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Tradable Permits vs Ecological Dumping

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Summary

In this paper we examine an alternative policy scenario, where governments allow polluting firms to trade permits in a strategic environmental policy model. We demonstrate, among other things, that with no market power in the permits market, governments of the exporting firms do not have an incentive to under-regulate pollution in order to become more competitive. This strategic effect is reversed and leads to a welfare level closer to the cooperative one and strictly higher to that when permits are non-tradable. Allowing for market power in the permits market, the incentive to under-regulate pollution re-appears regardless of whether permits are tradable or not. With tradable permits, however, the incentive to under-regulate pollution is comparatively weaker relative to the case of non-tradable permits. This entails potential benefits for the exporting firms and countries since the prisoners' dilemma is moderated.

Keywords: Strategic Environmental Policy, Tradable Permits, Race to the top

JEL Classification: Q58, F12, F18

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Abstract

In this paper we examine an alternative policy scenario, where governments allow polluting firms to trade permits in a strategic environmental policy model. We demonstrate, among other things, that with no market power in the permits market, governments of the exporting firms do not have an incentive to under-regulate pollution in order to become more competitive. This strategic effect is reversed and leads to a welfare level closer to the cooperative one and strictly higher to that when permits are non-tradable. Allowing for market power in the permits market, the incentive to under-regulate pollution re-appears regardless of whether permits are tradable or not. With tradable permits, however, the incentive to under-regulate pollution is comparatively weaker relative to the case of non-tradable permits. This entails potential benefits for the exporting firms and countries since the prisoners' dilemma is moderated.

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1 Introduction

Recent negotiations among the major polluting countries concerning the restrictions of greenhouse gas emissions, like CO2, surfaced the difficulty of finding common cooperative policies.[1] This difficulty brought into light old concerns on the strategic use of environmental policies, aiming towards enhancing the international competitiveness of the exporting industries. Today it is common understanding that some developing countries, such as China and India, favor increased production at the cost of environmental degradation consistently. However, this attitude is not a 'privilege' of developing countries only. For many decades the US and many western European countries, took advantage of the lack of environmental regulation and developed cost-minimizing and production-maximizing technologies without consideration of their environmental consequences (see footnote 1).

The 'Strategic Environmental Policy' or 'Ecological Dumping' literature, mainly established by Barrett (1994), Kennedy (1993), Conrad (1993), Rauscher (1994) and Ulph (1996), has provided interesting theoretical research on this issue.[2] A common suggestion in this literature is that governments engaging in international competition have a unilateral incentive to set the environmental regulation below the first best level when their representative firms compete a-là Cournot in world commodity markets. The rationale is that laxer environmental regulation provides a credible commitment device to the exporting firms, which leads them to increase their outputs and gain market shares from their rivals.[3]

Turning to a different strand of the literature, Montgomery (1972) in his seminal work

[1] A recent example are the annual negotiations that took place in Bali in December 2007. Delegates from 189 different countries negotiated a new pact to succeed the Kyoto protocol. However, the US and Australia refused to sign the pact claiming that the ratification of the Kyoto protocol would unfairly damage their energy-export based economies and cost jobs.

[2] Recent contributions to this literature e.g., Neary (2006), Simpson and Bradford (1996), Bayindir-Upmann (2003), Greaker (2003) and Straume (2006) develop extensions and point out earlier limitations.

[3] Recent empirical findings by Levinson and Taylor (2008), Woods (2006), Ederington et al. (2005), Fredriksson and Millimet (2002) and Ederington and Minier (2003) argue that indeed there is strategic interaction in an environmental policy setting and that environmental policy can be used as a secondary trade barrier.

argued that under perfect competition in product and permits markets, the use of tradable permits can lead to the cost minimizing solution and thus to greater welfare. Based on this result, during the last two decades regulators have extended the use of tradable permits. For instance, at the firm level the European Union implemented a wide carbon trading scheme since 2005 (Ellerman and Buchner, 2007), while in the US greenhouse gas emissions have been regulated locally through regional carbon dioxide trading schemes since 2001 (Rose et al., 2006). Both studies converge to the conclusion that overall efficiency of the system has improved after the introduction of tradable permits.

However, the policy implications of the use of tradable permits become less clear when product or permit markets are not perfectly competitive. For example, the main polluters seem to be the large chemical industries, characterized by large scale economies. Sartzetakis (1997, 2004), von der Fehr (1993) and Ehrhart et al. (2008), among others, provide examples where the existence of imperfect competition in the products markets, result in lower welfare levels. This result is exacerbated when a single firm can exert market power in the permits market, e.g., Hahn (1984), or more significantly when market power is determined endogenously and multilaterally, e.g., Malueg and Yates (2009) and Lange (2008).

To the best of our knowledge, there is no attempt in the literature, to incorporate tradable permits in a model of strategic environmental policy. That is because eco-dumping models imply that the governments decide unilaterally about the level of pollution allowed. Therefore, questions such as the following, arise; why one country accepts pollution from a rival one? Wouldn't this create an incentive to issue a large number of permits in each country leading to environmental degradation? If countries were to accept each other's allowances, what would restrict them from achieving a fully cooperative outcome such that welfare is maximized? In this paper we address these questions and we support the necessity and the potential benefits that may arise from the adoption of such a system.

We develop a model of an international symmetric duopoly where each government decides unilaterally the level of regulation but the firms are allowed to trade permits in a competitive permits market. Our main result suggests that if both countries allow trading of emission permits at the firm level, the unilateral incentive of the governments to set environmental policy insufficiently lax is reversed. This result holds irrespective of whether the model is symmetric or not and of the number of participants in the game. The policy implication of this outcome is that, when governments bargain for setting emissions caps, they are involved in a race to the top. This race to the top leads to higher welfare in the exporting countries compared to the case of non-tradable permits, and approaches the welfare of a cooperative solution game. The benefit of such a system versus a cooperative solution is that the governments do not have an incentive to deviate unilaterally from such a strategy. Thus, based on this result we conclude that countries with similar characteristics that allow cross boundary trading of pollution permits, should not worry about the welfare consequences of competition in environmental standards with the rival countries. The welfare implications remain unaffected when the firms exercise market power in the permits market.

2 The model

We consider a symmetric two country, home and foreign, two stage game. Each country is represented by an exporting firm. In stage 1 the rival governments select the environmental regulation level simultaneously so as to maximize welfare. Then in stage 2 the firms compete a-là Cournot in a world commodity market.[4] In order to focus on strategic trade issues we further assume that consumption of the goods in the two countries is zero, thus total production by the two firms is exported to the rest of the world (ROW). Production for the domestic firm is denoted by x, and the production cost is denoted by $c(x)$, where $c_x \geq 0$ and $c_{xx} \geq 0$ determine the marginal cost of production and the

[4] All choice variables and functions of the domestic (foreign) country and firm are denoted by lower case (upper case) letters. Since the two firms (countries) in the main case are assumed symmetric, we only present explicitly the variables and functions of the home firm (country). Those of the foreign are equivalently defined.

convexity of the cost function, respectively. Total revenues are $r(x, X)$, and we assume that the two outputs are substitutes, $r_X(x, X) < 0$.

