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On The Strategic Effect of International Permits Trading on Local Pollution: The Case of Multiple Pollutants

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Abstract

We introduce a model of strategic environmental policy where two firms compete à la Cournot in a third market under the presence of multiple pollutants. Two types of pollutants are introduced, a local and a transboundary one. The regulator can only control local pollution as transboundary pollution is regulated internationally. The strategic effect present in the original literature is also replicated in this setup. However, we illustrate that when transboundary pollution is regulated through the use of tradable emission permits instead of non-tradable ones then a new strategic effect appears which had not been identified thus far. In this case, local pollution increases further and welfare is lowered. We also provide evidence from the implementation of EU ETS over the pollution of PM_{10} and $PM_{2.5}$.

JEL classification: F12, F18, Q58.

Keywords: Environmental regulation, multiple pollutants, (non) tradable permits, strategic interactions.

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1 Introduction

There is a consensus among theorists, policymakers, and practitioners regarding the necessity to promote cooperation among individual countries to combat climate change and, in general, any international environmental problem in which a prisoner's dilemma situation applies. In practice the problem is complex due to the fact that concerns about competitiveness and carbon leakage co-exist. Despite the obstacles, small steps have been taken but a great deal still remains to be done. Many countries have signed the Kyoto protocol and other regional agreements that aim to fight transboundary pollution problems (United Nations, 1998). In December 2014 in the Lima United Nations conference, negotiators representing over 190 countries elaborated the elements of the new agreement, scheduled to be agreed upon in Paris in late 2015.[1] The intended national contributions will form the foundation for climate action post-2020 when the new agreement will be launched (United Nations, 2014).

In the specific context of curbing CO_2 emissions, most countries have put their faith in a combination of emission taxes, quotas, and tradable emission permits. Nonetheless, the optimal mode and level of regulation are debatable.[2] Moreover, who should bear the burden of environmental regulation is also questionable. Policymakers have expressed severe concerns regarding the loss of competitiveness as many firms are sensitive to environmental regulation and are thus footlose. Indeed, several European countries have been implementing carbon policies since the 1990s, and at the same time they have granted various forms of rebates to energy-intensive firms. A specific form of rebates is the free allocation of permits. For example, the European Commission decided to exempt from permit auctions the carbon-intensive and trade-exposed industries (Martin et al., 2014; Meunier et al., 2014).[3]

Following the prescription of cooperation many international programs have now been implemented regarding the regulation of CO_2. The most well-known example is the EU Emission Trading System (EU ETS) for CO_2 emissions which covers more than 11,000 power stations and manufacturing plants in the 28 EU member states as well as Iceland, Liechtenstein, and Norway. In total, the EU ETS limits around 45% of the total emissions in the participating countries (European Commission, 2013).

In reality CO_2 and other transboundary pollutants co-exist with other pollutants which affect the environment locally (or they are transboundary pollutants of a shorter range). Similarly to CO_2 regulation the governments tend to establish agreements for the local pollutants. To this end, different policy instruments have been used in various cases. An example is the 1999 Gothenburg

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[1] Lately, even the Pontiff is active on the issue. As John Vidal (2014) describes in The Guardian, Decemember 27: "*...pope's wish to directly influence next year's crucial UN climate meeting in Paris, when countries will try to conclude 20 years of fraught negotiations with a universal commitment to reduce emissions.*"

[2] Stern (2006) provides a general report on these issues. The interested reader may also refer to Weitzman (2007) for a critique of the Stern Review.

[3] The evidence, however, on the magnitude of the effect of climate policy over production or relocation decisions is mixed. In particular, Martin et al. (2014) do not testify that the UK Climate Change Levy caused output reductions or plant exit among treated firms. On the contrary, Wagner and Timmins (2009) and Hanna (2010), among others, argue that firms' choices are deterred by environmental regulatory stringency.

protocol that defines national emission ceilings for a number of pollutants. The protocol came into force on May 17, 2005 following two main provisions. Annex I determines the critical loads and levels and then Annex II sets emission ceilings for 2010 for four polluntants: sulphur, NOx, VOCs, and ammonia, while it was amended in 2012 to include national emission reduction commitments that should be achieved by 2020 and beyond (United Nations, 1999). Interestingly, a severe form of local pollutants that adversely affect human health-particulate matters (both PM_{10} and $PM_{2.5}$)- were not included in the initial amendments. The latter has been included in the revised version of the protocol signed in Geneva in May 2012 and defines emission reduction commitments for PM_{10} and $PM_{2.5}$ for 2020 and beyond, which are expressed as a percentage reduction from the 2005 emission level.

However, apart from the European air quality standards, EU individual governments are responsible for their own air quality policy and legislation. For example, the Environment Agency in the UK regulates the release of pollutants into the atmosphere that come from large and complex industrial processes. They also decide on the emissions generated from large-scale food processing factories and pig and poultry rearing activities. The Environment Agency works with local authories in England and Wales and their strategy sets air pollution standards in order to protect the environment, as well as people's health.

Our Contribution: The current paper aims to contribute in several directions. We establish a tractable analytical model where we assume that transboundary pollution is regulated internationally, while regulators control local pollution. More specifically, in a two-country, two-pollutants framework, we assume that local pollution is regulated through the use of emission standards, while for the transboundary pollution we examine two alternative policy instruments: non-tradable and tradable permits. These scenarios are consistent with the EU alternative regulations schemes; before and after the introduction of tradable permits in 2005. In this context, we aim to study whether local regulator-governments have an incentive to set more lenient environmental regulation in order to control local pollution so as to promote the exporting activity of polluting firms. The second objective is to examine whether the magnitude of this strategic incentive depends on the environmental policy instrument implemented for the regulation of the transboundary pollutant.

Our results suggest that there indeed exists a strategic effect in the multiple pollutants case. The most important finding, however, is that when transboundary pollution is regulated through the use of tradable permits then a regulator has a stronger incentive to relax regulation regarding local pollution compared to the case where transboundary pollution is controlled through the use of command and control. This implies that a stronger strategic distortion exists because of the presence of tradable permits which exacerbates the previously existing prisoner's dilemma. Put differently, we identify a channel which if not considered can lead to welfare losses. In the case where the permit price appears to be relatively high then its use may lead to a welfare improvement in this setup.[4]

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[4] A higher permit price may emerge from a possible withdrawal of permits. This was suggested by the European Commission and it is now being implemented. We discuss this in detail in section 4.

To support our theoretical results we then focus on several export sectors in the EU 28 countries that have participated in the EU ETS launched in 2005 and we observe that local pollution as expressed by concentrations of PM_{10} and $PM_{2.5}$, which, as discussed above, has been under the discretion of local regulators, initially increased, while both in non-export sectors and in sectors that are not participating in the EU ETS, the corresponding concentrations have decreased over time. To illustrate this, we provide some statistics that show the trend of the above local pollutants during the period 1990-2012 in the EU 28, which is then compared with the trend of the CO_2 in the same period.

The exemption of PM_{10} and $PM_{2.5}$ pollutants from the Gothenburg protocol provides us with the opportunity to isolate the effect that we are interested in. As our theoretical predictions and the anecdotal evidence seem to converge on the fact that regulation for these local pollutants was relaxed immediately after the imposition of the EU ETS, new policy implications arise. We caution that when governments are concerned about the competitiveness of their exporting sectors and sign agreements regarding international environmental problems they should not overlook the regulation of local pollutants.

