Strategic Environmental Policy and International Market Share Rivalry under Differentiated Bertrand Oligopoly

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Abstract

We analyse strategic environmental policies under international Bertrand oligopoly when firms in different industries, located in different countries, produce *differentiated* products. Under *cooperation*, emission prices *always exceed* the joint marginal damage from pollution. Under *non-cooperation*, internationally nontradable and tradable emission permit prices are *always higher* than the domestic marginal damage from emissions (the Pigovian tax); emission taxes can also exceed the Pigovian tax. The non-cooperative emission prices under all instruments can *exceed* the joint pollution damage. Internationally tradable permits generate outcomes closest to cooperation – they result in the *lowest pollution* and the *highest welfare* among all instruments under non-cooperation. Pollution is the highest and welfare the lowest with taxes. Our results provide support for allowing international trade in emission permits even when governments choose their permit levels *non-cooperatively.*

JEL Classification: Q56, F18, F12, H23.

Key Words: Strategic environmental policy, differentiated products, transboundary pollution, public bad, tradable permits, leakage, Bertrand competition, profit-shifting, permit revenue, overregulation.

1 Introduction

The literature on the relation between trade and environmental policies has highlighted that governments can distort environmental policies when firms have market power and as a second-best method of pursuing terms of trade goals.[1] When emissions are generated as a by-product of the production process by a firm which has market power, pollution policy can be used to correct for underproduction in the domestic market.[2] However, when such a firm exports its output, environmental policy can also be used for profit-shifting purposes if direct

[1] See, among others, Copeland and Taylor (2004) and Neary (2006) for comprehensive reviews of these issues.

[2] The optimal emission tax for a domestic monopoly can be lower than the marginal damage from pollution – this reduces the welfare loss from underproduction (see Baumol and Oates (1988), chapter 6). In a closed economy setting, when the government has a revenue-generation goal, firms produce differentiated products and compete on prices, Kurtyka and Mahenc (2011) show that the optimal emission tax differs from (and can exceed) the Pigovian tax. This is driven by the multiple distortions that the emission tax has to address.

trade policies are not available.[3] In the literature focusing on trade and environmental policies under imperfect competition (in the Brander and Spencer, 1985, framework), *Bertrand* competition between firms producing *differentiated* products has received relatively little attention.[4] However, this setup is applicable to many industries – ranging from agricultural products – for instance, coffee exports (Karp and Perloff, 1993), to automobiles (Berry et al., 1995, 1999 and Goldberg, 1995) and aircrafts (Irwin and Pavcnik, 2004). See, also, among others, Eaton and Lipsey (1989), Arnade et al. (1998), and Friberg and Ganslandt (2006). Further, as Chamberlin (1933) points out, 'virtually all products are differentiated, at least slightly'. We analyse strategic environmental policies when firms in different industries, located in two countries, produce differentiated pollution-intensive products and compete on prices in the world market.

The contribution of this paper is two-fold. First, we compare how different pollution policy instruments (internationally nontradable emission permits, internationally tradable permits and emission taxes) affect pollution and welfare. How does the price of emissions compare to the Pigovian tax, i.e., the domestic marginal damage from emissions, and to the joint marginal damage from pollution in the two countries? Which policy instrument results in the lowest pollution under non-cooperation and generates outcomes closest to the cooperative solution?

Our paper also contributes to the literature on international trade in emission permits. When permit trade is international, it is possible that the number of permits are not fixed by some supranational agency. Then, countries can further distort environmental policies to reduce leakage and to generate additional revenue from selling permits abroad (permit revenue effect). Under the EU Emission Trading System (ETS), the European Commission determined the participating sectors, but individual countries could initially set their permit supplies. In Phases 1 (2005 – 2007) and 2 (2008 – 2012), members submitted their National Allocation Plans determining the fraction of their national permit limit allocated to participating sectors to be approved by the European Commission (see, for instance, Antoniou et al., 2014, Kruger et al., 2007, and Malueg and Yates, 2009). As Kruger et al. (2007) indicate: for the Kyoto signatories, 'it is clear that the degree of supranational authority is much lower than in the EU ETS.' Holtsmark and Somervoll (2012) also note that 'the national emission targets in the Copenhagen Accord, which have been leading in subsequent negotiations, were quantified by individual governments after the Copenhagen meetings. Hence, those targets are not the result of negotiations and are therefore unlikely to maximize joint welfare as commonly assumed in the literature.' Although this type of international permit trading is

[3] See Ederington and Minier (2003) for evidence on the use of pollution policies as second-best trade policy. Eisenbarth (2017) analyses the use of trade policies as second-best environmental policies in China.

[4] Clarke and Collie (2003) study the gains from bilateral trade when Bertrand duopolies located in different countries, produce differentiated goods, in the *absence* of pollution externality. See Friberg and Ganslandt (2008) for similar analysis when there are multiple firms in each country.

not widely practiced, we show that international trade in emission permits generates outcomes closest to the cooperative outcome, even when countries *non-cooperatively* decide on the number of permits to issue, i.e., it results in the lowest pollution and the highest welfare levels among all policies when governments set policies non-cooperatively. Hence, this type of permit trading regime needs to be considered as a possible option when countries decide on pollution regulation.

When trade policies are not available (say, due to trade agreements or WTO obligations), environmental policies can be used as a second-best method of profit-shifting in favor of a domestic firm operating in an imperfectly competitive international market. Antoniou et al. (2014) compare internationally tradable and nontradable emission permits under *Cournot* competition. Two symmetric countries have one firm each, which produce and export a pollution-intensive good to a third market.[5] Tradable permits result in lower emissions and higher welfare than nontradable permits. Governments use lax environmental regulation as a second-best trade policy (export subsidy). When permits are tradable, since half the permits are used abroad, the incentive to set lax policy (i.e., issue more permits) is dampened. However, permit prices are still *lower* than the respective domestic marginal damage from emissions, i.e., lower than the Pigovian tax. In contrast to the above paper, we analyse price competition between firms in different industries selling differentiated products and compare taxes, nontradable and tradable permits. We show that the permit prices *always* exceed the Pigovian tax. Furthermore, not only are permit prices and emission taxes positive even when a country's environmental damage is small, but the non-cooperative emission prices can also *exceed* the joint environmental damage, i.e., the sum of the marginal damages in the two countries.

Carbone et al. (2009) analyse international emission permit trade in a multi-country CGE model when countries choose permit levels non-cooperatively. Trade in permits can lower the number of permits issued (hence, pollution) since countries that are net sellers of permits issue fewer permits to keep the permit price high. In contrast, our results are *not* driven by permit revenue effects but by the use of environmental policies as second-best trade policy instruments.[6]

[5]Conrad (1993) and Barrett (1994) use similar setups as Antoniou et al. (2014); the first considers only taxes when pollution is transboundary in nature, while the second considers environmental standards but with only local pollution. Rauscher (1994) analyses ecological dumping when taxes are the policy instruments and pollution is purely local. Kennedy (1994) uses a reciprocal dumping type model to analyse the dual role of pollution taxes in controlling pollution and as a second-best trade policy instrument. Bárcena-Ruiz (2006) analyses first-mover advantages in setting environmental taxes when two countries (with one firm each) producing and trading a homogeneous good are affected by transboundary pollution.

[6]Other papers analyzing international permit trade, but in the *absence* of goods trade, include the following. Helm (2003) finds that trade in permits can have ambiguous effects on pollution – 'more (less) environmentally concerned countries' choose lower (higher) permit levels. In a similar framework, Holtsmark and Sommervoll (2012) show that permit trade reduces efficiency and increases pollution. See Chander (2017) for an analysis of a cooperative game in a dynamic setup when pollution is stock externality.