We assume that production is associated with a pollutant which affects the citizens in both the exporting countries. Let denote $\overline{e}$ as the amount of pollution that the domestic firm is allowed to emit, or equivalently the number of issued permits. The damage caused from pollution in the domestic country is $d(\overline{e} + \gamma\overline{E})$ where $d_{\overline{e}}$, $d_{\overline{E}} > 0$, $d_{\overline{e}\overline{e}}$, $d_{\overline{e}\overline{E}}$, $d_{\overline{E}\overline{E}} \geq 0$ and $\gamma \in (0, 1]$. When $\gamma = 1$ the pollutant is perfectly transboundary and thus emissions in the rival country affect equally the citizens in the home country, while in any other case is partially transboundary.[5]

We further assume that each firm has a private abatement technology available, a, which allows adherence to the binding amount of permits issued by the governments. At the same time the governments allow the firms to trade permits. Each firm can increase (reduce) production above (below) $\overline{e}$, if it buys (sells) pollution permits from the rival one at a *given* price P^{ε} defined by the governments. This ensures that the firms are price takers in the permits market, in other words the permits market is competitive.[6] This is a simplifying assumption, yet at this point we aim to exploit the maximum of the possible benefits arising from the use of permits and thus we use this as an extreme or a reference scenario. Later on in the analysis, we relax this assumption and we examine how market power in the permits market weakens our results. If P^{ε} is sufficiently high (low) it may be convenient for the firm to sell (buy) an amount $e > 0$ (< 0) of its initially allocated permits $\overline{e}$ which drives the firm to reduce (increase) emissions by γe, where $\gamma e \leq \overline{e}$.[7] Given the possibility of trading permits, abatement is assumed to be

[5] Cross-border pollution is modeled here as in Kennedy (1994). However, it can be modeled in various ways different from $\overline{e} + \gamma\overline{E}$. An alternative way used in the relevant literature would be $(1 - \gamma)\overline{e} + \gamma\overline{E}$ or more generally $\gamma_1\overline{e} + \gamma_2\overline{E}$. In such a case the results are not modified qualitatively.

[6] This implies that the permits price is exogenous for the firms. This could be the case if the governments set the price at the world price level obtained from a global market of permits or any other price. The assumption that the permits market may be competitive while the output market not it is common in the relevant literature, e.g., Sartzetakis (1997, 2004).

[7] Note that e is multiplied by γ because one unit of pollution in the home country implies γ units of pollution in the foreign country. A permit allowing one unit of pollution at home should allow γ extra units to the foreign firm when it is sold to the foreign firm. In order to keep the sum of pollution in the two countries constant after trade we multiply γe.

$a = f(\theta x - \overline{e} + \gamma e) \geq 0$ where θ is a positive scalar, $f_x > 0$, $f_{\overline{e}} < 0$ and $f_e > 0$. We further assume a convex abatement cost function $q(a)$, where $q_a(a) > 0$ and $q(a)_{aa} > 0$. Given all the determinants of the profit functions we define profits as:

$$\pi = r(x, X) - c(x) - q(a) + P^{\varepsilon} e. \tag{1}$$

In stage 2 of the game, given the amount of permits issued, the firms maximize their profits with respect to output and the number of permits they sell (buy) subject to the constraint of abatement. Therefore, the first order conditions for the domestic and the foreign firms are:

$$\left\{ \begin{array}{c} \pi_x = r_x - c_x - q_x = 0 \\ \pi_e = P^{\varepsilon} - q_e = 0 \\ \Pi_X = R_X - C_X - Q_X = 0 \\ \Pi_E = P^{\varepsilon} - Q_E = 0 \end{array} \right\}. \tag{2}$$

Second order conditions are satisfied since $\pi_{xx} < 0$, $\pi_{ee} < 0$, $\pi_{xx}\pi_{ee} - \pi_{xe}^2 > 0$ and $\Pi_{XX} < 0$, $\Pi_{EE} < 0$, $\Pi_{XX}\Pi_{EE} - \Pi_{XE}^2 > 0$. Moreover, $\pi_{xX} < 0$ and $\Pi_{xX} < 0$ ensure that the output reaction functions are downward sloping. Stability in output competition and uniqueness is implied by $\pi_{xx}\Pi_{XX} - \pi_{xX}\Pi_{xX} > 0$.[8] The last equilibrium determinant in stage 2 is the equilibrium condition that clears the permits market:

$$e + E = 0. \tag{3}$$

This equality simply states that the amount of permits that a firm sells (buys) must be bought (sold) by the rival, or equivalently, the total amount of permits issued by the two governments equals the total number of permits used by the two firms. The permits market clearing condition (3) determines P^{ε}. Therefore, the scenario that we follow allows the governments to issue unilaterally the number of permits they wish by maximizing their own national welfare and then allow the firms to trade permits at a

[8] For the uniqueness and local stability conditions in Cournot games see Dastidar (2000).

given price.

2.1 Comparative statics

Here we examine the decisions made in stage 2 of the game and attain the comparative statics. The analysis considers first the case of a fully symmetric international duopoly. The results of this benchmark are then generalized in a case where various asymmetries, e.g., differences in abatement cost and in pollution damage functions may exist between the two countries. Further, they are extended to a more general case of a larger and unequal number of countries and firms.

In particular, we focus the comparative statics on the sign of the so called strategic effect that appears in eco-dumping models and leads to the prisoners dilemma situation. The strategic effect can be described as the effect that domestic environmental regulation has on foreign output (which in turn affects domestic profits). Algebraically, in terms of our modelling, it is denoted by $\frac{\partial X^*}{\partial \bar{e}}$, where the asterisk denotes stage 2 equilibrium value. Note that before proceeding to the analysis that the sign of this derivative in the relevant literature is negative, i.e., $\frac{\partial X^*}{\partial \bar{e}} < 0$.

2.1.1 Symmetric Case

Holding the assumption that everything in the model is fully symmetric we use a simpler, than the traditional, way to obtain the sign of the partial derivatives. The following proposition presents the sign of the strategic effect, $\frac{\partial X^*}{\partial \bar{e}}$, in the strategic environmental policy literature, and the signs of $\frac{\partial e^*}{\partial \bar{e}}$ and $\frac{\partial e^*}{\partial \overline{E}}$ which capture the way the domestic firm's net supply of permits is altered when the domestic and foreign country's endowments of permits change:

Proposition 1*:*

(a) The strategic (regulation) effect appears to be positive and equal to the direct (regulation) effect on foreign and domestic equilibrium output respectively, i.e., $\frac{\partial X^*}{\partial \bar{e}} = \frac{\partial x^*}{\partial \bar{e}} > 0$.