Related Literature: The environmental policy as a means to affect the competitiveness of the regulated sectors has been well studied in the 'Strategic Environmental Policy' or 'Ecological Dumping' literature, established, among others, by Conrad (1993), Barrett (1994), Kennedy (1994), Rauscher (1994), Ulph (1996), and Neary (2006). A common suggestion in the latter 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 à la Cournot in world commodity markets in order to enhance their profits and maximize national welfare.[5] As a result a race to the bottom occurs, which is detrimental for welfare.[6]

Although very informative, these models assume that there exists only a single pollutant, local or transboundary. In reality, as previously discussed, many pollutants co-exist at the same time and their cleaning-abatement costs are characterized by economies or diseconomies of scope. In particular, if joint abatement creates synergies then the pollutants are considered as complements in the abatement process, while in the opposite case they are considered as substitutes.[7] The linkages arising in the presence of multiple pollutants, especially from a theoretical point of view, have been underinvestigated. Ambec and Coria (2013) analyze a mix of tax and permit policies under uncertainty and determine the optimal policy depending on the substitutability or complementarity

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[5] Empirical findings by Levinson and Taylor (2008), Ederington et al. (2005) and Fredriksson and Millimet (2002) attest this strategic interaction.

[6] Hamilton and Requate (2004) argue that when vertical contracts are allowed the optimal policy corresponds to the Pigouvian tax regardless of the mode of competition. In addition, Antoniou et al. (2013) show that the race to the bottom described in the strategic environmental policy literature may even be reversed if the two exporting countries are linked through a permits market.

[7] These potential synergies are often captured in studies as 'ancillary' benefits from the reduction of other pollutants (e.g., Burtraw et al., 2003; Groosman et al., 2011 and Finus and Rübbelke, 2013).

The interested reader may find several examples of substitutability or complementarity of pollutants in studies by Sigman (1996), Greenstone (2003), Gamper-Rabindran (2006), Ren et al. (2011), Holland (2012) and Agee et al. (2014).

of pollutants. Another significant theoretical contribution is the study by Moslener and Requate (2007) which derives the optimal abatement strategies in a dynamic multi-pollutant model. Such dynamic considerations are, however, orthogonal to the issues we address and our model therefore abstracts from those ones.

Our paper is a natural extension of the Strategic Environmental Policy literature under the presence of multiple pollutants. Our findings are in line with the current stream of the literature on the sign of the strategic effect. The added value of our results is that we illustrate how the presence of permits trading further enforce the strategic motive and may thus lead to lower welfare.[8] A recent work by Fullerton and Karney (2014), in a completely different framework, also stresses that the implementation of different policy instruments may yield different outcomes and highlights the necessity of joint regulation in the presence of multiple pollutants. An interesting feature identified in our study, missing from the existing theoretical papers, is the correlation of the abatement costs of different pollutants not only through the presence of synergies but also through an indirect channel; that is, the regulation of one pollutant affects output and this directly affects the abatement costs of the other pollutant.[9]

Organization of the paper: In section 2 the theoretical model is introduced. Then, in section 3 the comparative statics of the model are presented and, in section 4, the welfare analysis follows. In section 5 an application to the EU ETS is discussed. Finally, the last section concludes the paper. All proofs of the corresponding lemma and propositions are relegated to an appendix.

2 The Model

Consider, initially, a symmetric two-country, home and foreign, two-stage game. Each country is represented by a government and an exporting firm. When firms produce they emit two different pollutants, a local and a global one. The global pollutant is regulated through an international agreement which implies that the governments are not flexible regarding the regulation of this pollutant. The timing structure is as follows:

Stage 1: The governments move simultaneously and individually select regulation for the local pollutant, while for the global one they are restricted by an international agreement.

Stage 2: The firms compete à la Cournot in the world commodity market.

Since the focus of the analysis is on strategic trade, 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, without loss of generality, is normalized to zero.[10] Total revenue is $r(x, X)$, and we assume that

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[8] In a different setup Caplan and Emilson (2005) show that the use of permits both for a global and a local pollutant may lead to a Pareto superior welfare outcome. Moreover, Emilson and Zhu (2009) show that in the presence of multiple pollutants the pollution haven hypothesis is verified despite the presence of a permits market for the global pollutant.

[9] Holland (2012) in a different model also defines an output effect, which is unrelated to ours. Holland (2012) introduces pollution as an input and the output effect follows from the changes in the corresponding price of pollution. On the contrary, we model pollution as a public bad.

[10] All choice variables and functions of the domestic (foreign) country and firm are denoted by lower- (upper-) case

the two outputs are substitutes, $r_X < 0$. Production emits two pollutants, z_i where $i = 1, 2$. The pollutant z_1 denotes the local and z_2 a perfectly transboundary. Both are related to production through the following equation: $z_i = \theta_i x$, θ_i is a positive scalar. Let $\overline{e}_i$ denote the maximum cap of emissions of each pollutant in the home country. Both pollutants adversely affect residents in the two countries. The corresponding damage function and its properties are the following: $d(\overline{e}_1, \overline{e}_2 + \overline{E}_2 + \sum_{j=1}^{n} \overline{e}_j)$, where $\overline{e}_j$ denotes transboundary pollution from sector j, whereas $d_{\overline{e}_i}$, $d_{\overline{E}_2} > 0$, $d_{\overline{e}_i\overline{e}_i}$, $d_{\overline{E}_2\overline{E}_2} > 0$ and $d_{\overline{e}_i\overline{e}_{-i}}$, $d_{\overline{e}_1\overline{E}_2} \geq 0$. These conditions simply state that the damage is increasing and convex with respect to pollution. When the last two conditions are satisfied with equality the damage of pollution is separable across the two pollutants.

Following the relevant literature (Ambec and Coria, 2013) we allow each firm to have private abatement technology (a_i) for each pollutant, which allows adherence to the binding level of regulation set by the governments. Should the international agreement on the global pollution allow firms to trade permits they can increase pollution if they purchase permits from the permits market. For example, the home firm can increase (reduce) emissions above (below) $\overline{e}_2$, if it buys (sells) pollution permits from (to) its rival at a given price P^e, determined in the competitive permits market. The firm may decide to sell (purchase) an amount $e_2 > 0$ (< 0) of (over) its initially allocated permits $\overline{e}_2$, and thus reduce (increase) its emissions by e_2. Given the possibility to trade permits, abatement for each pollutant is $a_i = \theta_i x - \overline{e}_i + (e_i) \geq 0$. Note that for the local pollutant, permits trading is not allowed. The abatement cost is as follows:

$$ac(a_i, a_{-i}) = \sum_{i=1}^{2} c_i(a_i) + \gamma a_i a_{-i}.$$

The total abatement cost functions consist of two components. The first one is the sum of the direct cost of reducing emissions by a_i units for $i = 1, 2$. For this term we assume that $ac_{ia_i}(a_i) > 0$ and $ac_{ia_ia_i}(a_i) > 0$. Put differently, the abatement cost is increasing and convex. The last component of the abatement cost function captures the possible spillovers across abatement levels for the two different pollutants. When $\gamma < 0$ they are complements, while when $\gamma > 0$ they are substitutes in the cost functions. Thus, complementarity (substitutability) implies that for all abatement levels $a_1 > 0$ and $a_2 > 0$, the cost of joint abatement is lower (higher) than the cost of reducing the emissions of each pollutant separately. These synergies resemble the economies of scope in production resulting from producers mergers. In addition, we need to assume that $ac_{xx}(a_i, a_{-i}) \geq 0$ which implies $\gamma \geq -\frac{c_{1xx}(\cdot)+c_{2xx}(\cdot)}{2} \equiv \overline{\gamma}$. This assumption implies that the marginal costs with respect to output should be constant or increasing. Profits are defined as:

$$\pi = r(\cdot) - ac(\cdot) + P^e e_2. \tag{1}$$

Since in the two countries there is no consumption of the good, the changes in consumer surplus are captured exclusively by the changes in the damage function. Welfare in the home country is

