_{pu^*}\eta\lambda) - R^*_{pt^*_z}(e_{pu}\eta\lambda + e^*_{pu^*}\eta)]dp$$

$$= [R_{pt_z} + R_{t_zt_z}(e_{pu}\eta + e^*_{pu^*}\eta\lambda)]dt_z + [R^*_{pt^*_z} + R^*_{t^*_zt^*_z}(e_{pu}\eta\lambda + e^*_{pu^*}\eta)]dt^*_z \tag{27}$$

where we define $\beta \equiv e_{pp} - R_{pp} < 0$ and $\beta^* \equiv e^*_{pp} - R^*_{pp} < 0$.

Eqs. (21), (22) and (27) can be written in matrix form as

$$\begin{bmatrix} e_u & 0 & M_x - R_{pt_z}(e_u\eta - t_z) - R^*_{pt^*_z} e_u \eta\lambda \\ 0 & e^*_u & M^*_x - R^*_{pt^*_z}(e^*_{u^*}\eta - t^*_z) - R_{pt_z} e^*_{u^*}\eta\lambda \\ e_{pu} & e^*_{pu^*} & (\beta+\beta^*) - R_{pt_z}(e_{pu}\eta + e^*_{pu^*}\eta\lambda) - R^*_{pt^*_z}(e^*_{pu^*}\eta + e_{pu}\eta\lambda) \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dp \end{bmatrix}$$

$$= \begin{bmatrix} R_{t_z t_z}(e_u\eta - t_z)dt_z + R^*_{t^*_z t^*_z} e_u\eta\lambda dt^*_z \\ R_{t_z t_z} e^*_{u^*}\eta\lambda dt_z + R^*_{t^*_z t^*_z}(e^*_{u^*}\eta - t^*_z)dt^*_z \\ [R_{pt_z} + R_{t_z t_z}(e_{pu}\eta + e^*_{pu^*}\eta\lambda)]dt_z + [R^*_{pt^*_z} + R^*_{t^*_z t^*_z}(e^*_{pu^*}\eta + e_{pu}\eta\lambda)]dt^*_z \end{bmatrix} \tag{28}$$

where M_x $(= e_p - R_p)$ 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., $e_{pu} = e^*_{pu^*} = 0$) in the rest of the paper. Hence, from the third equation in the above system we have

$$\frac{dp}{dt_z} = \frac{R_{pt_z}}{\beta + \beta^*} \tag{29}$$

Hence, $\frac{dp}{dt_z} > 0$ if X is relatively more pollution intensive than Y, i.e., if $\frac{\partial x}{\partial t_z} = R_{pt_z} < 0$ (since $(\beta+\beta^*) < 0$). Furthermore, the change in foreign pollution due to a change in the home country's pollution tax is $\frac{dz^*}{dt_z} = \frac{dz^*}{dp}\frac{dp}{dt_z} = -R^*_{pt^*_z}\frac{dp}{dt_z}$, and using eq. (29) we have

$$\frac{dz^*}{dt_z} = -\frac{R^*_{pt^*_z} R_{pt_z}}{\beta + \beta^*} \tag{30}$$

Since $(\beta + \beta^*) < 0$, $\frac{dz^*}{dt_z} > 0$ under symmetry, irrespective of whether X or Y is relatively more pollution intensive, i.e., foreign emissions unambiguously increase due to an increase in the home country's pollution taxes.

Note that our model nests the case of no externality, i.e., when $\eta = 0$, and also the case of no transboundary pollution, i.e., $\lambda = 0$. In the case of no externality, the home country's best response function, eq. (23), reduces to

$$e_u \frac{du}{dt_z} = (R_p - e_p)\frac{dp}{dt_z} + t_z \frac{dz}{dt_z}$$

If the home country is a net importer of X $(M_x > 0)$, and X is pollution intensive, i.e., $R_{pt_z} < 0$, then $\frac{dp}{dt_z} > 0$ and $\left(\frac{du}{dt_z}\right)_{t_z=0} < 0$. This is the standard terms of trade argument in effect: a large country should subsidize domestic production of the importable if the use of commercial policies is prohibited.