(b)The effects of a change in the domestic and foreign endowments of permits over the domestic permits net supply are $\frac{\partial e^*}{\partial \overline{e}} = -\frac{\partial e^*}{\partial \overline{E}} = \frac{1}{2\gamma} > 0.$

(See proof in the Appendix■)

The important implication of Proposition 1 is that when the domestic government changes the level of regulation, $\overline{e}$, it will affect in the same way both the domestic and foreign firms' outputs, i.e., $\frac{dx^*}{d\overline{e}} = \frac{dX^*}{d\overline{e}} > 0$. Hence, in our case, the strategic effect is positive instead of negative as it is in models of the standard strategic environmental policy literature, e.g., Barrett (1994), Kennedy (1993), Conrad (1993), Rauscher (1994) and Ulph (1996). It follows that when regulation in the home country is relaxed, the foreign firm increases its output equally to the domestic firm, while the profits of both firms fall.

We now turn to explaining the driving forces of this result. The negative sign of $\frac{dX^*}{d\overline{e}}$ in the strategic environmental policy models when permits are non-tradable, is due to the change in the marginal cost of abatement, which acts as a commitment device against the rival firm. That is, when the domestic government relaxes the emissions standard then, for a given level of output, abatement carried out by the firm is reduced. This, in turn, reduces the marginal cost of abatement and thus the domestic firm can credibly increase output, while the foreign firm decreases its output due to the negative slope of the output reaction function. Under the assumption that firms are allowed to trade pollution permits, the aforementioned mechanism breaks down. In equilibrium any increase in the number of permits by the regulator in the home or the foreign country will affect both firms' marginal costs of abatement in the same way. That is, because any change in the number of allowances affects the equilibrium permits price which is common for both firms. Hence, an increase in $\overline{e}$ reduces P^{ε} which implies lower marginal costs of abatement for both firms. As a result domestic and foreign output increase at the same level. Indeed, as we show later in the analysis allowing trade of permits between the two firms eliminates the commitment mechanism available to the governments, although in equilibrium no permits trade between firms takes place!

Part (b) of Proposition 1 determines the effect that a change in the number of permits issued by a government has over the domestic (foreign) firm's equilibrium net supply of permits. In particular, these effects are given as $\frac{\partial e^*}{\partial \overline{e}} = -\frac{\partial e^*}{\partial \overline{E}} = \frac{1}{2\gamma}$. These results depend crucially on part (a) of Proposition 1 which implies that equilibrium outputs will be the same across firms and the market clearing condition (3). In terms of our modelling these partial effects can be interpreted as follows: When the domestic government decides to issue a permit which allows an extra unit of emissions then the domestic firm increases (reduces) the number of permits sold to (purchased from) the rival by $\frac{1}{2\gamma}$ units of emissions. Hence, the rival is allowed to increase pollution by $\frac{1}{2}$ units of emissions, since it can only use a proportion γ of the permits bought. At the same time, pollution emitted by the domestic firm when a new permit is issued increases by $\frac{1}{2}$ units of emissions. As it can be seen in equation (A2) given in the Appendix, equilibrium supply of permits is given from $e^* = -E^* = \frac{\overline{e}-\overline{E}}{2\gamma}$, thus γ affects the volume of traded permits. In case that pollution is perfectly transboundary ($\gamma = 1$) then if $\overline{e} \neq \overline{E}$ the number of traded permits is minimized, while when the pollutant tends to be purely local ($\gamma \to 0$) then this number becomes very large. More precisely, the number of traded permits is a decreasing function of γ. However, pollution in each country remains constant regardless of the level of γ.

2.1.2 Asymmetric Cases-Extensions

It would be interesting to examine whether the previous results would hold if we relax some assumptions or we allow for asymmetries between the two countries and firms. Specifically, we may consider abatement cost or pollution damage functions across the two countries. Moreover, extensions that would simulate more realistic examples would be the existence of a larger number of firms and/or countries. Without loss of generality the previous analytical setting can accommodate such extensions and can replicate the major result so far. That is, in the case of tradable permits, the strategic effect has a positive sign. The following proposition brings into line these suggestions:

Proposition 2*:*

(a) In case where the abatement cost and of pollution damage functions differ across firms and countries, then the strategic effect has a positive sign, i.e., $\frac{\partial X^*}{\partial \bar{e}} > 0$.

(b) If we assume $n > 2$ *countries,* $m > 2$ *firms competing in the global market, where at least one firm is located in each country, then under symmetry of all other things, the strategic effect has a positive sign, i.e.,* $\frac{\partial x^{i*}}{\partial \bar{e}^t} = \frac{\partial x^{j*}}{\partial \bar{e}^t} > 0$.

(See proof in the Appendix■)

Proposition 2 is a generalization of Proposition 1. It simply states that if we allow for different abatement cost functions among firms, different assimilative capacities of the environments in the two countries, i.e., the damages caused from the same pollutant in the two countries differ, if the number of countries and firms is higher than two, the basic implication remains unaffected. The strategic effect remains positive. Put it differently, when the governments decide about the optimal number of permits, they face an additional disincentive to issue additional permits. This in turn has significant implications in terms of welfare as we will show later on in the analysis.

The driving forces of this result follow those of Proposition 1. In brief, the common permits price faced by the firms equalizes the marginal costs of abatement across firms. Given this, the problem reduces to a simple Cournot game with symmetric firms, implying equal equilibrium output levels by the firms in stage 2. Any parametric change, e.g., changes in the number of permits in one country, leads to a new equilibrium where outputs are still equal. Further extensions beyond Proposition 2 may be examined. However, introducing several asymmetries such as differences in abatement technologies require for a more elaborated analysis. The existence of different abatement technologies in the two countries, i.e., different θ's, breaks down the symmetry argument presented so far. Once more the permits price is common for the firms, implying that changes in the endowments of permits in one country affect the permits price equally. Yet, this is not sufficient to yield $q_x(\cdot) = Q_X(\cdot)$, which in turn implies that equilibrium outputs in stage 2 differ. Both, $q_x(\cdot)$ and $Q_X(\cdot)$, fall when the number of permits increases by one government, but not at the same level. As a result the output reaction function shift outwards asymmetrically.

Whether both equilibrium outputs increase or not, depends on the level of the change in the number of permits and on the slopes of the reaction functions. Nonetheless, the most likely scenario suggests that the strategic effect maintains its positive sign.

3 Welfare Effects

In this section we examine the welfare effects of environmental regulation, i.e., of pollution permits, by the two rival governments. In the analysis we retain the assumption of a perfectly symmetric international duopoly model. Before, however, proceeding to the welfare effects of our analysis, it is enlightening to introduce the welfare effects of two polar cases and see where does our scenario lie. The two polar cases are: first, the cooperative equilibrium where the two governments commonly decide the level of pollution and then distribute permits to the firms and, second, the Nash equilibrium where each government unilaterally decides on the level of regulation without allowing trading of permits between the firms. For clarity, we will denote our case as a "semi-cooperative" equilibrium since the governments issue permits unilaterally but allow a cross border trading of permits between firms.