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letters. Since the two firms (countries) in the main case are assumed to be symmetric, we only present the explicit variables and functions of the home firm (country).

defined by:[11]

$$w = \pi(\cdot) - d(\cdot). \tag{2}$$

We solve the problem backwards. Each firm maximizes its profits with respect to output, the corresponding abatement levels, and the number of permits it is willing to trade. Therefore, the maximizing problem of the firm is the following:

$$\begin{aligned} & \max_{x,a_i,e_2} \pi \\ \text{s.t. } a_i \quad = \quad & \theta_i x - \overline{e}_i + (e_i) \\ \Leftrightarrow \quad & \max_{x,e_2} \pi \end{aligned}$$

The first-order conditions for the two firms are:

$$\left\{ \begin{array}{c} \pi_x = r_x(\cdot) - ac_x(\cdot) = 0 \\ \Pi_X = R_X(\cdot) - AC_X(\cdot) = 0 \\ \pi_{e_2} = P^e + \frac{\partial P^e}{\partial e_2} e_2 - ac_{e_2}(\cdot) = 0 \\ \Pi_{E_2} = P^e + \frac{\partial P^e}{\partial E_2} E_2 - AC_{E_2}(\cdot) = 0 \end{array} \right\}. \tag{3}$$

The second-order conditions are satisfied since $\pi_{xx} < 0$, $\pi_{e_2 e_2} < 0$, $\delta^H \equiv \pi_{xx}\pi_{e_2 e_2} - \pi^2_{xe_2} > 0$ and $\Pi_{XX} < 0$, $\Pi_{E_2 E_2} < 0$, $\delta^F \equiv \Pi_{XX}\Pi_{E_2 E_2} - \Pi^2_{XE_2} > 0$. Moreover, $\pi_{xX} < 0$ and $\Pi_{xX} < 0$ ensure that the output reaction functions are downward sloping and are a strategic substitutability of outputs.

In the set of equations given by (3) we assume that $\frac{\partial P^e}{\partial e_2} = \frac{\partial P^e}{\partial E_2} = 0$ which implies that the firms act as price takers in the thick permits market. Indeed, the EU ETS scheme includes almost half of the EU's CO_2 emissions from 11,000 installations across all 28 member states.[12]

The equilibrium permit price, P^e, is the one that clears the permits market, that is,

$$e_2 + E_2 + \sum_{j=1}^{n} \varepsilon_j = 0, \tag{4}$$

where ε_j stands for the sales of permits of firms belonging to different sectors in the common permits market.

3 Comparative Statics

In this section we first present the results regarding the strategic effect in a general mode and then introduce a linear specification in order to go through the details of some extreme cases.

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[11] For simplicity it is assumed that permits are grandfathered to the firms so that welfare does not depend directly on permit revenues. This is consistent with the distribution mechanism adopted in the EU ETS during the first two phases.

[12] Price taking behavior in the permits market is a widely used assumption in the literature (Sartzetakis, 1997; Malueg and Yates, 2009; Meunier, 2011; Antoniou et al., 2014).

3.1 General Results

We examine the decisions made in stage 2 of the game and attain the comparative statics of a fully symmetric international duopoly. The comparative statics analysis focuses on the sign of the so-called 'strategic effect' that appears in eco-dumping models and leads to the prisoner's dilemma. The strategic effect can be described as the effect that home's environmental regulation has on the foreign firm's stage 2 equilibrium output, i.e., $\frac{\partial X^*}{\partial \bar{e}_1}$ or $\frac{\partial X^*}{\partial \bar{e}_2}$, where stars denote stage 2 equilibrium values. In models of standard strategic environmental policy with a unique pollutant the sign of each derivative separately is unambiguously negative. That is, an increase in the number of permits by one country lowers the marginal cost of abatement, and thus raises local output. The other country's output falls due to the reaction function of output. As in the current study we want to focus on a new strategic motive present due to the existence of the permits market for the transboundary pollutant, we need to distinguish between two alternative scenarios regarding the regulation of transboundary pollution:

Scenario 1 (NT) Transboundary pollution is regulated through the allocation of a fixed number of permits to each firm.

Scenario 2 (T) Transboundary pollution is regulated through the allocation of a fixed number of permits to each firm and the allowance to trade internationally.

Both scenarios above introduce a command and control approach for regulation with the difference being that in the second scenario firms are more flexible in the pollution they can emit since they can exchange permits. In order to make our point clear and comparable we assume that under both scenarios the regulator allocates the same amount of fixed permits. Everything being equal isolates the new strategic motive created by the presence of permit trading.

Since the regulators in the two countries are restricted by the international agreement regarding transboundary pollution they only have limited degree of freedom which translates to a unique choice variable, that is $\bar{e}_1$ and $\overline{E}_1$ respectively. The first necessary step toward our results is to determine of the strategic effect $\frac{\partial X^*}{\partial \bar{e}_1}$ in the two different scenarios and compare its magnitude. The following proposition summarizes this:

Proposition 1 *a) Under scenario 1,* $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} < 0$ *iff* $\gamma > -c_{1xx}(\cdot)$. *b) Under scenario 2,* $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{T} < 0$ *iff* $\gamma \in (-\gamma_1, \gamma_1)$.

From Proposition 1 (a) we observe that when command and control is used for regulating the transboundary pollutant the outcome is ambiguous and depends on the degree of complementarity. In particular, when the pollutants are substitutes in the cost functions ($\gamma > 0$) or independent ($\gamma = 0$) the strategic effect is always negative. Relaxing regulation of the local pollutant tends to decrease local marginal abatement costs and thus increase output. This in turn increases the abatement costs of the global pollutant. This is not sufficient to invert the sign of the strategic effect from negative to positive (see $\gamma = 0$). When $\gamma > 0$ the reduction of the aggregate marginal abatement costs is stronger because of the spillovers. When, however, the pollutants are complements ($\gamma < 0$) then the strategic effect is weakened for a relatively low degree of complementarity in absolute values. In case where this value equals the slope of the marginal abatement cost of the local pollutant, $-c_{1xx}(\cdot)$, the strategic effect is zero. In this particular case, there is no incentive for the regulator to distort regulation regarding the local pollutant as the lower marginal costs are then offset by the spillover effect. If the degree of complementarity exceeds this level then the strategic effect turns out to be positive. That is, the indirect effect attributed to the spillovers may exceed the negative direct effect on local marginal abatement costs following from a laxer standard. Therefore, in the presence of more than one pollutant it can be the case that the governments have an incentive to tighten regulation in order to enhance competitiveness, which is not possible under the standard eco-dumping models with a single pollutant (e.g., Barrett, 1994).

Another implication which follows from the proof for the sign of the strategic effect, yet is intuitively straightforward, is that without spillovers, when the slope of the direct marginal abatement cost for the transboundary pollutant (c_{2xx}) is infinite then the strategic effect tends to be zero. This describes a situation where there is no abatement technology available for the transboundary pollutant. Therefore, relaxing the local emission standard cannot increase production since production must adhere to the binding level of transboundary emissions.