Assumption 1. *Countries are said to be symmetric if they have the same preferences and technology.*

Definition 1. *The* ***symmetric equilibrium*** *occurs when countries have the same preferences and technology, and adopt identical policies.*

Now consider the case of a transboundary pollution externality. Consider the symmetric equilibrium, i.e., where $t_z = t_z^*$, and thus $M_x = 0$. Evaluating eq. (23) at the autarky solution, $t_z^a = e_u\eta$, we have

$$\left(\frac{du}{dt_z}\right)_{t_z=t_z^a} = \eta\lambda\left[\frac{R_{pt_z}R^*_{pt_z^*}}{\beta+\beta^*}\right] < 0 \tag{31}$$

Intuitively, the result in eq. (31) follows because increases in domestic taxes increase foreign pollution, i.e., $\frac{dz^*}{dt_z} > 0$. Thus, the transboundary pollution effect, due to carbon leakage, in our symmetric model, leads to lower environmental taxes for ***both*** countries under free trade. We summarize our result in the following proposition

Proposition 1. *In the symmetric equilibrium, if 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. *If countries set environmental taxes non-cooperatively but otherwise pursue free trade, then, in the symmetric equilibrium,*

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 we deviate from our symmetry assumption, by continuity, if countries 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 lower welfare in ***both*** countries. While the primary role of domestic environmental policies is regulation of pollution, in an open economy one must consider the impact of these policies both on the terms of trade and on foreign pollution (if transboundary pollution is present). The reason for under taxation of pollution, in our symmetric equilibrium, is ***strictly due to the transboundary pollution effect***, i.e., the incentive to reduce carbon leakage leads countries to lower the domestic environmental tax, resulting in a race to the bottom in environmental outcomes.

5.2 Quotas

Now suppose both governments use command and control policies, such as upper bounds on emissions, instead of taxes. Hence $z \leq L_z$ and $z^* \leq L_z^*$, where L_z and L_z^* are the emission limits in the home and foreign countries, respectively[11]. Governments simultaneously and non-cooperatively choose their quota levels to maximize welfare. Define the (shadow) value of a quota in the home (foreign) country as $\hat{\tau}_z$ ($\hat{\tau}_z^*$). If the quotas are auctioned off or traded domestically, then $\hat{\tau}_z$ and $\hat{\tau}_z^*$ are the market prices of the quotas in the home and foreign countries, respectively. Equilibrium is now described by

$$e(p, u + \eta\{z + \lambda z^*\}) = R(p, \hat{\tau}_z) + \hat{\tau}_z L_z \tag{32}$$

$$e^*(p, u^* + \eta\{\lambda z + z^*\}) = R^*(p, \hat{\tau}_z^*) + \hat{\tau}_z^* L_z^* \tag{33}$$

$$e_p + e_p^* = x + x^* \tag{34a}$$

$$x = R_p, \quad x^* = R_p^* \tag{34b}$$

$$z = -R_{\hat{\tau}_z} \leq L_z, \quad z^* = -R^*_{\hat{\tau}_z^*} \leq L_z^* \tag{34c}$$

where eqs. (32), (33) and (34) 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

[11]When quotas are used to regulate domestic pollution, and when there are multiple firms, then in order to reach the production possibility frontier, these quotas must be allocated efficiently among domestic producers. This could be done via an omniscient and omnipotent central planner or, more plausibly, by allowing quotas to be tradable domestically. We assume the latter to be true.

consumers. We assume that the quotas bind; hence, $\hat{\tau}_z, \hat{\tau}_z^* > 0$, and eq. (34c) holds with equality.