3.1 The Cooperative Equilibrium

Given that the two exporting countries are not consumers of the exporting good, the consumers surplus is captured exclusively by the changes in the damage function in the welfare analysis. Welfare in the home is determined as follows:

$$w = \pi - d(\overline{e} + \gamma \overline{E}). \tag{4}$$

In the cooperative solution we assume that the governments agree prior to stage 1 to maximize the joint welfare, i.e., $w+W$. In stage 1 of the game the governments maximize $w+W$ with respect to the number of issued permits in each of the two countries. Permits are then distributed to the firms. In this way, we derive two first order conditions, one with respect to $\overline{e}$ and one with respect to $\overline{E}$. However, it is straightforward that $\overline{e}$ and $\overline{E}$ are linearly dependent. In other words, the governments can determine a specific level of pollution that they are willing to accept and then distribute the total number of permits to the two firms. Since the model is fully symmetric we assume that the total number of permits is equally distributed between their two exporting firms. The first order conditions for the sum of welfare levels in the two countries are the following:[9]

$$\begin{aligned}
\frac{d(w+W)}{d\overline{e}} &= \underbrace{\frac{\partial \pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}} + \frac{\partial \pi^*}{\partial e^*}\frac{\partial e^*}{\partial \overline{e}}}_{\text{zero (F.O.Cs)}} + \underbrace{\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}}}_{\substack{\text{general}\\ \text{strat. eff.}\\ \text{(-)}}} + \underbrace{\frac{\partial \pi^*}{\partial \overline{e}}}_{\substack{\text{relaxing}\\ \text{regul benefit}\\ (+)}} + \\
& \underbrace{\frac{\partial \pi^*}{\partial P^{\varepsilon *}}\frac{\partial P^{\varepsilon *}}{\partial \overline{e}}}_{\substack{\text{permits price}\\ \text{effect}\\ \text{(ambiguous sign)}}} - \underbrace{\frac{\partial d}{\partial \overline{e}}}_{\substack{\text{regul.}\\ \text{benefit}\\ (+)}} + \underbrace{\frac{\partial \Pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}} + \frac{\partial \Pi^*}{\partial E^*}\frac{\partial E^*}{\partial \overline{e}}}_{\text{zero (F.O.Cs)}} + \underbrace{\frac{\partial \Pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}}}_{\substack{\text{general}\\ \text{strat. eff.}\\ \text{(-)}}} + \\
& \underbrace{\frac{\partial \Pi^*}{\partial P^{\varepsilon *}}\frac{\partial P^{\varepsilon *}}{\partial \overline{e}}}_{\substack{\text{permits price}\\ \text{effect}\\ \text{(ambiguous sign)}}} - \underbrace{\frac{\partial D}{\partial \overline{e}}}_{\substack{\text{regul.}\\ \text{benefit}\\ (+)}} = 0\ . \qquad (5)
\end{aligned}$$

and

$$\overline{e}^* = \overline{E}^* \qquad (6)$$

The asterisks denote equilibrium values and below each term we indicate the partial effect of $\overline{e}$ on the corresponding variables and its sign. The first two terms in (5) are zero by the firm's maximization problem. We call the third term "general strategic effect" and it corresponds to the strategic effect introduced in the previous section, $\frac{\partial X^*}{\partial \overline{e}}$, multiplied

[9] The second order conditons of the problem are satisfied since the problem is concave.

by $\frac{\partial \pi^*}{\partial X^*}$. The overall sign of this term is negative and compels the regulator towards a tighter standard. This term in a Barrett (1994) setting appears to be positive, in which case each regulator is forced to unilaterally set laxer standards, thus leading firms towards a race to the bottom. The next term, with a positive sign, represents the direct benefit from relaxing regulation, since the higher the standard is, the lower is the marginal cost of abatement. However, this comes at the cost of environmental deterioration represented by the sixth term. The permits price effect is ambiguous. In case the domestic firm is a permits seller (buyer) then the sign will be negative (positive) as $\frac{\partial \pi^*}{\partial P^{e*}} = e^*$. The partial effects for the foreign country follow similarly.

Using the properties of the model and the results so far, e.g., the permits price effects cancel out since they have an opposite sign, $\frac{\partial X^*}{\partial \overline{e}} = \frac{\partial x^*}{\partial \overline{e}} > 0$ by Proposition 1 and $\frac{\partial \pi^*}{\partial X^*} = \frac{\partial \Pi^*}{\partial x^*}$ due to symmetry, equation (5) is simplified to:

$$\frac{d(w+W)}{d\overline{e}} = 2\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}} + \frac{\partial \pi^*}{\partial \overline{e}} - \frac{\partial d}{\partial \overline{e}} - \frac{\partial D}{\partial \overline{e}} = 0. \tag{7}$$

Equation (7) determines the level of permits issued in the domestic country such that the sum of the two countries welfare is maximized. It can be shown that the cooperative scenario that we propose is not restricting in the sense that it can be modified and yield the same outcome. In particular, even if trade of permits is not allowed between firms the cooperative solution in equilibrium yields the same level of regulation and thus the same welfare level.[10]

3.2 The Nash Equilibrium

We now introduce the second polar case, where both governments set environmental standards unilaterally without allowing firms to exchange permits. This is the core of the eco-dumping models presented above. In order to adjust our analytical specification to these models, we assume that firms cannot trade permits in stage 2, i.e., $e = E = 0$.

[10]The proof can be provided upon request by the authors.

Thus, firms maximize their profits only with respect to their outputs. A well established result from the strategic environmental policy literature is that $\frac{\partial X^*}{\partial \overline{e}} < 0$.[11] Therefore, the welfare maximizing conditions are the following:

$$\frac{dw}{d\overline{e}} = \underbrace{\frac{\partial \pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}}}_{\text{zero (F.O.Cs)}} + \underbrace{\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}}}_{\substack{\text{general} \\ \text{strat. eff.} \\ (+)}} + \underbrace{\frac{\partial \pi^*}{\partial \overline{e}}}_{\substack{\text{relaxing} \\ \text{regul benefit} \\ (+)}} - \underbrace{\frac{\partial d}{\partial \overline{e}}}_{\substack{\text{regul.} \\ \text{benefit} \\ (+)}} = 0 \tag{8}$$

for the domestic government and due to symmetry, for the foreign government it is implied by equation (6).

Comparing the permits reaction functions of the domestic government in the two polar cases given by equations (7) and (8), we observe that in the Nash equilibrium there is a bias in favor of laxer regulation (higher $\overline{e}$), since contrary to the cooperative case, the general strategic effect is now positive forcing the governments to relax further the regulation level. At the same time, when governments set their standards unilaterally they do not take into account the externality caused from their own firms' emissions to the rival country strengthening this outcome. As a result a race to the bottom occurs in environmental policy setting among the rival governments, which lowers welfare in comparison to the cooperative case.