A number of papers compare policy instruments in competitive setups under international trade in goods. Copeland and Taylor (2005) analyse emission permit trade between the (relatively more human capital abundant) West and the East – they find that permit trade may increase global emissions. Ishikawa and Kiyono (2006) compare emission taxes, permits and standards. They show that domestic pollution regulation may cause carbon leakage, resulting in world pollution not declining even when a country controls its emissions. Kiyono and Ishikawa (2013) compare emission taxes and permits when large fossil-fuel consuming countries set policies non-cooperatively. They also show leakage through fossil-fuel prices when a country increases its tax; there is no leakage under internationally nontradable quotas. Lapan and Sikdar (2011) show that, in the absence of terms of trade effects, when pollution is a pure global public bad, internationally nontradable and tradable emission quotas result in the same outcome and welfare dominate taxes. A key difference driving the results between the competitive setup and the current paper is the lack of profit-shifting motive (as firms do not have any market power) in the former, while in the latter, under price competition, it can result in overregulation of pollution. Specifically, governments would tax exports to shift profits in favor of domestic firms; in the absence of trade policies (say, due to WTO obligations or trade agreements), the government uses overregulation of pollution as a second-best policy to achieve its profit-shifting objective. This can have a positive impact on environmental outcomes. Tsakiris et al. (2017) compare noncooperative emission taxes, intra-regionally and inter-regionally tradable permits in the presence of capital mobility and transboundary pollution under competitive conditions. Under regional capital mobility, intra-regionally tradable permits results in the highest welfare, while intra-regionally tradable permits and emission taxes are equivalent and result in higher welfare than inter-regionally tradable permits with international capital mobility.

We consider a Brander-Spencer type international Bertrand oligopoly model with multiple industries; each industry has one firm located in each of two countries. Firms in each industry produce differentiated products, which are exported to a third market. Emissions are a by-product of production and there is an abatement technology available to firms. Pollution is a pure public bad – it reduces welfare in both countries, i.e., there are both local and transboundary negative welfare effects of pollution. Governments simultaneously and strategically set pollution policies, after which firms choose output prices and abatement levels. Firms are price-takers in the permit market. Similar assumptions are used elsewhere in the literature; see, among others, Sartzerakis (1997), Malueg and Yates (2009), and Meunier (2011). Further, note that the firms' products in each industry are imperfect substitutes (given product differentiation), while emission permits are perfect substitutes. Hence, it is plausible that firms have market power in the product market, but not in the permit market. For instance, Toyota has sizeable market share in the car market – in 2018, it had the largest world market share.[7] However, it is not a major contributor to world emissions; Toyota (2018) indicates that direct and indirect emissions (Scopes 1 and 2) from production total 7.57 Mt CO_2, 7.81 Mt CO_2, and 7.79 Mt CO_2 in 2016, 2017, and 2018, respectively.[8] In these years, world CO_2 emissions were, respectively, 36.65, 37.07, and 40.4 Gt CO_2 (Olivier and Peters, 2018, and U.N., 2019), implying that Toyota's contribution to emissions were about 0.02% in each of these years. Hence, in an international emission permit market, Toyota would not be expected to have market power. Along similar lines, Nissan, another major global car manufacturer had total CO_2 emissions from production processes of 3.14 Mt in 2016 (Nissan, 2017) which accounts for 0.009% of global CO_2 emissions that year. Airbus accounted for 55% of the market share of industry orders of aircrafts (Leahy, 2017), while its emissions in 2016 and 2017 were, respectively, 0.94 and 1.01 Mt CO_2 (Airbus, 2017), accounting for 0.003% of overall CO_2 emissions in these years. The evidence indicates that, with multiple industries, competition in permit market is more plausible even though product markets are imperfectly competitive.

We compare different policy instruments – internationally nontradable permits, internationally tradable permits and emission taxes. Governments use environmental policy, in the absence of trade policies, to shift profits in favor of the domestic firm (thus, increasing domestic welfare).[9] The profit-shifting motive tends to make pollution policy *stricter* in *both* countries – this occurs for *all* policy instruments considered. Nontradable and tradable permit prices are always higher than the domestic marginal damage from emissions, i.e., *always higher* than the Pigovian tax, although leakages under taxes can lower the emission tax below the Pigovian level. The profit-shifting motive *always* tends to reduce pollution as compared to the situation in which this motive is absent. The extent of overregulation depends on how a change in a country's policy affects the foreign firms' prices (hence, the domestic firms' profits and domestic welfare) – this, in turn, depends on the policy instrument. The effect of relaxing environmental regulation on reducing foreign output prices is the lowest (highest) when the policy instrument is an emission tax (internationally tradable permit); this is driven by how foreign costs change for a given change in domestic emissions depending on the policy instrument.

When governments act non-cooperatively, internationally tradable permits result in the *lowest* pollution and the *highest* welfare levels, while pollution is the *highest* and welfare the *lowest* when the policy instrument is a tax on emissions. Internationally tradable permits give rise to outcomes closest to the cooperative equilibrium. In the latter, emission prices *exceed*

[7] Source: https://www.statista.com/statistics/316786/global-market-share-of-the-leading-automakers/.

[8] Mt CO_2 refers to million tons of CO_2. Gt CO_2 refers to giga tons of CO_2 and 1Gt = 1000 Mt.

[9] Eaton and Grossman (1986) show that, under international Bertrand competition, *without* pollution externality, when outputs of firms are substitutes, the Nash equilibrium involves governments imposing an export tax.

the joint marginal damage from pollution.[10] In fact, the non-cooperative permit prices and taxes can also *exceed* the joint pollution damage.[11] Further, even if environmental damage is *low*, it is in the self interest of governments to regulate pollution, i.e., set policies such that the emission price is positive; this applies under both non-cooperation and cooperation.

Our findings provide an argument in favor of international trade in emission permits, even when governments issue permits *non-cooperatively*, i.e., when countries choose their permit levels to maximize own welfare and these permits can subsequently be sold in an international permit market. The usual reservation against international permit trade in such situations is that countries would issue more permits to raise revenue than when such permits cannot be sold internationally, i.e., the permit revenue effect would result in excessive issuance of permits leading to higher pollution. We show that, on the contrary, allowing international permit trade, even when permits are issued non-cooperatively, results in a movement closer the cooperative equilibrium, thereby lowering pollution and increasing welfare, as compared to other non-cooperative policies. This highlights that, although such a pollution control regime is not common, is worth considering in the future.

The rest of the paper is organized as follows. In the next section, we present the model and derive emission prices under different policy instruments. Section 3 compares pollution and welfare under the different instruments. Section 4 concludes. An Appendix, available at the OUP website, contains verification of second-order conditions, derivation of equilibrium permit levels and taxes, and proofs of some Lemmas.

2 The Model

Consider a symmetric two-country, N-industry Brander-Spencer type model with transboundary pollution. There are $j = 1, 2, \ldots, N$ industries in each of the two countries ($i = 1, 2$). Each country has one firm in each industry. Firms within each industry produce a *differentiated* product and compete on price (à la Bertrand) in a third market. The latter does not behave strategically. We use i to denote country and a firm in industry j located in country i as ij.

Demand for firm ij's product is:

$$q_{ij} = \phi_{ij}(p_{ij}, p_{-ij}) = A - p_{ij} + bp_{-ij}, \quad i = 1, 2,\ j = 1, 2, \ldots, N, \tag{1}$$

where $-i$ is the country other than country i, while p_{ij} and p_{-ij} are the prices of industry j's product produced by firms in countries i and $-i$, respectively. The differentiated products

[10] This joint damage from pollution in the two countries is also the global damage if other countries are not affected by emissions from these countries.

[11] Note that, although the non-cooperative emission prices can be higher than the Pigovian taxes, the cooperative outcome still results in better environmental and welfare outcomes relative to non-cooperation.

within industry j are (imperfect) substitutes. Given differentiated products, we make the standard assumption that the own price effect is stronger than the cross price effect: $\frac{\partial \phi_{ij}}{\partial p_{ij}} < 0 < \frac{\partial \phi_{ij}}{\partial p_{-ij}}$ and $|\frac{\partial \phi_{ij}}{\partial p_{-ij}}| < |\frac{\partial \phi_{ij}}{\partial p_{ij}}|$, implying $b \in (0,1)$ in eq. (1) above. This demand structure implies that there is no demand interaction across industries although products within an industry are substitutes.

Firm ij's cost of production is $C(q_{ij}) = cq_{ij}$. Pollution is a by-product of the production process: production of one unit of output in industry j results in θ units of emission. Firms can abate pollution, so net emission in country i from industry j is: $z_{ij} = \theta q_{ij} - a_{ij}$, where $a_{ij} \geq 0$ is abatement undertaken by the firm ij. Firms face a strictly convex abatement cost: $B(a_{ij}) = \frac{1}{2}a_{ij}^2$. To begin with, assume that the pollution policy instrument is emission permits. Firm ij's profit is: $\pi_{ij} = (p_{ij} - c)q_{ij} - \frac{1}{2}a_{ij}^2 - R_i l_{ij}$, where R_i is the price that firm i has to pay for each unit of emission permit and l_{ij} is the number of emission permits purchased by firm ij.