Taking the total differential of eq. (32) we have

$$e_u du + e_u \eta dz - \hat{\tau}_z dL_z + e_u \eta \lambda dz^* = (R_p - e_p)dp; \quad dz = dL_z \tag{35}$$

Similarly, totally differentiating eq. (33) we have

$$e^*_{u^*} du^* + e^*_{u^*} \eta dz^* - \hat{\tau}^*_z dL^*_z + e^*_{u^*} \eta \lambda dz = (R^*_p - e^*_p)dp; \quad dz^* = dL^*_z \tag{36}$$

Differentiating eq. (32) with respect to L_z gives the home country's best response function as a function of the foreign country's quota

$$e_u \frac{du}{dL_z} = (R_p - e_p)\frac{dp}{dL_z} + (\hat{\tau}_z - e_u \eta)\frac{dz}{dL_z} - e_u \eta \lambda \frac{dz^*}{dL_z} \tag{37}$$

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 importable of the home country is pollution intensive. Issuing an additional permit, given that the quota binds, increases domestic emissions. If foreign emissions change 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

$$e^*_{u^*} \frac{du^*}{dL^*_z} = (R^*_p - e^*_p)\frac{dp}{dL^*_z} + (\hat{\tau}^*_z - e^*_{u^*} \eta)\frac{dz^*}{dL^*_z} - e^*_{u^*} \eta \lambda \frac{dz}{dL^*_z} \tag{38}$$

Eqs. (37) and (38) can be solved for the optimal autarky pollution quotas. In autarky, domestic consumption equals domestic production, i.e., $e_p(.) = R_p(.)$, the quota binds, i.e., $z = L_z$, and foreign pollution is independent of domestic policy, i.e., $\frac{dz^*}{dL_z} = 0$; hence, from eq. (37), we have $e_u \frac{du}{dL_z} = \hat{\tau}_z - e_u \eta$. Since $e_u > 0$, the domestic pollution tax equivalent of the optimal autarky pollution quota for the home country is

$$\hat{\tau}^a_z = e_u \eta \tag{39}$$

Similarly, the pollution tax equivalent of the optimal autarky pollution quota for the foreign country is

$$\hat{\tau}_z^{a*} = e_{u^*}^* \eta \tag{40}$$

These are, obviously, the same autarky implicit taxes as in the previous section, where taxes are the policy tools.

Now consider each country's optimal non-cooperative environmental policy, given a commitment to free trade. Let z^a and z^{a*} be the autarky pollution (quota) levels in the home and foreign countries, respectively. Furthermore, consider the home country's optimal choice of pollution quota, given that the foreign country chooses its autarky quota level. Since the quotas must bind in the autarky equilibrium $z^a = z^{a*}$ [12], then, given $L_z^* = z^{a*}$, by continuity there must exist a neighborhood around z^a such that for $L_z \in N(z^a)$, both the home and foreign quotas bind. Hence,

$$\left(\frac{dz^*}{dL_z}\right)_{L_z = z^a} = 0 \tag{41}$$

If $L_z^* = z^{a*} = z^a = L_z$, then at $L_z = z^a$, $z(L_z, L_z^*) = z^a$, and $R_p(.) = e_p(.)$. Thus, evaluating eq. (37) at the autarky solution, $L_z = z^a$, we have

$$\left(\frac{du}{dL_z}\right)_{L_z = z^a} = 0 \tag{42}$$

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

Proposition 3. *Suppose governments use emission 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 that X is the pollution intensive good and the foreign government imposes an upper bound on emissions equal to the autarky level, i.e., it regulates domestic pollution such that $z^* \leq L_z^* = z^{a^*}$. For any domestic emission level $z < z^a$, the reduced world output of good X (compared to the autarky situation) results in higher prices than in the (symmetric) autarky equilibrium and so the foreign country would want to increase its production of the pollution intensive good, X. Hence, the foreign pollution limit will bind. As the home

[12]The pollution quotas will always bind under the parametric assumptions $g_x, g_y < 0 < g_z$.

country increases its pollution quota level, L_z, in the domain $L_z < z^a$, the foreign pollution limit continues to bind and thus $\frac{dz^*}{dL_z} = 0$ in the domain $L_z < z^a$. Furthermore, at $L_z = z^a$, a (small) increase in L_z results in a (small) decline in the world price of the pollution intensive good, X, relative to autarky levels. Although the market value of a foreign emission quota falls, $\hat{\tau}_z^* > 0$ and hence the foreign quota continues to bind, leaving foreign emissions unaffected. Hence, in the neighborhood of $L_z = z^a$, we have $\frac{dz^*}{dL_z} = 0$, i.e., changes in the domestic quota level do not affect foreign emissions. Recall that, in our symmetric model, the driving force behind the race to the bottom in taxes was the motive to reduce the incidence of transboundary pollution. Since, when emission quotas are used, 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 once there is the possibility of trade between countries (even though in our symmetric model, there is no trade in equilibrium).