Regarding the case where tradable permits are used instead of command and control, i.e., Proposition 1 (b), we infer that the sign of the strategic effect is also ambiguous. In particular, when the degree of complementarity or substitutability does not exceed in absolute value the squared root of the product of the slopes of the direct marginal abatement costs of the local and the global pollutant, i.e., $\gamma \in (-\gamma_1, \gamma_1)$, where $\gamma_1 = \sqrt{c_{1xx}c_{2xx}}$, the strategic effect has a negative sign. Put differently, a government has an incentive to relax environmental policy for the local pollutant for strategic purposes as long as the spillovers are rather low in any direction. If this is not the case then the strategic effect can be zero or can even turn out to be positive. The spillovers tend to mitigate the strategic effect, as the firm responds to changes in local pollution in two ways. First, it adjusts output in a similar way as in the non-tradable permits case and, second, decides on the volume of permit trading. The latter is determined from the restriction that the marginal abatement costs of the transboundary pollutant are fixed at the international permits price. As γ departs from zero the volume of permit trading adjusts such that the aggregate marginal costs increase relative to the case where $\gamma = 0$.

To provide a clear comparison of the two scenarios under study, we need to compare the slopes of the marginal abatement cost of the local and the transboundary pollutants. This comparison leads to the following corollary.

Corollary 1 *(a) If the slope of the marginal abatement cost of the local pollutant is higher than the slope of the marginal abatement cost of the transboundary pollutant, i.e.,* $c_{1xx} > c_{2xx}$, *then the sign of the strategic effect* $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^i$, *where* $i = NT, T$, *is as follows:*

<table>
<tr><td>γ</td><td colspan="5">$-\infty$ $\quad -c_{1xx}$ $\quad -\gamma_1$ $\quad 0$ $\quad \gamma_1$ $\quad +\infty$</td></tr>
<tr><td>NT</td><td>$+$</td><td>$-$</td><td>$-$</td><td>$-$</td><td>$-$</td></tr>
<tr><td>T</td><td>$+$</td><td>$+$</td><td>$-$</td><td>$-$</td><td>$+$</td></tr>
</table>

(b) If the slope of the marginal abatement cost of the local pollutant is lower than the slope of the marginal abatement cost of the transboundary pollutant, i.e., $c_{1xx} < c_{2xx}$*, then the sign of the strategic effect is:*

<table>
<tr><td>γ</td><td colspan="5">$-\infty$ $\quad -\gamma_1$ $\quad -c_{1xx}$ $\quad 0$ $\quad \gamma_1$ $\quad +\infty$</td></tr>
<tr><td>NT</td><td>$+$</td><td>$+$</td><td>$-$</td><td>$-$</td><td>$-$</td></tr>
<tr><td>T</td><td>$+$</td><td>$-$</td><td>$-$</td><td>$-$</td><td>$+$</td></tr>
</table>

From Corollary 1(a) we observe that when the two pollutants are complements and the degree of complementarity is $\gamma \in (-c_{1xx}, -\gamma_1)$, the strategic effect is negative under emission standards and positive under tradable permits. Put differently, for a relatively high degree of complementarity the incentive to relax regulation for strategic purposes appears only when a government implements non-tradable permits as a means of regulation. The opposite is true in the case where the slope of the marginal abatement cost of the local pollutant is lower than the corresponding slope of the transboundary pollutant, and the degree of complemetarity $\gamma \in (-\gamma_1, -c_{1xx})$ (Corollary 1(b)). In this case the incentive to relax regulation for strategic purposes is present only when a government imposes tradable permits to deal with the global pollutant. The intuition for this follows directly from the mechanics previously presented.

Another obvious difference between the two modes of regulation is that in the tradable permits case the strategic effect can be positive even in the case where the pollutants are substitutes. That is, the domestic government relaxes local pollution and this results in lower domestic production. When the degree of substitutability is sufficiently high a possible relaxation of the standard over the local pollutant decreases the direct marginal abatement cost but this results in a proportionally higher increase in total marginal costs, which in turn leads to a total decrease in output. This is due to the presence of a competitive permits market which invalidates the direct effect of regulation on marginal costs through the spillovers. Another difference between the two scenarios is obtained when there is no abatement technology available for the transboundary pollutant and at the same time no spillover effects exist. Contrary to scenario 1, now, the strategic effect remains negative since the firm can always buy permits from the permits market and skate over the previously binding levels of emissions.

Most likely, at least for intermediate values of γ, in both scenarios the strategic effect is negative. Therefore, even if an agreement is reached regarding the transboundary pollutant, there is an incentive to disregard the local pollutant. The results of Proposition 1 extend and generalize the major results of the strategic environmental policy literature under multiple pollutants. From a welfare analysis perspective it is worth comparing the two alternative scenarios after introducing multiple pollutants. Doing so we obtain interesting results that cannot be anticipated at first sight. The following proposition compares the strategic effects in the two cases:

Proposition 2 *Given that the stage 2 equilibrium outputs are the same across the two scenarios then for* $|\gamma| \leq \varepsilon$ *it follows that* $\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$.

Proposition 2 is very important as it provides a ranking of the strategic effects across the two scenarios and this in turn is the driving force for the welfare analysis to follow. Stage 2 equilibrium outputs are set at the same level so that the two strategic effects are comparable. This is redundant for any linear demand function and quadratic abatement cost function, which are the usual assumptions introduced in the relevant literature as the level of the strategic effect is independent from the output level. Proposition 2 implies that, for a given equilibrium, if the government in the home country relaxes the emission standard for the local pollutant then there is a reduction in the foreign firm's output more in the case where the transboundary pollution is regulated through a permits market rather than the use of emission standards. Therefore, the strategic motive is higher in the first case.

The rationale is as follows. When transboundary pollution is regulated through non-tradable permits then a higher level of local pollution decreases the marginal abatement costs and production tends to rise. Following this, marginal abatement costs of the global pollutant increase as the firm must abate more and this in turn reduces the magnitude of the initial effect. The component of the abatement costs that corresponds to the global pollutant acts as an automatic stabilizer. On the contrary, when tradable permits are implemented the increase in output following the higher standard for local pollution does not increase the marginal abatement costs of the global pollutant as these are fixed at the international permits price.

Combining Proposition 2 and Corollary 1 we obtain an interesting implication. Since the strategic effect is higher in the non-tradable permits case (Proposition 2) and for $\gamma > \gamma_1$ the strategic effect in the tradable permits case turns positive, then by continuity there must exist a $\overline{\gamma} \in (0, \gamma_1)$ for which the values of the two strategic effects are equalized. For a degree of spillovers larger than $\overline{\gamma}$ the ranking of the strategic effects reverses its order.

3.2 Robustness: The Role of γ under a Linear Specification

Here, we introduce a linear specification of the model to examine in detail what happens when the spillovers are significant. In the linear specification case we introduce explicit functional forms. In particular, we assume a linear inverse-demand function as $P = B - b\,(x + X)$ and a quadratic abatement cost function as $ac(a_i, a_{-i}) = \sum_{i=1}^{2} \frac{1}{2} g_i a_i^2 + \gamma a_i a_{-i}$. Note that B is the demand intercept, $b > 0$ the slope of the inverse demand and g_i the slope of each direct marginal abatement cost, while all the rest is the same as in the benchmark model. Replacing these functions in the corresponding formulas we get the strategic effects in the two scenarios as follows:

$$\begin{aligned}
\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} &= -\frac{b(g_1 + \gamma)}{(b + g_1 + g_2 + 2\gamma)(3b + g_1 + g_2 + 2\gamma)} \\
\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T} &= -\frac{b g_2 \left(g_1 g_2 - \gamma^2\right)}{(3b g_2 + g_1 g_2 - \gamma^2)\left[(b + g_1)\, g_2 - \gamma^2\right]}
\end{aligned} \tag{5}$$

Comparing the two effects in (5) we obtain the following proposition:

Proposition 3 *If* $\gamma \in (\max\{-g_1, -g_2\}, \overline{\gamma})$ *then* $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{T}$.