Another important implication is that even if we assume that in the Nash case gov-

[11] In order to determine this sign we can differentiate the profit maximizing conditions of the firms with respect to outputs and solve for the comparative statics:

$$\begin{bmatrix} \pi_{xx} & \pi_{xX} \\ \Pi_{Xx} & \Pi_{XX} \end{bmatrix} \begin{bmatrix} dx^* \\ dX^* \end{bmatrix} = \begin{bmatrix} -\pi_{x\overline{e}} d\overline{e} \\ 0 \end{bmatrix}$$

$\Leftrightarrow$

$$\begin{bmatrix} \frac{dx^*}{d\overline{e}} \\ \frac{dX^*}{d\overline{e}} \end{bmatrix} = \begin{bmatrix} \pi_{xx} & \pi_{xX} \\ \Pi_{Xx} & \Pi_{XX} \end{bmatrix}^{-1} \begin{bmatrix} -\pi_{x\overline{e}} \\ 0 \end{bmatrix}$$

$\Leftrightarrow$

$$\begin{bmatrix} \frac{dx^*}{d\overline{e}} \\ \frac{dX^*}{d\overline{e}} \end{bmatrix} = \begin{bmatrix} -\frac{\Pi_{XX}\pi_{x\overline{e}}}{\pi_{xx}\Pi_{XX} - \pi_{xX}\Pi_{Xx}} \\ \frac{\Pi_{Xx}\pi_{x\overline{e}}}{\pi_{xx}\Pi_{XX} - \pi_{xX}\Pi_{Xx}} \end{bmatrix}.$$

Given the signs of the second partial derivatives of profits we obtain that $\frac{dx^*}{d\overline{e}} > 0$ and $\frac{dX^*}{d\overline{e}} < 0$.

ernments do not act strategically,[12] i.e., environmental regulation is set at the Pigouvian level, regulation will be laxer than the one in the cooperative scenario, resulting to lower welfare levels in both the exporting countries.

3.3 The Semi-Cooperative Equilibrium

Now we analyze the welfare effects of issuing pollution permits in the case of the "semi-cooperative" equilibrium, whereby the governments select unilaterally the level of regulation but then the firms are allowed to exchange pollution permits at a given price. The welfare maximizing conditions are the following:

$$\frac{dw}{d\overline{e}} = \underbrace{\frac{\partial \pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}} + \frac{\partial \pi^*}{\partial e^*}\frac{\partial e^*}{\partial \overline{e}}}_{\text{zero (F.O.Cs)}} + \underbrace{\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}}}_{\substack{\text{general}\\ \text{strat. eff.}\\ (-)}} + \underbrace{\frac{\partial \pi^*}{\partial \overline{e}}}_{\substack{\text{relaxing}\\ \text{regul benefit}\\ (+)}} + \underbrace{\frac{\partial \pi^*}{\partial P^{\varepsilon *}}\frac{\partial P^{\varepsilon *}}{\partial \overline{e}}}_{\substack{\text{permits price}\\ \text{effect}\\ \text{(ambiguous sign)}}} - \underbrace{\frac{\partial d}{\partial \overline{e}}}_{\substack{\text{regul.}\\ \text{benefit}\\ (+)}} = 0 \ . \tag{9}$$

and the one given in equation (6) due to symmetry.

Note that since $\overline{e}^* = \overline{E}^*$, then by using equation (A2) in the Appendix $e^* = -E^* = \frac{\overline{e}-\overline{E}}{2\gamma} = 0$. In this case the permits price effect, i.e., the term $\frac{\partial \pi^*}{\partial P^{\varepsilon *}}\frac{\partial P^{\varepsilon *}}{\partial \overline{e}} (= e^* \frac{\partial P^{\varepsilon *}}{\partial \overline{e}})$ is zero. Hence, the equation (9) can be rewritten as follows:

$$\frac{dw}{d\overline{e}} = \frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}} + \frac{\partial \pi^*}{\partial \overline{e}} - \frac{\partial d}{\partial \overline{e}} = 0. \tag{10}$$

[12] This term is attributed to Uplh (1996) and implies that the governments set the general strategic effect equal to zero when they maximize welfare.

Comparing the modified equation (10) to (8) we observe that in the former there is a bias towards tighter regulation because the general strategic effect has a negative sign. This implies that in the semi-cooperative equilibrium regulation will be tighter and thus pollution in the two countries will be lower. A double benefit appears in this case. On the one hand, environmental degradation is dampened due to stricter regulation, and on the other hand, the two firms coordinate and produce lower output increasing so the market price and thus increasing their profits. This result remains unaffected even if we assume that at Nash the governments act non-strategically, in which case the strategic effect is zero.

Comparing the modified equation (10) to (7) we directly observe that in the latter case regulation is tighter. The reason is twofold: first that the general strategic effect in the cooperative equilibrium is twice as strong as in the case of the semi-cooperative equilibrium. Second in the cooperative case the governments take into account the cross border externality caused from pollution.

The following proposition summarizes the ranking of the three pollution equilibria and equilibrium welfare levels:

Proposition 3: *The ranking of equilibrium pollution and welfare levels in the three different scenarios is:* $\overline{e}^*_{Cooperative} < \overline{e}^*_{Semi-cooperative} < \overline{e}^*_{Nash}$ *and* $w^*_{Cooperative} > w^*_{Semi-cooperative} > w^*_{Nash}$.

Intuitively, in the cooperative equilibrium we maximize $w + W$. Therefore, the domestic country's welfare equals $(\frac{w^*+W^*}{2})_{Cooperative}$ when $\overline{e}^* = \overline{E}^*$. Since in the other two equilibria $\overline{e}^*$ is higher and welfare is a concave function of regulation, then regulation is set above the optimal level. This implies that $w + W$ is lower and in turn $w^*_{Semi-cooperative} = (\frac{w^*+W^*}{2})_{Semi-cooperative} > w^*_{Nash} = (\frac{w^*+W^*}{2})_{Nash}$.

The ranking of welfare is an important feature proposed in this study. It simply states that a Pareto superior outcome in terms of welfare can be achieved if the governments act unilaterally but allow cross border trading of permits between the firms compared to the case where they do not. Naturally, a question that arises from the analysis is that since the governments can agree to accept trade of permits, why don't they agree to a cooperative solution which maximizes their joint welfare? The answer to it is based on the sustainability issue. On the one hand, in the cooperative game, there is always an incentive for the governments to break up the agreement. Each government knows that in the cooperative equilibrium it can benefit if it deviates unilaterally so that its own firm gains a greater market share. This outcome becomes likelier as the coalition consists of a large number of participants.