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. Both countries simultaneously issue emission quotas[13] and the quotas issued by one country can be used in the other country also, i.e., there exists an international emission permits market. Thus, the market price of pollution quotas, τ_z, is equalized across countries. Governments simultaneously and non-cooperatively choose their own quota limits to maximize welfare. Equilibrium is now described by

$$e(p, u + \eta\{z + \lambda z^*\}) = R(p, \tau_z) + \tau_z L_z \tag{43}$$

$$e^*(p, u^* + \eta\{\lambda z + z^*\}) = R^*(p, \tau_z) + \tau_z L_z^* \tag{44}$$

$$e_p + e_p^* = x + x^* = R_p + R_p^* \tag{45a}$$

[13] There is no restriction on the number of quotas that each country can issue.

$$z + z^* = -R_{\tau_z} - R^*_{\tau_z} \leq L_z + L^*_z \tag{45b}$$

where eqs. (43), (44) and (45) 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, $\tau_z > 0$ and

$$-R_{\tau_z} - R^*_{\tau_z} = L_z + L^*_z \tag{46}$$

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

Taking the total differential of eq. (43) we have

$$e_u du + e_u\eta dz + e_u\eta\lambda dz^* - \tau_z dL_z - (L_z + R_{\tau_z})d\tau_z = (R_p - e_p)dp;$$

$$dz + dz^* = dL_z + dL^*_z \quad \text{and} \quad -R_{\tau_z} - R^*_{\tau^*_z} = L_z + L^*_z \tag{47}$$

Similarly, from eq. (44) we have

$$e^*_{u^*} du^* + e^*_{u^*}\eta dz^* + e^*_{u^*}\eta\lambda dz - \tau^*_z dL^*_z - (L^*_z + R^*_{\tau^*_z})d\tau^*_z = (R^*_p - e^*_p)dp;$$

$$dz + dz^* = dL_z + dL^*_z \quad \text{and} \quad -R_{\tau_z} - R^*_{\tau^*_z} = L_z + L^*_z \tag{48}$$

The best response function of the home country in terms of the foreign country's quota is derived by differentiating eq. (43) with respect to L_z, holding L^*_z constant,

$$e_u\frac{du}{dL_z} = (R_p - e_p)\frac{dp}{dL_z} + (L_z + R_{\tau_z})\frac{d\tau_z}{dL_z} + (\tau_z - e_u\eta)\frac{dz}{dL_z} + (\tau_z - e_u\eta\lambda)\frac{dz^*}{dL_z} \tag{49}$$

Note that $\frac{dz}{dL_z} + \frac{dz^*}{dL_z} = 1$. 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, and it depends on whether the home country is an importer of emission quotas. 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 emissions increase with an increase in domestic quotas and on the public bad characteristic of pollution.

The foreign country's best response function is

$$e^*_{u^*}\frac{du^*}{dL^*_z} = (R^*_p - e^*_p)\frac{dp}{dL^*_z} + (L^*_z + R^*_{\tau_z})\frac{d\tau_z}{dL^*_z} + (\tau_z - e^*_{u^*}\eta)\frac{dz^*}{dL^*_z} + (\tau_z - e^*_{u^*}\eta\lambda)\frac{dz}{dL^*_z} \tag{50}$$

Differentiating eqs. (45a) and (46) with respect to L_z we have, respectively[14],

$$(\beta+\beta^*)\,\frac{dp}{dL_z} = \left(R_{p\tau_z} + R^*_{p\tau_z}\right)\frac{d\tau_z}{dL_z} \tag{51}$$

$$\left(R_{\tau_z\tau_z} + R^*_{\tau_z\tau_z}\right)\frac{d\tau_z}{dL_z} + \left(R_{p\tau_z} + R^*_{p\tau_z}\right)\frac{dp}{dL_z} = -1 \tag{52}$$