Generally interpreted, Proposition 3 states that for moderate values of γ the results presented thus far are not altered. In particular, the difference in the strategic effects under tradable and non-tradable permits is always negative as long as the degree of complementarity does not exceed in absolute terms the slope of any of the two direct marginal abatement costs. When the degree of spillovers is rather small there are two effects following a laxer local standard affecting the level of the strategic effect. The direct marginal abatement cost is reduced but the marginal abatement cost of the transboundary pollutant tends to increase when standards are used while it is zero when permits are implemented. Since in any scenario the first effect is stronger than the latter the result is a decrease in total marginal abatement costs. Therefore, the domestic firm's output tends to increase. Contrary to that, when tradable permits are implemented, the increase in output as a response to the relaxed policy for the domestic pollutant does not have secondary effects through the marginal abatement costs of the transboundary pollutant because these are tied down by the permits price. In this case, no automatic stabilizers are present, which implies that the strategic effect is even more negative. Due to the fact that the indirect effect tends to increase the total marginal abatement costs in scenario 1, the strategic effect is greater compared to scenario 2.

When the two pollutants are complements, or the degree of substitutability is relatively low, the ordering of the strategic effects in the two scenarios does not change. The spillover effect tends to affect the difference between the two strategic effects because in the tradable permits case the firm reacts to the policy change through its decision regarding permits, reducing the magnitude of the effect of the change in regulation over the overall marginal abatement costs. For intermediate values of γ the ordering of the strategic effects does not change as the effects described above prevail. When the degree of substitutability, however, takes relatively high values, i.e., $\gamma > \overline{\gamma}$ this ordering is reversed. Now, if the domestic regulator relaxes regulation for the local pollutant then foreign output decreases more under scenario 1 compared to scenario 2. In this case the regulator's incentive to relax local regulation in order to gain a market share is dampened when tradable permits are implemented.

4 Welfare Effects

So far we have analyzed the sign of the strategic effects in the two scenarios and their relative magnitude. In the original eco-dumping literature the presence of the strategic effect in both exporting countries is detrimental for welfare. Both countries are involved in a prisoner's dilemma where both exporters produce too much output and emit too much pollution. Therefore, we shall expect that the higher this effect in absolute terms the higher the welfare losses.

To set this formally we introduce the welfare maximization problem of the regulator in the home country. In order to make the results of the two scenarios comparable and abstract from any other effects we need to *assume* that the level of the transboundary pollution is exactly the same across the two scenarios.[13] In any case the regulator has as a unique choice variable the level of the local pollutant. The welfare maximization problem translates to:[14]

$$\left(\frac{dw}{d\bar{e}_1}\right)^i = \underbrace{\left(\frac{\partial\pi^*}{\partial x^*}\frac{\partial x^*}{\partial\bar{e}_1} + \frac{\partial\pi^*}{\partial e_2^*}\frac{\partial e_2^*}{\partial\bar{e}_1}\right)}_{=0\ \text{(FOCs)}} + \underbrace{\frac{\partial\pi^*}{\partial\bar{e}_1}}_{\substack{\text{abatement effect}\\ \text{(MC)}}} + \underbrace{\frac{\partial\pi^*}{\partial X^*}\frac{\partial X^*}{\partial\bar{e}_1}}_{\text{strategic effect}} - \underbrace{\frac{\partial d}{\partial\bar{e}_1}}_{\substack{\text{regulation benefit}\\ \text{(MD)}}} = 0,\ i = NT, T. \tag{6}$$

The second-order condition is satisfied from concavity. Applying the envelope theorem, the terms in the parenthesis are equal to zero. The third effect corresponds to the decrease in abatement costs when regulation is relaxed, while the next one indicates how the strategic effect affects profits. The last term denotes the benefits from regulation. In a context where the regulator uses environmental policy only to deal with the externality, i.e., non-strategically (NS), the first-order condition is reduced to the Pigouvian rule where the marginal cost of abatement should be equal to the level of the marginal damage, $\left(\frac{\partial\pi^*}{\partial\bar{e}_1}\right)^{NS} = \left(\frac{\partial d}{\partial\bar{e}_1}\right)^{NS}$. When, however, the regulator acts strategically (S), a bias in favor of laxer regulation appears due to the strategic effect. As a result a government has an incentive to increase local pollution for trade purposes, i.e., $(\bar{e}_1)^S > (\bar{e}_1)^{NS}$.

Given the previous assumption that the level of transboundary pollution is the same across the two scenarios it follows that, *ceteris paribus*, in the absence of the strategic effect the two scenarios in terms of welfare are equivalent. That is, the permits price and the marginal abatement cost of the transboundary pollutant must be equal. This marks a benchmark point in order to focus on the strategic effect and its implications for welfare. The following lemma compares the two scenarios in terms of pollution in equilibrium:

Lemma 1 *Given the equivalence of pollution across the two scenarios, when the governments act non-strategically and Proposition 2, then in the strategic game equilibrium pollution is higher in scenario 2 compared to scenario 1.*

Lemma 1 states that the presence of a permits market for the transboundary pollutant leads to higher pollution as a result of laxer regulation compared to the case where that pollutant is controlled directly through command and control. This implies that equilibrium outputs will be higher. This result is expected to hold true for any spillover as long as the ranking of the strategic effects does not change. A direct implication of Lemma 1 is the following proposition which provides a welfare ranking across the two alternative policy scenarios:

Proposition 4 *The resulting equilibrium welfare under scenario 2 is lower than the corresponding one of scenario 1 for* $|\gamma| \leq \varepsilon$, *i.e.,* $\left(w^S\right)^T < \left(w^S\right)^{NT}$

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[13] On average the CO_2 emissions in the EU 27 countries excluding Romania, Bulgaria, and Malta increased by 1.9% between 2005 and 2007 (European Commission, 2008)

[14] Here, we implicitly assume that the government does not consider any permit price effects as this is expected to converge to zero when regulation for a single sector is relaxed.