On the other hand, the semi-cooperative equilibrium is sustainable. Both governments do not have an incentive to deviate unilaterally from the equilibrium level. If we assume that there exists a pre-stage level where the governments decide whether or not to accept permits issued in the rival country, then it can be shown that it is a dominant strategy to accept permits issued in the rival country regardless of what that country does. If, hypothetically, the foreign country announces that permits issued in the home country are not accepted, the home country should still accept permits from abroad. To understand this we should once more focus on stage 1 of the game where the level of regulation is determined. From equation (A2) we know that the domestic firm buys permits from its foreign counterpart only if $\overline{e} < \overline{E}$. The governments anticipate this in stage 1. So, they assign a positive probability to that the domestic firm will buy permits from the foreign one when they select the level of regulation, because each government does not observe the rival's choice. Hence, the objective welfare functions for the domestic and the foreign governments will be consisted by a weighted sum of the welfare functions in the two cases (semi-cooperative and Nash). As a result the domestic government will achieve higher welfare as regulation will be tighter in both countries. The mechanism proposed in this paper continue to apply, though a bit moderated.

What the paper neglected so far are the welfare effects in ROW and hence, in global welfare. If ROW is negatively affected from the pollution caused in the two exporting countries then by all means ROW is benefited when the exporting countries allow the trade of permits. Yet, this does not mean that the citizens will be better off. Since the citizens in ROW are the consumers of the product, they will be damaged when permits are tradable as the price will be higher. Which of the two effects will prevail is uncertain and depends on the selected functions. If the pollutant is very injurious then welfare in ROW will be higher in the semi-cooperative than the Nash scenario and the reverse. Using a similar rationale global welfare implications follow.

4 The Role of Market Power

To this point we assumed a competitive permits market where for a given market clearing price P^{ε}, firms in stage 2 of the game decide, among other things, on the number of permits to trade, i.e., to buy from (sell to) the rival. Here on this assumption is relaxed. In particular, we consider the case whereby firms can influence the permits price when they select their desired number of permits to trade. If so, then in stage 2 of the game, firms no longer are price takers in the permits market. This non-competitive specification, however, creates analytical complexities which affect the clarity of the results. For this we adopt specific linear functional forms already used in the relevant literature to facilitate the analysis. Thus, we assume that the inverse demand function of the consumers in the third country is $P(x, X) = B - x - X$, where B is the demand intercept. The inverse demand function implies that the good is homogenous (x and X are perfect substitutes). In the same spirit we assume that θ, $\gamma = 1$, $c(x) = cx$, $q(a) = \frac{1}{2}ga^2$ and that the damage from pollution is represented by $d(\overline{e} + \overline{E}) = \frac{1}{2}k(\overline{e} + \overline{E})^2$. Moreover, k, g and c are positive scalars. In the Appendix of the paper we set out the competitive, non-market power, solution of the linear specification, to which we compare the results of the market power scenario.

The assumption firms possessing market power in the permits market, implies that the firms do not know how their decision regarding the supply of permits affects the demand function of the rival and the price of permits. To facilitate the analysis we introduce the "implicit" demand functions for permits. The use of this term refers to the marginal utility obtained by each firm from buying one permit. Here, the marginal utility of every additional permit equals to the reduction of the marginal cost of abatement. Hence, the implicit demand for permits for the domestic firm is $P^{\varepsilon} = g(x - \overline{e} + e)$. The sign in front of e is positive. Recalling that when $e < 0$ the firm demands permits it follows that the demand function has a negative sign. Given this, the derivatives $\frac{\partial P^{\varepsilon}}{\partial e}, \frac{\partial P^{\varepsilon}}{\partial E} = g$ are calculated by the firms when they select the supply of permits. The maximization problem that the firm faces is:[13]

$$\begin{aligned} & \max_{x,P^{\varepsilon}} \pi \\ \text{subject to } e + E &= 0. \end{aligned} \tag{11}$$

The first order conditions with respect to output remain unchanged. Substituting the constraint into the objective function and differentiating with respect to x and P^{ε} we obtain the first order conditions for the domestic firm:

$$\left\{ \begin{array}{c} \frac{d\pi}{dx} = B - c - 2x - X - g(x - \overline{e} + e) = 0 \\ \frac{d\pi}{dP^{\varepsilon}} = -E - \frac{\partial E}{\partial P^{\varepsilon}} P^{\varepsilon} - g(x - \overline{e} - E)\frac{\partial E}{\partial P^{\varepsilon}} = -E - \frac{P^{\varepsilon}}{g} + (x - \overline{e} - E) = 0 \end{array} \right\}. \tag{12}$$

where $\frac{\partial E}{\partial P^{\varepsilon}} = \frac{1}{g}$. Solving simultaneously (12) with the corresponding foreign ones and using the equilibrium condition for the permits market given by (3) we obtain the equilibrium outputs, supply of permits and permits price, as a function of the domestic and foreign number of permits issued by the governments:

$$\left\{ \begin{array}{c} x^{**} = \frac{2(2+g)(B-c)+g[(5+2g)\overline{e}-\overline{E}]}{2(3+g)(2+g)} \\ X^{**} = \frac{2(2+g)(B-c)+g[(5+2g)\overline{E}-\overline{e}]}{2(3+g)(2+g)} \\ e^{**} = -E^{**} = \frac{(\overline{e}-\overline{E})}{2(2+g)} \\ P^{\varepsilon **} = \frac{g[2(B-c)-3(\overline{e}+\overline{E})]}{2(3+g)} \end{array} \right\}. \tag{13}$$

[13]This methodology was first introduced by Hahn (1984) to model a permits market where a single firm possesses market power.

Comparing the stage 2 equilibrium values in (13) to those in (A4) given in the Appendix, i.e., the market power versus non-market power, yields an important result. The equilibrium values of permits supply (demand) are lower than in the case where the firms possess market power. This is due to the fact that $\frac{\partial E}{\partial P^{\varepsilon}} = \frac{1}{g} > 0$. This denotes the market power of the domestic firm and implies that a possible increase in the permits price P^{ε} lowers the foreign demand for permits. This reduces the amount of permits sold, while the opposite holds in case the domestic firm is an importer of permits. On the one hand the higher price yields higher profits, while on the other hand, a higher price implies lower exports which reduces the revenues. Hence, these two opposing forces must be balanced by the firms. As a result, the supply of permits is reduced so that the domestic firm exercises its market power over the foreign firm's demand and vice-versa.