Total emissions in country i is $Z_i = \sum_j z_{ij}$. Pollution is a pure public bad, i.e., transboundary pollution spillovers are complete and the marginal damage from domestic emission is the same as that from the inflow of transboundary pollution. The damage from pollution in country i is: $D(Z_i + Z_{-i}) = \frac{\delta}{2}(Z_i + Z_{-i})^2 = \frac{\delta}{2}(\sum_i \sum_j z_{ij})^2$, $\delta > 0$; the marginal damage from pollution in each country is, thus, $\delta(Z_i + Z_{-i})$. Since the industries are symmetric, we drop the subscript j in most of the following analysis. Symmetry implies, for instance, $l_{ij} = l_i, \forall j$. Welfare in country i is: $W_i = \sum_j \pi_{ij} + R_i L_i - D(Z_i + Z_{-i})$, where L_i is the number of permits issued by government i and the second term is the permit revenue.[12] We focus on the symmetric equilibrium and consider different policy instruments: internationally nontradable permits, internationally tradable permits, and emission taxes.

The timing of the game is as follows:

1. Governments simultaneously and non-cooperatively set their pollution policies.

2. Firms simultaneously choose product prices and abatement; output is produced and if emission permits are tradable across firms/countries, firms also trade permits simultaneously.

Internationally Nontradable Emission Permits. When permits are internationally nontradable, although permits can be tradable domestically, emissions in both countries are fixed at their respective permit supply levels: $L_i = Z_i$, while permit market equilibrium implies: $L_i = Nl_i$ and $\frac{\partial l_i}{\partial L_i} = 1/N$. Further,

$$z_i = \theta q_i - a_i = l_i \quad \Rightarrow \quad a_i = \theta q_i - l_i, \quad i = 1, 2. \tag{2}$$

[12]We assume that the permit limits bind. Of course, if they do not bind, there would be no point to the government implementing policy.

Firm ij's profit can be written as (using eq. 2): $\pi_i = (p_i - c)q_i - \frac{1}{2}[\max(0, \theta q_i - l_i)]^2 - R_i l_i$. Profit maximization yields (assuming positive abatement and since eq. 1 implies $\frac{\partial q_i}{\partial p_i} = -1$):

$$\frac{\partial \pi_i}{\partial l_i} = -R_i + (\theta q_i - l_i) = 0 \quad \Rightarrow \theta q_i - l_i = a_i = R_i, \tag{3}$$

$$\text{and} \quad \frac{\partial \pi_i}{\partial p_i} = q_i - [p_i - c - \theta(\theta q_i - l_i)] = 0 \Rightarrow q_i - [p_i - c - \theta R_i] = 0. \tag{4}$$

Note that, since eq. (1) implies $\frac{\partial q_i}{\partial p_{-i}} = b$, using eqs. (3) and (4), we have:

$$\frac{\partial \pi_i}{\partial p_{-i}} = [p_i - c - \theta(\theta q_i - l_i)]\frac{\partial q_i}{\partial p_{-i}} = [p_i - c - \theta R_i]b = bq_i. \tag{5}$$

Total pollution is: $\sum_i Z_i = \sum_i L_i$. Using eqs. (1) and (3), we can write eq. (4) as: $(1+\theta^2)(A - p_i + bp_{-i}) - p_i + c - \theta l_i = 0$, $i = 1, 2$. For each of the N industries, this can be written as:

$$\begin{bmatrix} 2+\theta^2 & -b(1+\theta^2) \\ -b(1+\theta^2) & 2+\theta^2 \end{bmatrix} \begin{bmatrix} p_i \\ p_{-i} \end{bmatrix} = \begin{bmatrix} (1+\theta^2)A + c - \theta l_i \\ (1+\theta^2)A + c - \theta l_{-i} \end{bmatrix},$$

which implies:[13]

$$p_i^{NT} = \frac{1}{\Delta}\left[\{(2+\theta^2) + b(1+\theta^2)\}\{(1+\theta^2)A + c\} - \theta\{(2+\theta^2)l_i + b(1+\theta^2)l_{-i}\}\right], \tag{6}$$

where we define $\Delta \equiv (2+\theta^2)^2 - b^2(1+\theta^2)^2 > 0$. Hence, we have:

$$\frac{\partial p_i^{NT}}{\partial L_i} = \frac{\partial p_i^{NT}}{\partial l_i}\frac{\partial l_i}{\partial L_i} = \frac{-\theta(2+\theta^2)}{N\Delta} \equiv -\mu < 0 \text{ and } \frac{\partial p_i^{NT}}{\partial L_{-i}} = \frac{\partial p_i^{NT}}{\partial l_{-i}}\frac{\partial l_{-i}}{\partial L_{-i}} = \frac{-\theta b(1+\theta^2)}{N\Delta} \equiv -\alpha < 0, \tag{7}$$

$$\text{implying} \quad \left|\frac{\partial p_i^{NT}}{\partial L_i}\right| > \left|\frac{\partial p_i^{NT}}{\partial L_{-i}}\right|, \tag{8}$$

$$\frac{\partial q_i}{\partial L_i} = -\frac{\partial p_i^{NT}}{\partial L_i} + b\frac{\partial p_{-i}^{NT}}{\partial L_i} = \frac{\theta}{N\Delta}[(2+\theta^2) - b^2(1+\theta^2)] \text{ and } \frac{\partial q_{-i}}{\partial L_i} = b\frac{\partial p_i^{NT}}{\partial L_i} - \frac{\partial p_{-i}^{NT}}{\partial L_i} = -\frac{\theta b}{N\Delta}. \tag{9}$$

Also, note that (using the permit market equilibrium condition and eqs. 3 and 9):

$$\frac{\partial R_i}{\partial L_i} = \theta\frac{\partial q_i}{\partial L_i} - \frac{\partial l_i}{\partial L_i} = -\frac{2(2+\theta^2) - b^2(1+\theta^2)}{N\Delta} < 0 \text{ and } \frac{\partial R_{-i}}{\partial L_i} = \theta\frac{\partial q_{-i}}{\partial L_i} = -\frac{b\theta^2}{N\Delta} < 0, \tag{10}$$

$$\Rightarrow \frac{\partial R_i}{\partial L_i} < \frac{\partial R_{-i}}{\partial L_i} < 0. \tag{11}$$

[13] We use the superscript NT to denote that the strategic policy instrument is internationally nontradable emission permits.

As government i issues more permits, i.e., as $L_i \uparrow$, the permit price in country i (R_i) falls, resulting in an increase in the output produced by its firms, q_i, and a decrease in its product prices, p_i^{NT}. As products in industry j produced in the two countries, $j = 1, 2, \ldots, N$, are substitutes, p_{-i}^{NT} falls; hence, $\frac{\partial p_{-i}^{NT}}{\partial L_i} < 0$. The resulting fall in q_{-i} leads to a fall in abatement, a_{-i}, since emissions do not change in country $-i$ (given the permit limit binds in country $-i$). Permit prices decline in both countries, but the decline is more in the country issuing the additional permit, i.e., in country i.

Under simultaneous moves, $\frac{\partial Z_{-i}}{\partial Z_i} = 0$, i.e., a change in country i's policy does not change emissions in the other country, $-i$, and there is *no* leakage when the policy instrument is nontradable permits.