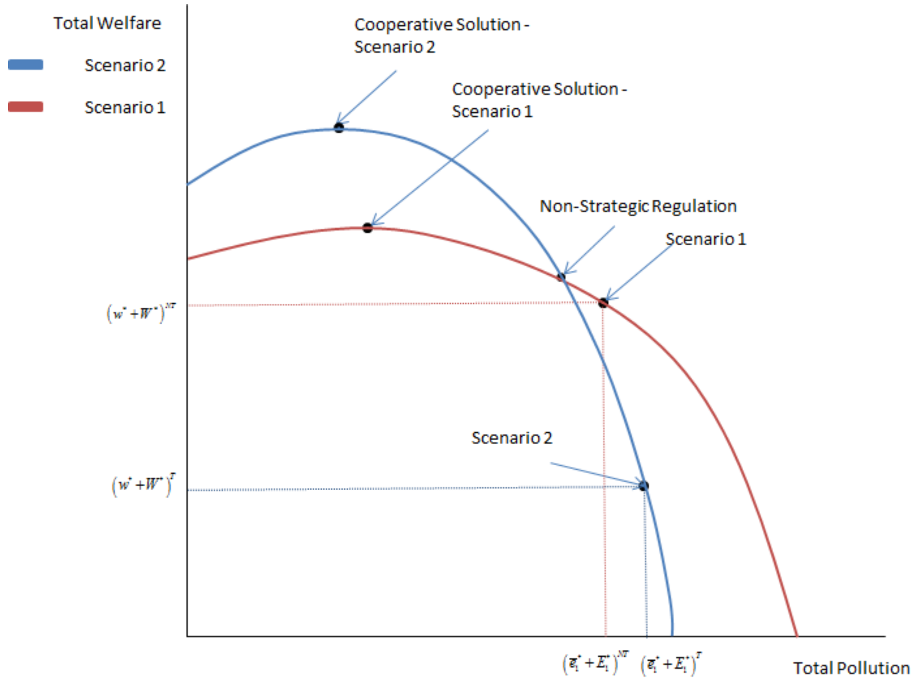

Figure 1: Aggregate welfare levels under tradable and non-tradable permits

Proposition 4 defines the bottom line of our results. In particular, when transboundary pollution is regulated through the use of tradable permits we end up with welfare losses compared to the case where each country directly regulates pollution through command and control. To understand the driving forces of this result we introduce Figure 1.[15] Aggregate welfare levels are represented for each scenario as a function of aggregate local pollution. These are concave functions and we observe that the cooperative solution in the tradable permits case leads to higher welfare compared to the non-tradable permits case. Therefore, a supranational regulator would have an incentive to reduce pollution further because the total marginal abatement cost is higher now due to the fact that the permit price is fixed at the Pigouvian level. The resulting welfare, however, is now higher because stricter regulation tends to reduce the marginal abatement cost of the transboundary pollutant and the firms become permit sellers.

Moving to the right from the non-strategic regulation level, in Figure 1, the ranking of aggregate welfare levels across the two scenarios is reversed. As is shown in the proof of Proposition 4 the critical point is to determine that at the non-strategic node the slope of the joint welfare function is larger in absolute terms in the tradable permits case compared to the non-tradable permits one. This combined with Lemma 1 implies that relaxing regulation decreases aggregate welfare less under scenario 1 vis-à-vis scenario 2. That is, an increase of aggregate pollution decreases relatively more the total marginal abatement cost in scenario 2 which leads to excess competition among firms and lower profits. In addition to that, the firms must pay in order to buy the corresponding number of

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[15] The point of intersection in Figure 1 denotes the non-strategic case. The permits price is such that the marginal abatement costs are equivalent across the two scenarios in this case.

permits. Using the resulting strategic effects from Proposition 3, we infer that the non-cooperative equilibrium under scenario 2 implies higher pollution compared to scenario 1. Therefore, aggregate welfare is clearly lower in scenario 2 and, due to symmetry, the same holds for each country's welfare.

From the analysis above a ranking of the equilibrium pollution levels and the equilibrium welfare levels follows immediately:

Corollary 2 *For moderate values of γ, i.e., $|\gamma| < \varepsilon$, the ranking of equilibrium pollution and welfare levels is: $(e+E)^C < (e+E)^{NS} < (e+E)^S$ and $(w+W)^C > (w+W)^{NS} > (w+W)^S$ under both senarios.*

The comparison of the equilibrium welfare levels shows that even though the government has an incentive to impose lax environmental regulation for the local pollutant in order to improve competitiveness, this instrument leads to a Pareto inferior outcome in terms of welfare. These outcomes are a natural extension of the results provided by Ulph (1996) for the multiple pollutants case and the intuition follows along the same lines.

Changes in the Permit Price

The analysis and the discussion of our results regarding welfare are based on the fact that the two scenarios are equivalent in terms of welfare when the two governments act non-strategically. For this to be true, it is implicitly assumed that the permit price adjusts accordingly. However, it is not necessary to believe that this is indeed true in a complex world. In reality this would require perfect information and knowledge of all markets and their interrelations such that the designers issue the proper number of permits. Therefore, it is worth considering what the implications are and how the results of Proposition 4 change as we agitate the permit price away from the one that corresponds to the non-strategic case, i.e., $P^e \neq P^{eNS}$.

To do so we introduce Figure 2 which summarizes the results based on a linear variation of our model. The two solid curves simply replicate the previous analysis. The two dashed curves represent two alternative cases where the permit price is different to the one that corresponds to the non-strategic case. In particular, for a higher permit price, i.e., $P^e > P^{eNS}$, aggregate welfare under scenario 2 shifts upwards for every level of aggregate emissions. On the contrary, aggregate welfare is lower when $P^e < P^{eNS}$. Though a higher permit price increases the total marginal abatement costs of the firm, aggregate welfare is higher because the firms increase their abatement level and profitably sell permits to the other sectors, while at the same time competition is softened. Hence, a double dividend is present for the firms, which results in higher profits. The opposite happens when permit prices decline. That is, a lower permit price reduces total marginal abatement costs and thus firms tend to increase production. The firms purchase permits which results in tighter competition and lower profits.

Given these, it follows that when $P^e > P^{eNS}$ then scenario 2 may welfare dominate scenario 1. Despite the fact that under scenario 2 regulation is too lax due to the stronger strategic effect

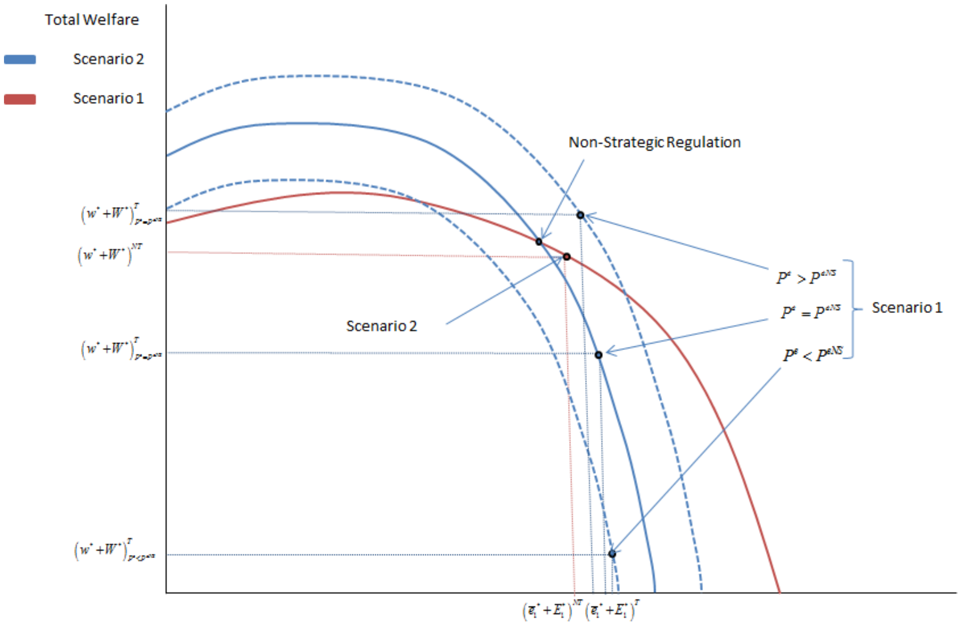

Figure 2: Aggregate welfare levels under tradable and non-tradable permits: Changes in permits price

relative to scenario 1, the positive effect of the higher permit price may outweigh the negative effect created by the race to the bottom. However, it must be noted that the higher the permit price is, the stricter the level of regulation and vice-versa. On the other hand, when $P^e < P^{eNS}$, scenario 2 is clearly detrimental for welfare compared to scenario 1 since the lower permit price is supportive of the existing negative strategic effect. Given that in the EU emissions trading scheme permit prices were very low we may conjecture that the introduction of tradable permits was indeed welfare reducing.