In the case of non-market power (directly follows from Proposition 1) the derivative of the supply of permits e with respect to the number of permits issued by the governments $\overline{e}$ and $\overline{E}$ is $\frac{de^*}{d\overline{e}} = \frac{1}{2}$ and $\frac{de^*}{d\overline{E}} = \frac{1}{2}$, respectively. These results imply that for every permit issued, half of it is sold to the rival firm. Hence, we concluded that relaxing regulation would affect both firms' marginal cost of abatement equally, eliminating the incentive for the strategic use of regulation. Allowing firms to exercise market power in the permits market the corresponding derivatives become $\frac{de^{**}}{d\overline{e}} = \frac{1}{2(2+g)} > 0$ and $\frac{de^{**}}{d\overline{E}} = -\frac{1}{2(2+g)} < 0$, which are smaller in absolute terms than $\frac{1}{2}$. This implies that an increase in $\overline{e}$ will create an incentive to the domestic firm to sell a proportion of these permits, yet this proportion is lower than half of the quantity issued. This is in line with the results proposed by Malueg and Yates (2009) and Lange (2008) who illustrated that a multilateral oligopoly in the permits markets restricts the volume of trade and leads to an inefficient outcome.[14] In other words, the marginal costs of abatement, are now affected asymmetrically when the endowments of allowances change in the two countries. For every additional permit issued by a government the firm uses a proportion above 50% for increasing production

[14] In these studies the authors introduce supply function equilibria to deal with the issue of market power of firms in permits markets.

and the rest for selling its allowances to the rival firm, which in turn can increase its own production. Since the derivative is lower than half, when the domestic (foreign) government relaxes regulation for the firm located in that country, it decreases the marginal cost of abatement for both firms. The decrease for the firm that is located in this country, is greater in absolute terms than the one of the rival. As a result, two opposing forces appear concerning the output of the rival firm. First, a lower marginal cost of abatement implies higher output. Second, the reduction in marginal cost of abatement appears to be greater for the domestic firm and thus domestic output increases more than the foreign one. Consequently, a negative effect appears on the foreign output through the reaction function of output which is negatively sloped. The net effect is negative as suggested by the derivative $\frac{dX^{**}}{d\bar{e}} = -\frac{g}{(2+g)(3+g)} < 0$, obtained after differentiating foreign output in (13) with respect to the amount of permits issued in the home country. This is due to the fact that the second effect prevails to the first one.

A direct implication carried out from the aforementioned analysis is that the strategic effect is negative which implies that the governments have the incentive to relax the regulation level below the first best (Pigouvian) level. However, this incentive is aggravated when permits are non-tradable (i.e., they take the form of a binding emission standard for the firm). The implications concerning welfare are significant since the intensity of the prisoners dilemma in the governments game, when permits are tradable, is mitigated such that it leads to increased welfare levels in both countries, compared to the non-tradable permits scenario. This, as well as, a welfare ranking across the polar cases are provided explicitly in the following proposition:

Proposition 4*:*

(a) Welfare with market power < Welfare with no market power.

(b) Allowing for market power in the permits market, Proposition 3 is replicated.

(See proof in the Appendix■)

The main implication reflected by Proposition 4 is that the welfare ranking within the different scenarios is not affected by the introduction of market power in the permits market. We do, however, understand that if the permits price is not set exogenously to the firms, the efficiency of the semi-cooperative scenario is reduced. The driving force of this outcome is that the sign of the strategic effect is reversed. Despite this outcome, the semi-cooperative scenario still yields a Pareto superior outcome both in terms of pollution and welfare compared to the case suggested in the eco-dumping models. As a result, all the benefits and possible implications of such a scenario continue to apply.

5 Conclusion

Our aim in this paper was to investigate if and how, the introduction of tradable permits in a model of strategic environmental policy could alter the standard result in the literature, namely: in an oligopolistic international market structure with firms competing a-là Cournot, each government engaging in international competition has a unilateral incentive to set the environmental policy level below the first best. We show that in the case where the firms do not have market power in the permits market, allowing them to exchange permits, reverses the sign of the strategic effect from negative (in the case of non-tradable permits) to positive although in equilibrium no trade of permits takes place!

This indicates a reversal of the incentives of the involved governments towards not fully internalizing the externality caused from pollution. In our model, both governments appear to be unwilling to assist the rival firm to increase output through lowering the marginal cost of abatement ensured by the possibility of buying permits. This implies that both governments are negative towards selecting lax regulation levels, over-internalizing pollution. The introduction of tradable permits can be viewed alternatively as the introduction by the governments of a more complex strategy. Such a strategy suggests that the choice of the optimal level of regulation in each country should be a function of the choice of the rival government. When, for instance, $\overline{e} > \overline{E}$ then the domestic government allows the domestic firm to increase pollution above the binding level of $\overline{e}$ by $\frac{\overline{e}-\overline{E}}{2\gamma}$ and the reverse. This alternative scenario yields the same properties as the "semi-cooperative" one suggested in this study when the permits market is competitive.

What are the implications of this result? The appearance of a disincentive to relax the country-specific environmental policy, leads governments towards tightening their standards. Hence, the prisoners dilemma at the government level is reversed, which results in higher welfare levels in both exporting countries compared to the case where the governments do not allow the firms to exchange permits. However, equilibrium welfare remains lower than the corresponding cooperative one. These results are still valid when firms exercise market power in the permits market. The introduction of market power causes welfare losses without altering the welfare ranking between the three scenarios. The main benefit of the alternative scenario suggested in this paper, i.e., choosing the number of permits unilaterally but allowing firms exchanging them, is that it is feasible. Put it differently, the governments would not have an incentive to deviate from this strategy.

Possible extensions of our model could concern the welfare effects after the introduction of moderations or asymmetries in the model as suggested in section 2. If we allow for a larger number of players (firms and governments) in the game our welfare implications remain robust. Yet, allowing several asymmetries, as for instance, that the two countries have different scalars determining the marginal cost of abatement or marginal damage functions a more elaborated analysis is demanded and it is left for future research. In particular, the welfare effects are uncertain. If the range of these asymmetries is insignificant or rather small, we expect our main results to hold. If not, then possibly one of the two countries will be harmed affecting so the sustainability issue.

Appendix

Proof of Proposition 1:

(a) We use the first order conditions of (2) and (3) to solve the game in stage 2. Note that $q_x = \theta q_a$ and $q_e = \gamma q_a$. After some simple rearrangements we have $q_x = \frac{\theta}{\gamma} q_e$. Using the second equation in (2) gives $P^{\varepsilon} = q_e$. Now $\pi_x = 0$ and $\Pi_X = 0$ can be rewritten as:

$$\left\{ \begin{array}{c} \pi_x = r_x - c_x - \frac{\theta}{\gamma} P^{\varepsilon} = 0 \\ \Pi_X = R_X - C_X - \frac{\theta}{\gamma} P^{\varepsilon} = 0 \end{array} \right\} \tag{A1}$$

We observe that the term $\frac{\theta}{\gamma} P^{\varepsilon}$ is common for both firms. Since the problem is symmetric we can solve the two first order conditions, $\pi_x = 0$ and $\Pi_X = 0$, separately from the rest and we obtain that in stage 2 equilibrium outputs are equal, i.e., $x^* = X^*$. Having that P^{ε} is common for both firms $\Rightarrow \frac{\partial q_x}{\partial \bar{e}} = \frac{\theta}{\gamma} \frac{\partial P^{\varepsilon}}{\partial \bar{e}} = \frac{\partial Q_X}{\partial \bar{e}} < 0$. Hence, ceteris paribus a change in the domestic level of regulation affects equally the domestic and foreign marginal cost of abatement which implies $\frac{\partial x^*}{\partial \bar{e}} = \frac{\partial X^*}{\partial \bar{e}} > 0$ Q.E.D.