The above two equations, together, imply

$$\frac{d\tau_z}{dL_z} = -\frac{(\beta+\beta^*)}{(\beta+\beta^*)(R_{\tau_z\tau_z} + R^*_{\tau_z\tau_z}) + (R_{p\tau_z} + R^*_{p\tau_z})^2} \tag{53}$$

Since both countries face the same price vectors, if we define $J(p,\tau_z) \equiv R(p,\tau_z) + R^*(p,\tau_z)$, then $J(p,\tau_z)$ is convex in prices. Hence, the denominator in the above equation is negative and $\frac{d\tau_z}{dL_z} < 0$. Furthermore, since $z^* = -R^*_{\tau_z}$, we have

$$\frac{dz^*}{dL_z} = -R^*_{\tau_z\tau_z}\frac{d\tau_z}{dL_z} - R^*_{p\tau_z}\frac{dp}{dL_z}$$

which, using eqs. (51) and (53), gives us

$$\frac{dz^*}{dL_z} = \frac{(\beta+\beta^*)R^*_{\tau_z\tau_z} + R^*_{p\tau_z}(R_{p\tau_z} + R^*_{p\tau_z})}{(\beta+\beta^*)(R_{\tau_z\tau_z} + R^*_{\tau_z\tau_z}) + (R_{p\tau_z} + R^*_{p\tau_z})^2} \in (0,1) \tag{54}$$

Furthermore, if both countries have the same technology and face the same price vector, then $\frac{dz^*}{dL_z} = \frac{dz}{dL_z} = \frac{1}{2}$.

Consider, as before, the symmetric equilibrium: if $L_z = z^a = z^{a*} = L^*_z$, then $e_p(.) = R_p(.)$ and $\tau_z = e_u\eta$. Evaluating eq. (49) at the autarky solution, $L_z = z^a$, we have

$$\left(e_u\frac{du}{dL_z}\right)_{L_z=z^a} = (\tau^a_z - e_u\eta\lambda)\,\frac{dz^*}{dL_z} \tag{55}$$

$(\tau^a_z - e_u\eta\lambda) > 0$ if the marginal damage from domestic pollution is higher than that from trans-

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

boundary pollution, i.e., if $\lambda < 1$, and eq. (54) $\Rightarrow \frac{dz^*}{dL_z} > 0$; thus, eq. (55) implies (since $e_u > 0$)

$$\left(\frac{du}{dL_z}\right)_{L_z=z^a} > 0 \quad \text{if} \quad \lambda < 1 \tag{56}$$

We summarize our result in the following proposition

Proposition 4. *If domestic emissions result in a higher marginal damage than transboundary pollution, i.e., if $\lambda < 1$, then, in the symmetric equilibrium, under free trade in both goods and emission permits, each country's optimal response is to choose a quota level higher than the equilibrium autarky quota level, L_z^a.*

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

Proposition 5. *In the symmetric equilibrium, if the marginal damage from domestic emissions is higher than that from transboundary pollution, i.e., if $\lambda < 1$, and countries set emission quotas non-cooperatively but otherwise pursue free trade in goods and emission quotas, 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 we move away from our assumption of symmetry, as long as countries are ***sufficiently*** similar, then, by continuity, the above results hold.

Corollary 2. *If countries are sufficiently similar and 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 $\lambda < 1$.*

Thus, the more similar countries are, the more likely it is that ***both*** countries will be worse off due to trade liberalization if $\lambda < 1$. Note that, in the symmetric equilibrium, assuming identical and unique solutions, eq. (55) implies

$$\left(\frac{du}{dL_z}\right)_{L_z=z^a} = 0 \quad \text{if} \quad \lambda = 1 \tag{57}$$