5 The EU ETS and Local Pollution

In this section we aim to exploit the data provided from the survey of the European Environment Agency (EEA) at the industry level for the EU 28 countries regarding the levels of several local pollutants across the time period spanning within 1990-2012. Given the predictions of our theory we expect that the introduction of a permits market would lead, *ceteris paribus*, to an increase in local pollution. The introduction of the EU Emissions Trading System (EU ETS) fits the theory presented above since during Phase I (2005-2008) the emission allowances were distributed through grandfathering, according to the previous reported emissions of the participating industries. That is, the target of the regulator for the CO_2 emissions should be the same between the years prior to the introduction of the EU ETS in 2005 and the following years.

The main focus of the paper is theoretical, and thus this section can be viewed only as a natural experiment regarding the verification of the theoretical predictions of our model. Initially,

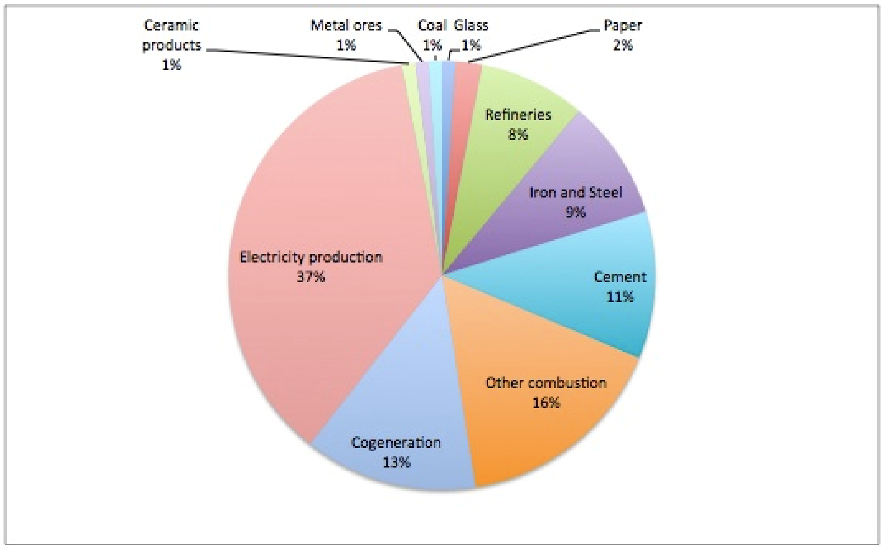

Figure 3: Sectors participating in the EU ETS during 2008-2012.

it is useful to identify the participating sectors. In Figure 3 it can be observed that most of the allowances were distributed to electricity producers and combustion industries, followed by iron and steel, cement, and refineries.

From the analysis of the previous section it follows that the level of permit prices also plays a key role in determining the optimal level of local pollution. In particular, our calculations for the linear specification suggest that the permit price and local pollution are negatively related when the spillovers are relatively small. In reality, however, regulation regarding local pollution rarely adjusts, while permit prices are highly volatile and vary on a daily basis. The reader can view our theoretical results from a long-term perspective. In Figure 4 we introduce the graph regarding the evolution of permit prices. Two different lines are represented since allowances are traded in future markets where promises must be fulfilled at different time periods. The price of permits was at relatively high levels in 2005 while thereafter for the next two years it followed a decrease. In 2008 the price increased again to a level close to the 2005 levels.

Toward the end of that period the permit price dropped, once more opening a discussion within the EU commission as to whether to withdraw a significant amount of permits. As published in the Financial Times on January 24, 2013 (see Clark et al., 2013): "*Connie Hedegaard, the EU climate commissioner, said the price collapse should serve as a 'final wake-up call' for both member states and the parliament.'The recent events show that something has to be done urgently', she said, and urged support for a proposal to postpone auctions of 900m carbon permits while discussions get under way on a more fundamental fix.*" A temporary withdrawal was indeed approved. However, the effectiveness of this measure on permit prices remains questionable. According to our theoretical results a higher permit price results in higher welfare as exporting firms coordinate on lower production levels while simultaneously earning windfall profits from permit trading. Therefore, our policy prescriptions sourcing from the theoretical model are fully aligned with the intentions of the

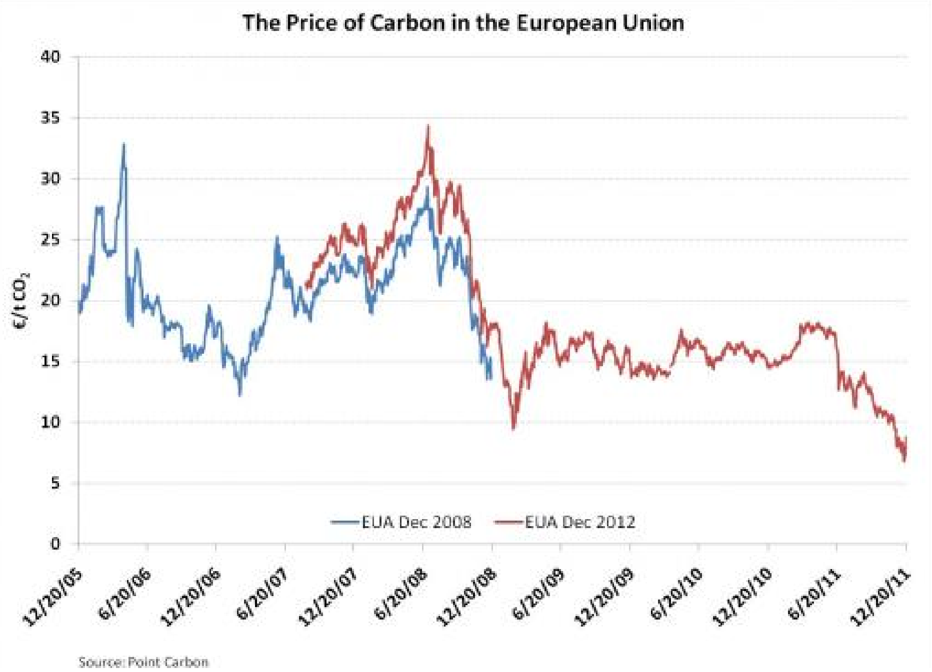

Figure 4: Changes in the permits price over the period 2005-2011 (Source: Point Carbon)

European Commission to raise the carbon price, despite the fact that this suggestion was opposed by the individual governments.