Government i chooses its permit limit, L_i, to maximize its welfare, W_i, taking L_{-i} and firms' behavior as given. This yields government i's best-response function:[14]

$$\begin{aligned}\frac{dW_i^{NT}}{dL_i} &= \sum_j \left(\frac{\partial \pi_{ij}}{\partial p_{ij}^{NT}} \frac{\partial p_{ij}^{NT}}{\partial L_i} + \frac{\partial \pi_{ij}}{\partial l_{ij}} \frac{\partial l_{ij}}{\partial L_i} + \frac{\partial \pi_{ij}}{\partial p_{-ij}^{NT}} \frac{\partial p_{-ij}^{NT}}{\partial L_i} \right) + \left(\sum_j \frac{\partial \pi_{ij}}{\partial R_i} + L_i \right) \frac{\partial R_i}{\partial L_i} + R_i \\ &\quad -\delta(L_i + L_{-i}) = 0,\end{aligned}$$

$$\Rightarrow \qquad J_i^{NT}(L_i, L_{-i}) \equiv \frac{dW_i^{NT}}{dL_i} = N \frac{\partial \pi_i}{\partial p_{-i}^{NT}} \frac{\partial p_{-i}^{NT}}{\partial L_i} + R_i - \delta(L_i + L_{-i}) = 0, \tag{12}$$

$$\Rightarrow \qquad R_i = \underbrace{\delta(L_i + L_{-i})}_{\text{domestic marginal damage}} - \underbrace{N \frac{\partial \pi_i}{\partial p_{-i}^{NT}} \frac{\partial p_{-i}^{NT}}{\partial L_i}}_{\text{profit-shifting effect}} = \delta(L_i + L_{-i}) + Nb\alpha q_i > \delta(L_i + L_{-i}), \tag{13}$$

where we have used symmetry, the envelope theorem ($\frac{\partial \pi_i}{\partial p_i^{NT}} = 0$ and $\frac{\partial \pi_i}{\partial l_i} = 0$), the equilibrium condition, $N \frac{\partial \pi_i}{\partial R_i} + L_i = 0$, and eqs. (5) and (7). The profit-shifting motive results in $R_i > \delta(L_i + L_{-i})$. It is well known that the efficient price of emissions (from the perspective of these two countries) that internalizes the pollution externality is the joint marginal damage from pollution, i.e., $2\delta(L_i + L_{-i})$. Note that the permit price can exceed this aforementioned price, i.e., $R_i > 2\delta(L_i + L_{-i})$, implying permit prices *higher* than the joint marginal damage if the profit-shifting motive is sufficiently strong, i.e., if $N\alpha b q_i > \delta(L_i + L_{-i})$. Furthermore, even if the damage from pollution is small, i.e., if $\delta \to 0$, countries benefit from regulating emissions: $R_i(.; \delta \to 0) = -N \frac{\partial \pi_i}{\partial p_{-i}^{NT}} \frac{\partial p_{-i}^{NT}}{\partial L_i} = N\alpha b q_i > 0$. We derive the equilibrium permit level in terms of the primitives of the model and Lemma 1.2 in the Appendix. We summarize our findings as follows:

Lemma 1. *Suppose countries non-cooperatively set internationally nontradable permit limits to regulate pollution.*

[14] All second-order conditions are verified in the Appendix. Further, it is straightforward to see that the best-response functions are linear in the strategic variables; hence, the solution in each game is unique.

1. *The strategic aspect of policy setting, driven by profit-shifting motives, implies that* ***both*** *governments issue permits such that the permit prices in both countries are* ***higher*** *than the domestic marginal damage from emissions, i.e.,* $R_i > \delta(L_i + L_{-i})$*,* $i = 1, 2$*.*

2. *The permit prices are* ***higher*** *than the joint marginal damage from pollution, i.e.,* $R_i > 2\delta(L_i + L_{-i})$*,* $i = 1, 2$*, if* $\frac{(1+\theta^2)b^2(2N\delta+1)}{N[(2+\theta^2)^2-b^2\theta^2(1+\theta^2)]} - 2\delta > 0$*. Then, the profit-shifting motive is sufficiently strong.*

3. *Even if pollution damage is small, i.e., if* $\delta \to 0$*, countries benefit from regulating emissions:* $R_i(.;\delta \to 0) = Nb\alpha q_i > 0$*.*

Hence, the strategic aspect of policy setting (due to the market power of firms) increases nontradable permit prices above the marginal damage from pollution. Governments restrict emissions as a second-best way of taxing exports; this is meant to increase the domestic firms' profits by (implicitly) allowing these firms to commit to higher prices. In fact, this can result in policies such that the permit prices exceed the joint marginal damage from pollution. This is likely if, *ceteris paribus*, the damage from pollution (δ) is low or the degree of product differentiation is low (b is high) or the number of industries (N) is low.

Internationally Tradable Emission Permits. Now, suppose that the emission permits, issued non-cooperatively, are internationally tradable. Hence, permits issued by one government can be used by firms in either country. With internationally tradable permits, it is no longer necessary that $L_i = \sum_j l_{ij} = Nl_i$. Further, $R_i = R_{-i} \equiv R^T$, where R^T is the price of an emission permit and the superscript T denotes that the strategic policy instrument is internationally tradable permits. Also, each government's permit revenue need not equal the domestic firms' expenditure on purchasing permits. Equilibrium in the international permit market implies: $\sum_i \sum_j l_{ij} = N(l_i + l_{-i}) = L_i + L_{-i} \equiv L^T$, where L^T is the total supply of permits. Symmetry implies $l_i = l_{-i} = \frac{L^T}{2N}$. Using these in eq. (6), we have, for $i = 1, 2$:

$$p_i^T = \frac{A(1+\theta^2) + c - \theta(L^T/2N)}{(2+\theta^2) - b(1+\theta^2)}, \tag{14}$$

$$q_i^T = \frac{A - (1-b)c + \theta(1-b)(L^T/2N)}{(2+\theta^2) - b(1+\theta^2)}, \tag{15}$$

$$\text{and} \quad R^T = \frac{\theta(A - (1-b)c) - (2-b)(L^T/2N)}{(2+\theta^2) - b(1+\theta^2)}, \tag{16}$$

$$\text{implying} \quad \frac{\partial p_i^T}{\partial L_i} = \frac{\partial p_{-i}^T}{\partial L_i} = -\frac{\theta/2N}{(2+\theta^2) - b(1+\theta^2)} \equiv -\beta, \tag{17}$$

$$\frac{\partial q_i^T}{\partial L_i} = \frac{\partial q_{-i}^T}{\partial L_i} = \frac{\theta(1-b)}{2N[(2+\theta^2) - b(1+\theta^2)]} > 0, \tag{18}$$

$$\text{and} \quad \frac{\partial R^T}{\partial L_i} = \frac{\partial R^T}{\partial L_{-i}} = -\frac{2-b}{2N[(2+\theta^2) - b(1+\theta^2)]} < 0. \tag{19}$$

That is, changes in the product and permit prices and output levels are the same in both countries if either country changes the number of permits issued. This is in contrast to nontradable permits where the product and permit prices decline more in the country which issues an additional permit (eqs. 8 and 11). Hence, we have:

Lemma 2. *When the non-cooperative policy instrument is internationally tradable emission permits, the output levels, the permit price and the product prices depend* ***only*** *on the total number of permits issued,* ***not*** *which country issues these permits. The same applies for the impact of issuing an additional permit on either prices and product quantities.*

Irrespective of which country issues an additional permit, since the permits are tradable, the impact is the same. *Only* the total number of permits, $L^T = L_i + L_{-i}$, matters and not its composition.

We can compare the effect of issuing an additional permit on product prices, depending on the policy instrument, as follows (using eqs. 7 and 17):

$$-\frac{\partial p_i^{NT}}{\partial L_i} - \left(-\frac{\partial p_i^T}{\partial L_i}\right) = \frac{\theta(2+\theta^2)}{N\Delta} - \frac{\theta/2N}{(2+\theta^2) - b(1+\theta^2)} = \frac{\theta/2N}{(2+\theta^2)+b(1+\theta^2)} > 0,$$

and
$$-\frac{\partial p_{-i}^T}{\partial L_i} - \left(-\frac{\partial p_{-i}^{NT}}{\partial L_i}\right) = \frac{\theta/2N}{(2+\theta^2) - b(1+\theta^2)} - \frac{\theta b(1+\theta^2)}{N\Delta} = \frac{\theta/2N}{(2+\theta^2)+b(1+\theta^2)} > 0.$$

Hence, we have:

Lemma 3. *When country i issues an additional emission permit, it lowers the product prices in both countries. The impact on product prices can be ranked as follows:*

$$\frac{\partial p_i^{NT}}{\partial L_i} < \frac{\partial p_i^T}{\partial L_i} = \frac{\partial p_{-i}^T}{\partial L_i} < \frac{\partial p_{-i}^{NT}}{\partial L_i} < 0, \quad i = 1, 2,$$

i.e., when permits are tradable, the impact on either country's product prices is the same. However, when permits are nontradable, the absolute value of the impact of the increased number of permits is the largest for own country's product prices and the smallest for the other country's prices; the impact for tradable permits is intermediate between the above two.