Thus, we have

Proposition 6. *If pollution is a pure global public bad, i.e., if $\lambda = 1$, then, in the symmetric equilibrium, the free trade equilibrium with internationally tradable pollution permits is the same as the autarky and internationally 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 1 unit, given that the quota binds. However, when pollution is not a pure global public bad, with free trade in goods and permits, in the symmetric equilibrium, when the home country issues an additional quota, it leads to a less than proportional increase in domestic pollution as some of the additional quotas are used in the foreign country; now pollution increases by $\frac{1}{2}(1+\lambda) < 1$ if $\lambda < 1$. Furthermore, the home country also raises revenue from the sale of quotas to the foreign country, which exceeds the marginal damage from increased incidence of transboundary pollution. This leads to a race to the bottom in pollution policies when the marginal damage from transboundary pollution is less than that from domestic pollution. However, if pollution is a pure global public bad, i.e., if $\lambda = 1$, the source of emissions does not matter as the marginal damage is the same irrespective of the origin of pollution, and there is no incentive to issue more quotas under trade as compared to autarky; hence, there is no race to the bottom.

5.4 Pollution and Welfare

In this section we derive the optimal (equivalent) taxes and compare welfare under different policy instruments. We also derive conditions under which the (symmetric) internationally tradable quota equilibrium is strictly welfare-superior to the (symmetric) tax equilibrium. The equilibrium non-cooperative pollution tax under autarky is $t_z^a = e_u\eta$, while the Pareto efficient tax is

$$t_z^e = e_u\eta + e_{u*}^*\eta\lambda > t_z^a \tag{58}$$

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

$$t_z^a = \hat{\tau}_z^a = \tau_z^a = e_u\eta \tag{59}$$

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. In the open economy case, when the policy instrument is an environmental tax, the non-cooperative equilibrium pollution tax for the home country can be calculated using eq. (23). Setting $\frac{du}{dt_z} = 0$, and using eqs. (21) - (27), we have the non-cooperative equilibrium pollution tax as[15]

$$t_z = e_u\eta + \frac{R_{pt_z}}{(\beta+\beta^*)R_{t_zt_z}}\left[e_u\eta\lambda R^*_{pt^*_z} - M_x\right]$$

In the non-cooperative symmetric equilibrium, assuming an identical and unique solution, we have $M_x = 0$, $R_{pt_z} = R^*_{pt^*_z}$, and $\beta = \beta^*$, so

$$t_z = e_u\eta + e_u\eta\lambda\frac{(R_{pt_z})^2}{2\beta R_{t_zt_z}} < e_u\eta = t^a_z \tag{60}$$

With internationally nontradable permits, in the symmetric case, the autarky and free trade equilibria coincide, and the pollution tax equivalent of the optimal free trade quota is

$$\hat{\tau}_z = e_u\eta = t^a_z \tag{61}$$

Finally, with internationally tradable permits, the emission tax equivalent of the equilibrium level of tradable quotas can be found by equating $\frac{du}{dL} = 0$ in eq. (49), using the fact that $R_{\tau_z} = -L_z$ and that, in the symmetric equilibrium, $M_x = 0$,

$$\tau_z = e_u\eta\frac{dz}{dL_z} + e_u\eta\lambda\frac{dz^*}{dL_z} = e_u\eta + e_u\eta(\lambda-1)\frac{dz^*}{dL_z} < e_u\eta = \hat{\tau}_z \Leftrightarrow \lambda < 1$$

The LHS reflects the revenue raised by an additional tradable quota, the RHS the damages done to the domestic economy due to the additional pollution generated by that quota. If $\lambda = 1$, the quotas issued (equivalent tax for the quota) are the same for both internationally tradable and nontradable quotas, whereas for $\lambda < 1$, the tradable quota system leads to more quotas (lower taxes) than the nontradable quota system. In the symmetric equilibrium $\frac{dz}{dL_z} = \frac{dz^*}{dL_z} = \frac{1}{2}$, so we

[15] Of course, this is the formula which determines the tax - it has to be evaluated at the equilibrium price and pollution levels.

have

$$\tau_z = e_u\eta - \frac{e_u\eta}{2}(1-\lambda) \tag{62}$$

Thus,

$$\tau_z \gtreqless t_z \quad \text{as} \quad \lambda \gtreqless M^* \equiv \frac{1}{1-\frac{(R_{pt_z})^2}{\beta R_{t_z t_z}}}, \quad \text{where} \quad M^* \in (0,1) \tag{63}$$