(b) Since P^{ε} is common for both firms, from the other set of equations in (2), $\pi_e = 0$ and $\Pi_E = 0$, is implied that abatement cost functions are the same across firms $\Rightarrow q_e = Q_E \Leftrightarrow \theta x - \bar{e} + \gamma e = \theta X - \overline{E} + \gamma E$. Recalling that $x^* = X^*$ and using the market clearing condition (3) we obtain:

$$e^* = -E^* = \frac{\bar{e} - \overline{E}}{2\gamma}. \tag{A2}$$

Differentiating (A1) we get $\frac{\partial e^*}{\partial \bar{e}} = -\frac{\partial e^*}{\partial \overline{E}} = \frac{1}{2\gamma} > 0$. Q.E.D.

Proof of Proposition 2:

(a) If abatement cost functions are different across firms and everything else is symmetric $\Rightarrow q(\cdot) \neq Q(\cdot)$. From (2) it follows that $P^{\varepsilon} = q_e = Q_E$ which implies that the profit maximizing conditions with respect to output are the same as in (A1). Since everything else is symmetric it follows that equilibrium outputs in stage 2 are equal. Using $\frac{\partial q_x}{\partial \bar{e}} = \frac{\partial Q_X}{\partial \bar{e}} = \frac{\theta}{\gamma} \frac{\partial P^{\varepsilon}}{\partial \bar{e}} < 0 \Rightarrow \frac{\partial x^*}{\partial \bar{e}} = \frac{\partial X^*}{\partial \bar{e}} > 0$ Q.E.D.

The fact that the damage functions are different across countries, i.e., $d(\cdot) \neq D(\cdot)$ should not affect firms' first order conditions in stage 2 since the damage functions do not appear in the firms' objective functions. Hence, Proposition's 1 implications remain unchanged Q.E.D.

(b) Firms' first order conditions are in total $2 * m$ and are given by:

$$\left\{ \begin{array}{c} \pi_x^i = r_x^i - c_x^i - q_x^i = 0 \\ \pi_e^i = P^{\varepsilon} - q_e^i = 0 \end{array} \right\}, \tag{A3}$$

where i describes a random firm, i.e., $i = 1, 2, ..., m$. From the second equation in (A3) we obtain that $P^{\varepsilon} = q_e^1 = ... = q_e^i = ... = q_e^m$. Using that $q_x^i = \theta q_a^i$ and $q_e^i = \gamma q_a^i \Rightarrow q_x^i = \frac{\theta}{\gamma} q_e^i \Rightarrow q_x^i = \frac{\theta}{\gamma} P^{\varepsilon}$. It follows that $\pi_x^i = r_x^i - c_x^i - \frac{\theta}{\gamma} P^{\varepsilon} = 0$. Since everything is symmetric stage 2 equilibrium outputs will be equal, i.e., $x^{i*} = x^{j*}$ where $i \neq j$. Using this and $\frac{\partial q_x^i}{\partial \bar{e}^t} = \frac{\partial q_x^j}{\partial \bar{e}^t} = \frac{\theta}{\gamma} \frac{\partial P^{\varepsilon}}{\partial \bar{e}^t} < 0 \Rightarrow \frac{\partial x^{i*}}{\partial \bar{e}^t} = \frac{\partial x^{j*}}{\partial \bar{e}^t} > 0$, where $i \neq j$ and t stands for a random country, i.e., $t = 1, 2, ..., n$ Q.E.D.

Stage 2 equilibrium for the linear specification case with no market power:

Solving simultaneously the system of equations given in (2) and the market clearing condition for permits given by equation (3) we obtain the equilibrium outputs, net supply of permits and permits price, as a function of the domestic and foreign total number of permits issued by the governments:

$$\left\{ \begin{array}{c} x^* = X^* = \frac{2(B-c)+g(\bar{e}+\overline{E})}{2(3+g)} \\ e^* = -E^* = \frac{\bar{e}-\overline{E}}{2} \\ P^{\varepsilon *} = \frac{2g[(B-c)-3(\bar{e}+\overline{E})]}{2(3+g)} \end{array} \right\}. \tag{A4}$$

We observe from (A4) that $\frac{dx^*}{d\bar{e}} = \frac{dX^*}{d\bar{e}} = \frac{g}{2(3+g)} > 0$.

Proof of Proposition 4:

(a) In the linear specification with market power, the derivatives of the terms that represent the market power with respect to P^{ε} are equal to zero. Algebraically these terms are represented by $\frac{\partial^2 E}{\partial P^{\varepsilon 2}} = \frac{\partial^2 e}{\partial P^{\varepsilon 2}} = 0$. Using (10) we illustrate that in equilibrium the number of issued permits in the case of market power is greater than the corresponding one in the case of non-market power. Since $\frac{dX^{**}}{d\bar{e}} = -\frac{g}{(2+g)(3+g)} < 0 \Rightarrow$ the general strategic effect is positive. Thus, a force towards laxer regulation is present. Using the same rationale as in Proposition 3 it follows that Welfare with market power < Welfare with no market power Q.E.D.

(b) From part (a) and Proposition 3 it follows that welfare in the cooperative case is higher than the one in the semi-cooperative case with market power. It remains to show that the latter is greater than the Nash welfare. For this it is sufficient to show that $\overline{e}$ is greater in the Nash case.

In order to solve for stage 2 outputs in the Nash case in the absence of tradable permits, we solve backwards. The initial equations are the same as in the linear specification case with the difference that now we set $e = E = 0$. Thus, in stage 2 firms have x and X as choice variables. Solving simultaneously the profit maximizing conditions with respect to outputs given in (2), we obtain equilibrium outputs in stage 2 as functions of $\overline{e}$ and $\overline{E}$:

$$x^{***} = \frac{(B-c)(1+g) + g(2+g)\overline{e} - g\overline{E}}{(1+g)(3+g)} \text{ and } X^{***} = \frac{(B-c+\theta)(1+g) + g(2+g)\overline{E} - g\overline{e}}{(1+g)(3+g)}.$$

Differentiating X^{***} with respect to $\overline{e}$ we have $\frac{\partial X^{***}}{\partial \overline{e}} = -\frac{g}{(1+g)(3+g)}$. Yet, $\frac{\partial X^{***}}{\partial \overline{e}} < \frac{\partial X^{**}}{\partial \overline{e}} \Rightarrow$ the general strategic effect is stronger in the Nash scenario than in the semi-cooperative $\Rightarrow$ regulation will be laxer in the first case Q.E.D.

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GC	1.2010	Cristina Cattaneo: Migrants' International Transfers and Educational Expenditure: Empirical Evidence from Albania
SD	2.2010	Fabio Antoniou, Panos Hatzipanayotou and Phoebe Koundouri: Tradable Permits vs Ecological Dumping