An increase in the permit limit in either country (say, country i) reduces prices of all products irrespective of whether the permits are internationally tradable. However, the absolute value of the impact of the increased number of permits is the largest on the own firms' product prices (p_i) when permits are nontradable, and the impact on the other country's product prices (p_{-i}) is smallest (in absolute value) when permits are nontradable. In both cases, increased production in country i lowers p_i; given the substitutability between products of countries i and $-i$ (in the same industry), the resulting lower demand for country $-i$'s products lowers p_{-i}. However, with internationally tradable permits, the impact on p_{-i} is greater since part of the additional permit (1/2 under symmetry) is used in country $-i$, which further lowers the (net) production costs for firms in country $-i$; hence, $\left|\frac{\partial p^T_{-i}}{\partial L_i}\right| > \left|\frac{\partial p^{NT}_{-i}}{\partial L_i}\right|$.

Government i chooses L_i to maximize its welfare, W_i, taking L_{-i} and firms' behavior as given; this yields its best-response function:

$$\begin{aligned}\frac{dW_i^T}{dL_i} &= \sum_j \left(\frac{\partial \pi_{ij}}{\partial p^T_{ij}}\frac{\partial p^T_{ij}}{\partial L_i} + \frac{\partial \pi_{ij}}{\partial l_{ij}}\frac{\partial l_{ij}}{\partial L_i} + \frac{\partial \pi_{ij}}{\partial p^T_{-ij}}\frac{\partial p^T_{-ij}}{\partial L_i}\right) + \left(\sum_j \frac{\partial \pi_{ij}}{\partial R^T} + L_i\right)\frac{\partial R^T}{\partial L_i} + R^T \\ &\quad -\delta(L_i + L_{-i}) = 0,\end{aligned}$$

$$\Rightarrow \qquad J_i^T(L_i, L_{-i}) \equiv \frac{dW_i^T}{dL_i} = N\frac{\partial \pi_i}{\partial p^T_{-i}}\frac{\partial p^T_{-i}}{\partial L_i} + (L_i - Nl_i)\frac{\partial R^T}{\partial L_i} + R^T - \delta(L_i + L_{-i}) = 0, \quad (20)$$

$$\Rightarrow \quad R^T = \underbrace{\delta(L_i + L_{-i})}_{\text{domestic marginal damage}} - \underbrace{N\frac{\partial \pi_i}{\partial p^T_{-i}}\frac{\partial p^T_{-i}}{\partial L_i}}_{\text{profit-shifting effect}} = \delta(L_i+L_{-i})+Nb\beta q_i > \delta(L_i+L_{-i}), \quad (21)$$

where we have used the envelope theorem ($\frac{\partial \pi_i}{\partial p_i^T} = 0$ and $\frac{\partial \pi_i}{\partial l_i} = 0$), symmetry ($\frac{\partial \pi_i}{\partial R^T} = -l_i \Rightarrow Nl_i = L_i$), and eqs. (5) and (17). Hence, $R^T > \delta(L_i+L_{-i})$ always; in fact, the emission price exceeds the joint marginal damage from pollution if the profit-shifting motive is sufficiently strong, i.e., if $N\beta bq_i > \delta(L_i + L_{-i})$. Further, even with $\delta \to 0$, countries benefit from regulating pollution. The equilibrium permit level in terms of the parameters of the model and Lemma 4.2 are derived in the Appendix. We summarize our findings as follows:

Lemma 4. *Suppose countries use internationally tradable permits to regulate pollution.*

1. *Governments non-cooperatively issue permits such that the resulting permit price is **higher** than the domestic marginal damage from emissions, i.e.,* $R^T > \delta(L_i+L_{-i}), i = 1, 2$.

2. *The tradable permit price is **higher** than the joint marginal damage from pollution, i.e.,* $R^T > 2\delta(L_i+L_{-i}), i = 1, 2,$ *when* $\frac{b(2N\delta+1)}{N[2\{(2+\theta^2)-b(1+\theta^2)\}-b]} - 2\delta > 0$. *Then, the profit-shifting motive is sufficiently strong.*

3. *Countries benefit from pollution regulation even when* $\delta \to 0$, *i.e.,* $R^T(.;\delta = 0) = N\beta bq_i > 0$.

When firms compete on prices in international product markets, with either nontradable or tradable permits, the permit prices always exceed the domestic marginal damage from pollution, i.e., governments *always overregulate* emissions under non-cooperation. This is in contrast to quantity competition (Antoniou et al., 2014) where permit prices, in general, are lower than this marginal damage. In their (Cournot) model, the strategic variables are substitutes – in equilibrium $\frac{\partial q_{-i}}{\partial q_i} < 0$, so a subsidy in country i which raises output, q_i, lowers q_{-i}, thereby increasing profits of firms in country i; thus, there is an incentive to increase the subsidy (i.e., increase emission permit levels or lower pollution taxes). In contrast, in our (Bertrand) setup, the strategic variables are complements. Hence, for substitute goods, $\frac{\partial p_{-i}}{\partial p_i} > 0$, so a policy that raises prices in country i (fewer permits or higher pollution taxes) causes p_{-i} to rise, which increases profits of firms in country i (since $\frac{\partial \pi_i}{\partial p_{-i}} > 0$). This results in overregulation of emissions (emission prices higher than the own marginal damage from emissions) in our setup. Further, we show that the non-cooperative permit prices can *exceed* the joint marginal damage from pollution. This is likely if, *ceteris paribus*, the damage from pollution (δ) is low or the degree of product differentiation is low (b is high) or the number of industries (N) is low.

Emission Taxes. Next, suppose that government i regulates pollution using an emission tax, t_i, $i = 1, 2$. With nontradable permits, emissions in both countries are fixed at the respective permit limits. However, with taxes, a change in the tax in one country will result in changes in the emissions of both countries, i.e., there is *leakage*. Further, the strategic impact of a change in a country's policy on the other country's product prices also differs depending on whether the policy instrument is a tax or emission permit.

The profit of a firm located in country i is now given by: $\pi_i = (p_i - c)q_i - \frac{1}{2}a_i^2 - t_i z_i$. Profit maximization yields (since eq. 1 implies $\frac{\partial q_i}{\partial p_i} = -1$):

$$\frac{\partial \pi_i}{\partial a_i} = -a_i + t_i = 0 \qquad \Rightarrow \; a_i = t_i, \tag{22}$$

$$\text{and} \qquad \frac{\partial \pi_i}{\partial p_i} = q_i - [p_i - c - \theta t_i] = 0. \tag{23}$$

Comparing the above conditions to the case when the policy instrument is internationally nontradable emission permits, eqs. (3) and (4), it can be seen that these profit-maximization conditions are the same as the ones when the policy instrument is emission permits, with the permit prices, R_i's, replaced by the taxes, t_i's. Once again, using eq. (23), we have (since $\frac{\partial q_i}{\partial p_{-i}} = b$):

$$\frac{\partial \pi_i}{\partial p_{-i}} = [p_i - c - \theta t_i]b = bq_i. \tag{24}$$

Eq. (23) implies, for each of the N industries in country i: $(A - p_i + bp_{-i}) - (p_i - c - \theta t_i) = 0$, $i = 1, 2$. This can be written as:

$$\begin{bmatrix} 2 & -b \\ -b & 2 \end{bmatrix} \begin{bmatrix} p_i \\ p_{-i} \end{bmatrix} = \begin{bmatrix} A + c + \theta t_i \\ A + c + \theta t_{-i} \end{bmatrix}, \tag{25}$$

which implies, for each of the N industries in country i (with the superscript t denoting the tax game):

$$p_i^t = \frac{A+c}{2-b} + \frac{\theta(2t_i + bt_{-i})}{4-b^2} \qquad \Rightarrow \qquad \frac{\partial p_i^t}{\partial t_i} = \frac{2\theta}{4-b^2} > \frac{\partial p_i^t}{\partial t_{-i}} = \frac{\theta b}{4-b^2} > 0, \tag{26}$$

i.e., as the industry's emission tax in either country increases, product prices in both countries, p_i^t and p_{-i}^t, increase. Since $z_i = \theta q_i - a_i$, using eqs. (22) and (26), we have, for each of the N industries:

$$\begin{aligned}
\frac{\partial z_i}{\partial t_i} &= \theta \frac{\partial q_i}{\partial t_i} - \frac{\partial a_i}{\partial t_i} = \theta \left(-\frac{\partial p_i}{\partial t_i} + b\frac{\partial p_{-i}}{\partial t_i} \right) - 1 \\
&= -\frac{2(2+\theta^2) - b^2(1+\theta^2)}{4-b^2} \equiv -\gamma < 0, \qquad (27)\\
\frac{\partial z_{-i}}{\partial t_i} &= \theta \frac{\partial q_{-i}}{\partial t_i} = \theta \left(-\frac{\partial p_{-i}}{\partial t_i} + b\frac{\partial p_i}{\partial t_i} \right) = \frac{b\theta^2}{4-b^2} > 0 \;\Rightarrow\; \frac{\partial z_{-i}}{\partial t_i} < \left| \frac{\partial z_i}{\partial t_i} \right|, \qquad (28)\\
\text{and } \frac{\partial (Z_i + Z_{-i})}{\partial t_i} &= N \left(\frac{\partial z_i}{\partial t_i} + \frac{\partial z_{-i}}{\partial t_i} \right) = -N\theta(1-b) \left(\frac{\partial p_i}{\partial t_i} + \frac{\partial p_{-i}}{\partial t_i} \right) - N \\
&= -N \left[\frac{\theta^2(1-b)}{2-b} + 1 \right] < 0. \qquad (29)
\end{aligned}$$

Given $Z_i = Nz_i$, $\frac{\partial Z_i}{\partial t_i} = N\frac{\partial z_i}{\partial t_i}$. Eqs. (26) and (27) imply $\frac{\partial p_{-i}^t/\partial t_i}{\partial Z_i/\partial t_i} < 0$. An increase in t_i reduces production in country i, $q_i \downarrow$, leading to a fall in emissions ($z_i \downarrow$) and an increase in p_i. The latter results in an increase in the demand for the substitute products of country $-i$ and in their prices, p_{-i}. There is an increase in country $-i$'s production, thus, its emissions increase ($Z_{-i} \uparrow$), entailing a *leakage effect* reflected in eq. (28), which lowers the benefit to country i from setting stricter environmental policies due to the transboundary/ public bad nature of pollution.

Note that taxes and nontradable permits differ, in terms of controlling optimal behavior, because of leakage and because the strategic effects differ. We have seen that a reduction in the permit limit, say, in country i, causes output of corresponding firm (in the same industry) in country $-i$ to increase, which in turn means that, under permits, the price of emissions (permits) increases in country $-i$. However, under a tax, an increase in t_i does not change the emission price in country $-i$. That is, a decrease in the nontradable permit limit in country i is likely to lead to a greater increase in product prices in country $-i$ than would a tax increase that had the same effect on country i's emission. This means that, with environmental policies as strategic profit-shifting instruments, nontradable permits are likely to be more effective as a strategic instrument than an emission tax.[15] Using eqs. (7),

[15] Recall that an increase in p_{-i} increases firm i's profit since $\frac{\partial \pi_i}{\partial p_{-i}} > 0$ (eqs. 5 and 24).

(26), and (27), we have:

$$\left|\frac{\partial p^t_{-i}/\partial t_i}{\partial Z_i/\partial t_i}\right| = \frac{\theta b}{N[2(2+\theta^2)-b^2(1+\theta^2)]} \equiv \eta \quad < \quad \left|\frac{\partial p^{NT}_{-i}}{\partial L_i}\right| = \frac{\theta b(1+\theta^2)}{N\Delta} = \alpha \text{ if } \theta > 0. \quad (30)$$

Lemma 5. *When country i changes (reduces) its tax, t_i, such that its emissions, Z_i, increase by one unit, this lowers the prices of products in the other country less than when country i issues an additional nontradable permit (which also increases Z_i by one unit).*

With either policy instrument, as environmental policy in country i is relaxed, z_i increases and product prices in both countries, p_i and p_{-i}, decrease. Under nontradable permits, given binding permit limits in country $-i$ (L_{-i}), the permit price in country $-i$ falls, i.e., $R_{-i} \downarrow$; this directly reduces production cost of firms in country $-i$. When taxes are the policy instruments, given t_{-i}, the price of emissions in country $-i$ is fixed; hence, the additional effect of cost reduction for firms in country $-i$ is not present and the decline in p_{-i} is less in magnitude with taxes than with nontradable permits. Thus, for a given reduction in domestic emission, the nontradable permit has a more favorable strategic (profit-shifting) effect and a better effect on overall pollution, as there is no leakage.

Welfare in country i is now given by: $W_i = N\pi_i + t_i Z_i - D(Z_i + Z_{-i})$; government i chooses t_i to maximize W_i taking t_{-i} and the firms' behavior as given:

$$\begin{aligned}\frac{dW^t_i}{dt_i} &= N\left(\frac{\partial \pi_i}{\partial t_i}\frac{\partial p_i}{\partial t_i} + \frac{\partial \pi_i}{\partial z_i}\frac{\partial z_i}{\partial t_i} + \frac{\partial \pi_i}{\partial p_{-i}}\frac{\partial p_{-i}}{\partial t_i}\right) + N\left(\frac{\partial \pi_i}{\partial t_i} + z_i\right) + t_i\frac{\partial Z_i}{\partial t_i} \\ &\quad -\delta(Z_i + Z_{-i})\left(\frac{\partial Z_i}{\partial t_i} + \frac{\partial Z_{-i}}{\partial t_i}\right) = 0,\end{aligned}$$

$$\Rightarrow \quad J^t_i(t_i, t_{-i}) \equiv \frac{dW^t_i}{dt_i} = N\frac{\partial \pi_i}{\partial p^t_{-i}}\frac{\partial p^t_{-i}}{\partial t_i} + t_i\frac{\partial Z_i}{\partial t_i} - \delta(Z_i + Z_{-i})\left(\frac{\partial Z_i}{\partial t_i} + \frac{\partial Z_{-i}}{\partial t_i}\right) = 0, \quad (31)$$

$$\begin{aligned}\Rightarrow \quad t_i &= \underbrace{\delta(Z_i + Z_{-i})}_{\text{domestic marginal damage}} \underbrace{+\,\delta(Z_i + Z_{-i})\frac{\partial Z_{-i}/\partial t_i}{\partial Z_i/\partial t_i}}_{\text{leakage effect}} \underbrace{-\,N\frac{\partial \pi_i}{\partial p^t_{-i}}\frac{\partial p^t_{-i}/\partial t_i}{\partial Z_i/\partial t_i}}_{\text{profit-shifting effect}}, \\ &= \delta(Z_i + Z_{-i}) - N\delta(Z_i + Z_{-i})\theta\eta + Nb\eta q_i, \quad (32)\end{aligned}$$

where we have used the envelope theorem ($\frac{\partial \pi_i}{\partial p^t_i} = 0$, $\frac{\partial \pi_i}{\partial z_i} = 0$), the equilibrium condition ($\frac{\partial \pi_i}{\partial t_i} + z_i = 0$), $\frac{\partial Z_i}{\partial t_i} = N\frac{\partial z_i}{\partial t_i}$, $\frac{\partial Z_{-i}}{\partial t_i} = N\frac{\partial z_{-i}}{\partial t_i}$, and eqs. (24) and (30). The *leakage effect* lowers the tax on own emission since eqs. (27) and (28) imply $\frac{\partial Z_{-i}/\partial t_i}{\partial Z_i/\partial t_i} = \frac{\partial z_{-i}/\partial t_i}{\partial z_i/\partial t_i} = -\frac{\theta^2 b}{2(2+\theta^2)-b^2(1+\theta^2)} = -N\theta\eta < 0$. Eqs. (26) and (27), along with the fact that $\frac{\partial \pi_i}{\partial p^t_{-i}} > 0$, imply that the profit-shifting effect increases the tax. Thus, $t_i > \delta(Z_i + Z_{-i})$ if the leakage effect is dominated by the profit-shifting effect, i.e., if $\left|\delta(Z_i + Z_{-i})\frac{\partial Z_{-i}/\partial t_i}{\partial Z_i/\partial t_i}\right| < N\left|\frac{\partial \pi_i}{\partial p^t_{-i}}\frac{\partial p^t_{-i}/\partial t_i}{\partial Z_i/\partial t_i}\right|$; this occurs if $\theta\delta(Z_i + Z_{-i}) < bq_i$. In fact, t_i can exceed the joint marginal damage from pollution if the profit-shifting motive is sufficiently strong relative to the leakage effect, i.e., if $N\eta b q_i > (1+N\theta\eta)\delta(Z_i+Z_{-i})$. Further, even with $\delta \to 0$, countries benefit from setting $t_i = N\eta b q_i > 0$. We derive the equilibrium emission tax in terms of the primitives of the model, along with Lemmas 6.1 and 6.2 in the Appendix. We summarize these findings as follows:

Lemma 6. *Suppose countries set emission taxes non-cooperatively to regulate pollution.*

1. *The tax is higher (lower) than the domestic marginal damage from pollution, i.e.,* $t_i > (<)\delta(Z_i + Z_{-i})$ *if* $\frac{b+2N\delta(b-\theta^2)}{2N\delta\{1+(1-b)(1+\theta^2)\}-b(1-b)} > (<)0$. *Then, the profit-shifting effect dominates (is dominated by) the leakage effect.*

2. *The emission tax is* higher *than the joint marginal damage from pollution, i.e.,* $t_i > 2\delta(Z_i + Z_{-i})$, *if* $b^2 - 8N\delta + 6b^2N\delta - 2(2-b)(1+b)N\delta\theta^2 > 0$. *Then, the profit-shifting motive is sufficiently strong.*

3. *Countries impose a positive emission tax even when environmental damage is small, i.e.,* $t_i(.;\delta \to 0) = N\eta b q_i > 0$.

Strict pollution policy (high emission tax), say, in country i, increases product prices in country i (p_i) and the demand for the substitute products; hence, p_{-i}'s increase. Given t_{-i}, production in country $-i$ increases, as does emissions, Z_{-i}. The accompanying increase in total pollution reduces government i's marginal benefit from regulating own emissions. This leakage effect tends to lower the emission tax in country i. On the other hand, the use of the emission tax for profit-shifting in favor of the domestic firm tends to increase the tax. Whether there is overregulation of pollution with taxes depends on which of these effects dominate. *Ceteris paribus*, a lower damage from pollution, i.e., a low δ, or a lower number of industries, N, is likely to result in a tax *higher* than the own marginal damage from emissions. The non-cooperative tax is likely to *exceed* the joint marginal damage from pollution if, *ceteris paribus*, the damage from pollution (δ) is low or the degree of product differentiation is low (b is high) or the number of industries (N) is low. Note that if production is *clean*, i.e., if $\theta = 0$ and $Z_i = Z_{-i} = 0$, implying $\eta = 0$ (using eq. 30) and hence, $t_i = 0$ (using eq. 32).

We can summarize our results of Lemmas 1, 4, and 6 as follows:

Proposition 1. *Suppose governments set environmental policies non-cooperatively.*

1. *The profit-shifting motive* ***always*** *tends to increase the price of emissions (i.e., permit prices and taxes) above the domestic marginal damage from emissions in* ***both*** *countries.*

2. *The (nontradable and tradable) permit prices* ***always exceed*** *this domestic marginal damage, while the emission tax can also exceed this marginal damage.*

3. The emission prices can ***exceed*** *the joint marginal damage from pollution.*

4. Even if environmental damages are small, i.e., even if $\delta \to 0$, countries benefit from regulating pollution and set policies such that the emission price is positive.

Cooperative Equilibrium. When governments cooperate, aggregate welfare in the two countries is: $\overline{W} = W_i + W_{-i} = \sum_i N\pi_i + \sum_i R_i L_i - 2D(L_i + L_{-i})$, $i = 1, 2$, and the last term is the sum of the pollution damages in the two countries. Suppose governments cooperatively choose the *nontradable* permit limits in each country to maximize $\overline{W}$ taking the firms' non-cooperative behavior as given:[16,17]

$$\begin{aligned}\frac{d\overline{W}}{dL_i} &= N\left(\frac{\partial \pi_i}{\partial p_i}\frac{\partial p_i}{\partial L_i} + \frac{\partial \pi_i}{\partial l_i}\frac{\partial l_i}{\partial L_i} + \frac{\partial \pi_i}{\partial p_{-i}}\frac{\partial p_{-i}}{\partial L_i}\right) + N\left(\frac{\partial \pi_{-i}}{\partial p_{-i}}\frac{\partial p_{-i}}{\partial L_i} + \frac{\partial \pi_{-i}}{\partial l_{-i}}\frac{\partial l_{-i}}{\partial R_{-i}}\frac{\partial R_{-i}}{\partial L_i} + \frac{\partial \pi_{-i}}{\partial p_i}\frac{\partial p_i}{\partial L_i}\right) \\ &\quad + \left(N\frac{\partial \pi_i}{\partial R_i} + L_i\right)\frac{\partial R_i}{\partial L_i} + R_i + \left(N\frac{\partial \pi_{-i}}{\partial R_{-i}} + L_{-i}\right)\frac{\partial R_{-i}}{\partial L_i} - 2\delta(L_i + L_{-i}),\end{aligned}$$

$$\Rightarrow \quad \bar{J}_i(L_i, L_{-i}) \equiv \frac{d\overline{W}}{dL_i} = N\left(\frac{\partial \pi_i}{\partial p_{-i}}\frac{\partial p_{-i}}{\partial L_i} + \frac{\partial \pi_{-i}}{\partial p_i}\frac{\partial p_i}{\partial L_i}\right) + R_i - 2\delta(L_i + L_{-i}) = 0, \quad (33)$$

$$\begin{aligned}\Rightarrow \quad R_i^* &= \underbrace{2\delta(L_i + L_{-i})}_{\text{joint marginal damage}} - \underbrace{N\frac{\partial \pi_i}{\partial p_{-i}}\frac{\partial p_{-i}}{\partial L_i}}_{\text{country } i\text{'s profit-shifting effect}} - \underbrace{N\frac{\partial \pi_{-i}}{\partial p_i}\frac{\partial p_i}{\partial L_i}}_{\text{country } -i\text{'s profit-shifting effect}}, \\ &= 2\delta(L_i + L_{-i}) - Nb\left(q_i\frac{\partial p_{-i}}{\partial L_i} + q_{-i}\frac{\partial p_i}{\partial L_i}\right), \\ &= 2\delta(L_i + L_{-i}) + Nb\left(\alpha q_i + \mu q_{-i}\right) > 2\delta(L_i + L_{-i}), \quad (34)\end{aligned}$$

where R_i^* is the cooperative emission permit price. We have used the envelope theorem and equilibrium conditions, as before, along with eqs. (5) and (7). The emission price that internalizes the pollution externality in the two countries is the joint marginal damage from pollution. However, to (cooperatively) capture a larger surplus from the product market, governments choose permit levels such that the resulting emission price is *always higher* than the joint marginal damage. The equilibrium cooperative permit levels in terms of the parameters of the model are derived in the Appendix. Moreover, even with $\delta \to 0$, the price of emissions under cooperation is positive and exceeds the non-cooperative prices.

[16]Coordination by firms can be difficult, say, due to antitrust and competition policies in the product market. Further, coordination by firms in multiple industries is likely to be more difficult than coordination by two governments.

[17]In our setup, the choice of instrument, nontradable/tradable permits or taxes, does *not* matter. Each can replicate the outcome under the other instruments. Any cooperative tradable permit choice can be subsumed in the cooperative nontradable permit regime.

Proposition 2. *Suppose governments set environmental policies cooperatively.*

1. *The price of emissions (i.e., the permit price or the emission tax) in the cooperative equilibrium is* ***always higher*** *than the joint marginal damage from pollution:* $R_i^* > 2\delta(Z_i + Z_{-i})$.

2. *The emission price is positive and exceeds the non-cooperative prices even if the damage from pollution is small, i.e., even if* $\delta \to 0$, $R_i^*(.;\delta \to 0) = Nb(\alpha q_i + \mu q_{-i}) > 0$.

Under cooperation, governments choose permit limits not only to account for joint damage from emissions, but also to move output towards the monopoly level; the latter increases the profits of firms in both countries. Note that, if firms were unable to abate pollution, governments, by choice of permit limits under cooperation, could push firms (even when the latter do not cooperate) to the monopoly output level.

3 Pollution and Welfare

We, now, compare emission prices and pollution levels in the different policy regimes; we also rank welfare under these policies.