Hence, the effective taxes under the alternative policies can be ordered as follows

$$\begin{aligned}
t_z^e > t_z^a = \hat{\tau}_z \quad &= \quad \tau_z > t_z \qquad \text{if} \quad \lambda = 1 \\
t_z^e > t_z^a = \hat{\tau}_z \quad &> \quad \tau_z > t_z \qquad \text{if} \quad 1 > \lambda > M^* \\
t_z^e > t_z^a = \hat{\tau}_z \quad &> \quad t_z > \tau_z \qquad \text{if} \quad M^* > \lambda > 0 \\
t_z^e > t_z^a = \hat{\tau}_z \quad &= \quad t_z > \tau_z \qquad \text{if} \quad \lambda = 0
\end{aligned} \tag{64}$$

We summarize these results in the following proposition

Proposition 8. *If countries simultaneously and non-cooperatively choose pollution policies but otherwise pursue free trade, then, in the symmetric equilibrium,*

1. *if pollution is a pure global public bad, i.e., if $\lambda = 1$, then the pollution tax equivalent for the case of internationally tradable and nontradable quotas are equal and are both higher (emissions are lower) than in the case in which pollution taxes are the policy instrument;*

2. *if international pollution spillovers are large, but not complete, i.e., if $\lambda \in (M^*, 1)$, then the pollution tax equivalent is highest for internationally nontradable quotas, intermediate in the case of internationally tradable quotas and lowest in the case in which pollution taxes are the policy instrument;*

3. *if international spillovers occur but are not too large, i.e., if $\lambda \in (0, M^*)$, then the pollution tax equivalent is highest in the case of internationally nontradable quotas, intermediate in the case in which pollution taxes are the policy instrument and lowest in the case of internationally tradable quotas;*

4. *if there are no international spillovers, i.e., if $\lambda = 0$, then internationally nontradable quotas and pollution taxes result in the same tax equivalent (and pollution level), which equals the efficient level, while internationally tradable quotas result in a lower pollution tax equivalent*

and more pollution.

The intuition behind these results is as follows. With internationally nontradable quota levels set simultaneously, each government can ignore the impact of its own policy on the foreign level of pollution. If there are no international spillovers, i.e., if $\lambda = 0$, this choice leads to efficiency but, of course, in the presence of international spillovers, pollution emissions will be too high. In the case of pollution taxes, the home government realizes that an increase in tax on domestic pollution will, given the foreign pollution tax, lead to ***carbon leakage***, i.e., to an increase in foreign pollution levels ***due to changes in the prices of internationally traded goods***. Assuming $R_{pt_z} = \frac{\partial x}{\partial t_z} < 0$, the increased domestic pollution tax reduces domestic output of X, thereby raising the world price of X. How much world price increases depends upon the price responsiveness of excess demand for X, i.e., on $\beta < 0$. The increased world price of X leads to more foreign pollution as $R_{pt_z} = -\frac{\partial z}{\partial p} < 0 \Rightarrow \frac{\partial z}{\partial p} > 0$. Thus, the amount of carbon leakage is directly related to $|R_{pt_z}|$ and inversely related to $|\beta|$.

Finally, the relative inefficiency of internationally tradable quotas, when pollution is not a pure public good, is ***not*** due to carbon leakage, but rather to the revenue raised from foreign firms from the sale of the quota. From a domestic welfare perspective, the revenue the government raises from domestic quota sales does not augment welfare, but the revenue raised from foreign sales does raise domestic welfare (though, from a world perspective, it is just a transfer). Thus, given the foreign quota level, the domestic government knows that when it issues one more quota, world ***aggregate*** pollution will increase by one unit (just as when the quotas are not tradable). It also knows that some (one-half, in the symmetric equilibrium) of these quotas will be sold to foreigners, so if the price paid for the quota, τ_z, exceeds the marginal damage to the domestic economy of that increased foreign pollution, $e_u \eta \lambda$, then selling more quotas is beneficial. Hence, the problem with tradable quotas is not carbon leakage, but rather the revenue impact of quota sales. Finally, note that pollution taxes are likely to be superior to tradable quotas when the carbon leakage effect is small and the welfare impact of spillovers is small (e.g., when $|\beta|$ is large or λ is small), whereas the tradable quotas will be preferable when carbon leakage is large and the welfare impact of spillovers is also large.