The following Lemma, which applies to our symmetric equilibrium, is proved in the Appendix:

Lemma 7. $J_i^{NT}(.)$, $J_i^T(.)$, *and* $\bar{J}_i(.)$ *are monotonically decreasing in* L_i, *while* $J_i^t(.)$ *is monotonically decreasing in* t_i, $i = 1, 2$.

Suppose (L_i^{NT}, L_{-i}^{NT}) is the solution in the nontradable permit game. Evaluating eq. (20) at (L_i^{NT}, L_{-i}^{NT}), we have (using eq. 5 and since, given symmetry, $Nl_i = L_i$):

$$J_i^T(L_i^{NT}, L_{-i}^{NT}) = R^T - \delta(L_i + L_{-i}) + Nbq_i \frac{\partial p_{-i}^T}{\partial L_i}.$$

Further, $R_i = R_{-i} = R^T$ and $q_i^T(L_i^{NT}, L_{-i}^{NT}) = q_i^{NT}(L_i^{NT}, L_{-i}^{NT}) > 0$. Hence, using Lemmas 3 and 7, we have:

$$J_i^T(L_i^{NT}, L_{-i}^{NT}) < 0 \quad \Rightarrow \quad L_i^T < L_i^{NT},$$

where L_i^T is the permit level when emission permits are internationally tradable. Hence, we have:

Proposition 3. *Under non-cooperation, governments issue more permits (hence, pollution is higher) when the strategic policy instrument is internationally nontradable permits as compared to the situation in which emission permits are internationally tradable.*

When country i issues an additional permit, the resulting fall in product prices in country $-i$, i.e., the fall in p_{-i}, is greater if the permits are internationally tradable than if they are nontradable (Lemma 3); hence, the negative impact on the profits of firms located in country i is stronger in the former case than in the latter (since $\frac{\partial \pi_i}{\partial p_{-i}} > 0$). Thus, with tradable permits, the incentive to overregulate pollution is strengthened and, under non-cooperation, tradable permits result in an equilibrium with fewer permits relative to nontradable permits.

Suppose (L_i^{NT}, L_{-i}^{NT}), the solution in the nontradable permit game, implies permit prices (R_i, R_{-i}). Let $(t_i, t_{-i}) = (R_i, R_{-i})$; given symmetry and that the firms' optimality conditions are the same under permits and taxes (compare eqs. 3 and 4 to eqs. 22 and 23), we can conclude that $(z_i, z_{-i}) = (l_i^{NT}, l_{-i}^{NT})$ and $(Z_i, Z_{-i}) = (L_i^{NT}, L_{-i}^{NT})$. Evaluating eq. (31) at (R_i, R_{-i}), we have (using eq. (24)):

$$J_i^t(R_i, R_{-i}) \quad = \quad \left[N \frac{\partial \pi_i}{\partial p_{-i}^t} \left(\frac{\partial p_{-i}^t / \partial t_i}{\partial Z_i / \partial t_i} \right) + t_i - \delta(Z_i + Z_{-i}) \left(1 + \frac{\partial Z_{-i}/\partial t_i}{\partial Z_i/\partial t_i} \right) \right] \frac{\partial Z_i}{\partial t_i}.$$

Further, $q_i^t(R_i, R_{-i}) = q_i^{NT}(R_i, R_{-i}) > 0$, while $\frac{\partial Z_i}{\partial t_i} < 0$, $\frac{\partial Z_{-i}}{\partial t_i} > 0$, and $\frac{\partial Z_{-i}}{\partial t_i} < \left| \frac{\partial Z_i}{\partial t_i} \right|$ (since $Z_i = N z_i$ and using eqs. 27 and 28). Hence, using eq. (30) and Lemma 7, we have :

$$J_i^t(R_i, R_{-i}) < 0 \quad \Rightarrow \quad t_i < R_i.$$

Thus, we have:

Proposition 4. *The non-cooperative emission tax is lower than the price of internationally nontradable emission permits under non-cooperation. Hence, pollution is higher when the strategic policy instrument is a tax than when internationally nontradable emission permits are used to regulate pollution.*

The fall in p_{-i} is less when t_i is lowered such that Z_i increases by one unit than when government i issues an additional nontradable permit (which also increases Z_i by one unit). Hence, the fall in profits of firms in country i is lower in the former situation, which results in relatively lax pollution policy with taxes as compared to nontradable permits. The leakage effect when the policy instrument is a tax, which is not present with nontradable permits, further lowers the emission tax.

In the *cooperative equilibrium*, the optimal L_i^* is determined by eq. (33); evaluating eq. (33) at the non-cooperative tradable permit solution, (L_i^T, L_{-i}^T), we have (using eq. 5):

$$\bar{J}_i(L_i^T, L_{-i}^T) = R_i - 2\delta(L_i^T + L_{-i}^T) + Nbq_i \frac{\partial p_{-i}}{\partial L_i} + Nbq_{-i} \frac{\partial p_i}{\partial L_i}.$$

Using eqs. (7) and (17), and Lemmas 3 and 7, we have (given symmetry):

$$\bar{J}_i(L_i^T, L_{-i}^T) < 0 \quad \Rightarrow \quad L_i^* < L_i^T.$$

Thus, we have:

Proposition 5. *The emission permit limit in each country under cooperation is lower than that when countries set tradable permit limits non-cooperatively.*

Using Propositions 3 – 5 and Lemma 7, we can rank the (equivalent) taxes, pollution and welfare under the different policy regimes as follows:

Proposition 6. *The outcomes under different non-cooperative policy instruments and the cooperative outcome can be ranked as follows, for $i = 1, 2$:*

1. *price of emissions: $R^* > R^T > R_i^{NT} > t_i$;*
2. *pollution: $Z_i^* < Z_i^T < Z_i^{NT} < Z_i^t$;*
3. *welfare: $W_i^* > W_i^T > W_i^{NT} > W_i^t$.*

It is straightforward to see from Proposition 6:

Corollary 1. *Suppose that pollution damage is small, i.e., $\delta \to 0$. The emission prices can be ranked as follows: $R^* > R^T > R_i^{NT} > t_i$, $i = 1, 2$.*

Note that if we relax our assumption of symmetry, by continuity, provided countries and industries are sufficiently similar, our results would continue to hold. Hence, we have:

Corollary 2. *Even if countries and industries are asymmetric, provided they are sufficiently similar, our results hold.*

The market power of firms results in governments pushing the emission price under cooperation above the joint marginal damage from pollution to increase firms' profits. In the non-cooperative equilibria, governments overregulate pollution (relative to the domestic marginal damage from pollution) as a second-best way of taxing the exports of their respective firms for profit-shifting motives. The degree of overregulation depends on the impact on the other country's firms' product prices; the latter affects the domestic firms' profits (hence, domestic welfare). With emission taxes, leakage effects reduce the incentive to overregulate pollution. Overall, when governments act non-cooperatively, internationally tradable emission permits result in outcomes closest to the cooperative equilibrium.

4 Concluding Remarks

This paper compared different pollution policy instruments in the empirically important case of international Bertrand competition in differentiated products. We find that, in the non-cooperative equilibria, prices of nontradable and tradable emission permits *always exceed* the domestic marginal damage from pollution, i.e., they are higher the Pigovian tax. Emission taxes exceed the Pigovian tax if the profit-shifting effect dominates the leakage effect. Internationally tradable permits generate the *lowest* pollution and the *highest* welfare in *both* countries. This outcome is closest to the cooperative equilibrium despite countries non-cooperatively choosing policies (permit levels) to maximize own welfare, i.e., there is no supranational agency that determines the number of permits allocated to each country. Further, even if the environmental damage is small, it is in the self interest of countries to regulate their emissions under cooperation and non-cooperation. All our results hold even in this case.

Our results provide a rationale for the push for an international emission permit trading regime even when governments may issue permits non-cooperatively to maximize own welfare. As discussed in the Introduction, this is relevant for real world situations: similar types of regimes were allowed in Phases 1 and 2 of the EU Emission Trading System and under the Copenhagen Accord. Hence, permit trade as envisioned in these cases can be instrumental in reducing pollution even when governments do not cooperate and despite strategic incentives being present. The latter have often been blamed as a contributing reason for lax environmental policies.

Finally, the paper also provides a testable hypothesis. Given previous results in the literature indicating industries in which price competition is prevalent (see the Introduction), future work can verify if pollution policy is stricter in such industries.

Supplementary Material

Supplementary material (the Appendix) is available online at the OUP website.

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