Since the only reason a first best solution is not obtained is because of the failure to internalize the international pollution spillovers, it is fairly clear that the welfare rankings of different policy instruments follow the ordering of tax equivalents. Thus, for any case in which $\lambda \in (0, 1]$, the non-cooperative equilibrium will result in lower welfare than the cooperative equilibrium, and for any $\lambda \in (0,1)$, the case of internationally nontradable quotas will be welfare superior to both internationally tradable quotas and pollution taxes. The internationally tradable quotas will provide higher welfare than pollution taxes if, and only if, $\lambda > M^*$, i.e., only when international spillovers have a significant impact on welfare and carbon leakage under taxes is large.

6 Concluding Remarks

We have used a simple model to highlight the effect of trade liberalization in the presence of transboundary pollution and to evaluate the welfare ranking of different policy instruments when countries strategically set domestic environmental policies. 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 outcome of trade liberalization depends on the particular policy instrument used to regulate pollution. The movement from autarky to free trade can be welfare reducing. In the symmetric non-cooperative tax equilibrium, 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 emissions, thereby leading to a race to the bottom in environmental taxes, which makes ***both*** countries worse off relative to autarky.

When internationally nontradable quotas are the policy instruments, changes in domestic policy do not affect 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, when pollution is not a pure public bad, the revenue from foreign sales raised by the additional quota exceeds the marginal damage done to the domestic economy by the foreign pollution, and this revenue effect leads to a race to the bottom in that more pollution quotas will be issued.

The internationally nontradable quota equilibrium is welfare-superior to both the internationally tradable quota equilibrium and the tax equilibrium. Whether the internationally tradable quota equilibrium strictly welfare-dominates the tax equilibrium depends on the severity of transboundary pollution and the relative slopes of the demand and supply schedules in the two countries. Pollution is the lowest when internationally nontradable quotas are the policy instruments and the pollution ranking of the internationally tradable quota equilibrium and the tax equilibrium depends on the ratio of transboundary to domestic pollution and the relative slopes of the supply and demand schedules. Although we have analyzed the symmetric equilibrium to isolate the role of carbon leakage, it should be clear that, by continuity, our results hold even if we deviate from the symmetric case, provided countries are ***sufficiently*** similar.

We find that internationally nontradable quotas are welfare-superior to taxes. 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 strategic 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. An important policy implication is that, when countries negotiate on free trade, it might be beneficial to negotiate on the policy instrument, if not the exact level of the policy instrument, that is used to regulate the domestic externality in each country.

A 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. Future work could also analyze the ranking of these policy instruments when pollution causes a production externality.

References

Bagwell, K. and Staiger, R. W. (2001). Domestic policies, national sovereignty, and international economic institutions. *Quarterly Journal of Economics*, 116(2):519–562.

Copeland, B. and Taylor, M. S. (1995). Trade and transboundary pollution. *American Economic Review*, 85(4):716–737.

Kiyono, K. and Ishikawa, J. (2004). *International Economic Policies in a Globalized World*, chapter Strategic Emission Tax-Quota Non-Equivalence under International Carbon Leakage, pages 133–150. Springer.

Kiyono, K. and Okuno-Fujiwara, M. (2003). Domestic and international strategic interactions in environment policy formation. *Economic Theory*, 21:613–633.

Ludema, R. and Wooton, I. (1994). Cross-border externalities and trade liberalization: The strategic control of pollution. *Canadian Journal of Economics*, 27(4):950–966.

Markusen, J. (1975). International externalities and optimal tax structure. *Journal of International Economics*, 5:15–29.

Rauscher, M. (1997). *International Trade, Factor Movements and the Environment.* Claredon Press, Oxford.