This section is interesting when we focus on the year 2005 where the EU ETS is introduced and results in a switch of regimes in the regulation of CO_2. At the same time Annex I of the Gothenburg protocol was applied and this creates a unique opportunity to identify how the regulation of local pollution responded to this switch of the regulatory regime. To relate the information relegated above to our theory we focus on local pollution as described by the pollutants PM_{10} and $PM_{2.5}$ by several sectors introduced in figures 5-6. The interesting feature that these pollutants share is that they were initially exempted from the Gothenburg protocol. This in turn implies that the regulation of these pollutants has been under the discretion of local authorities. The top two graphs in each figure ((a) & (b)) present the emissions generated by industries that participate in the EU ETS, while the bottom graphs ((c) & (d)) refer to non-participants. Also, the left-hand side graphs ((a) & (c)) show the emissions generated by industries that have significant exporting activity, while in the right-hand side graphs, ((b) & (d)), we observe the corresponding emissions of non-export-oriented industries. The five different sectors introduced here are both export-oriented and participate in the EU ETS: Cement, Combustion: Non-ferrous metals, Combustion: Chemicals, Aluminium and Solid fuels & other energy industries. More precisely, the exports of the EU countries as a percentage of the world exports are 47% for the combustion of chemicals, 43% for food processing, beverages, tobacco, 40% for aluminium, 34% for non-ferrous metals, 28% for cement, and 16% for solid fuels.[16]

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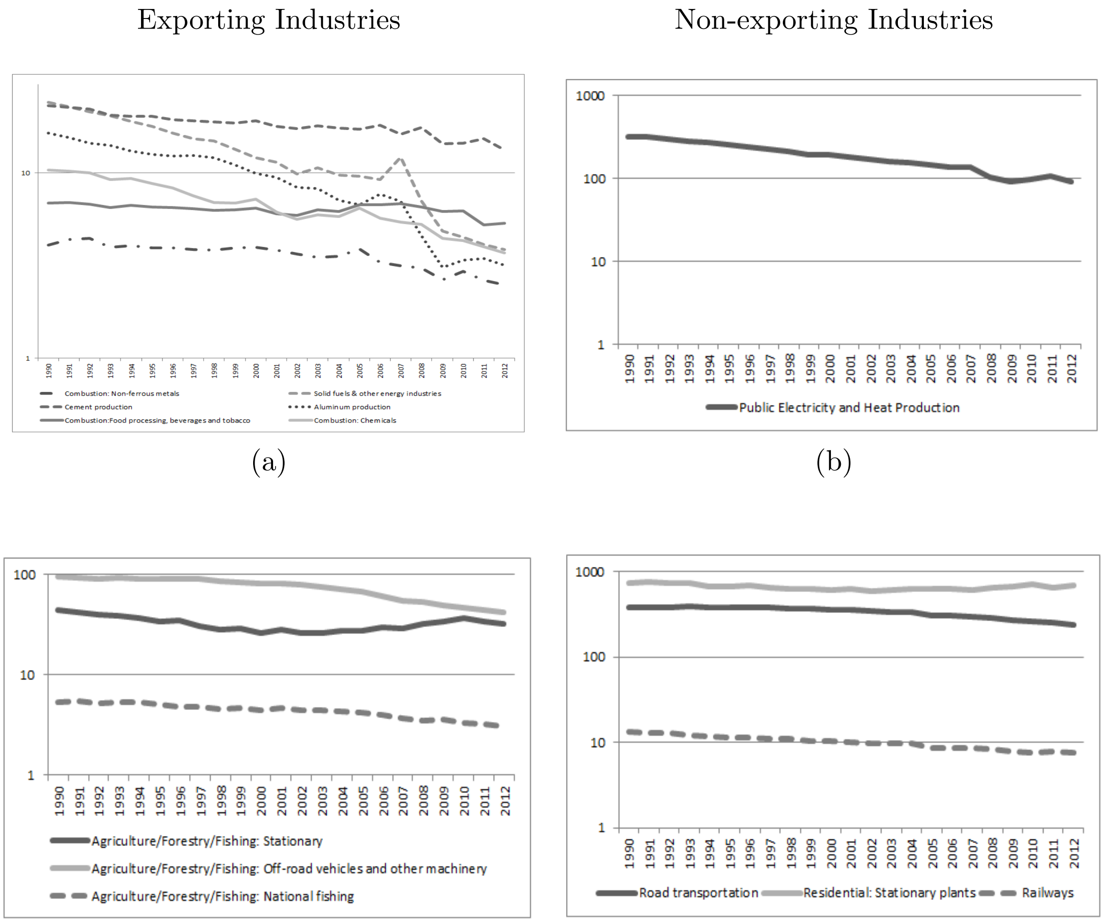
[16] The data are taken from the UN Comtrade database, apart from the export percentage of the solid fuels which was taken from the International Trade Centre. All that data refer to the exports of 2011.



Exporting Industries

Non-exporting Industries

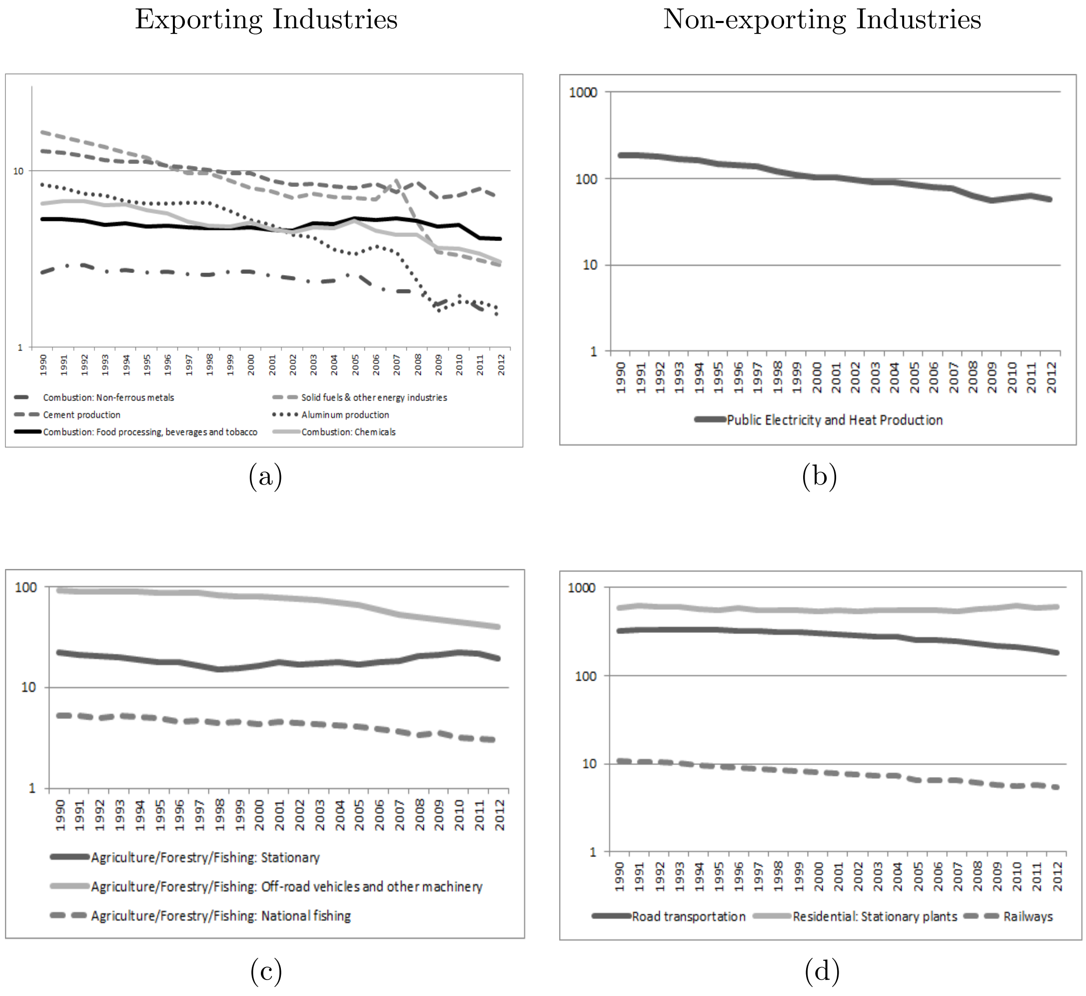
(a) (b)

(c) (d)

Figure 5: EU28 Air pollutant emissions, PM10 - Gg (1000 tons), (Logarithmic scale)

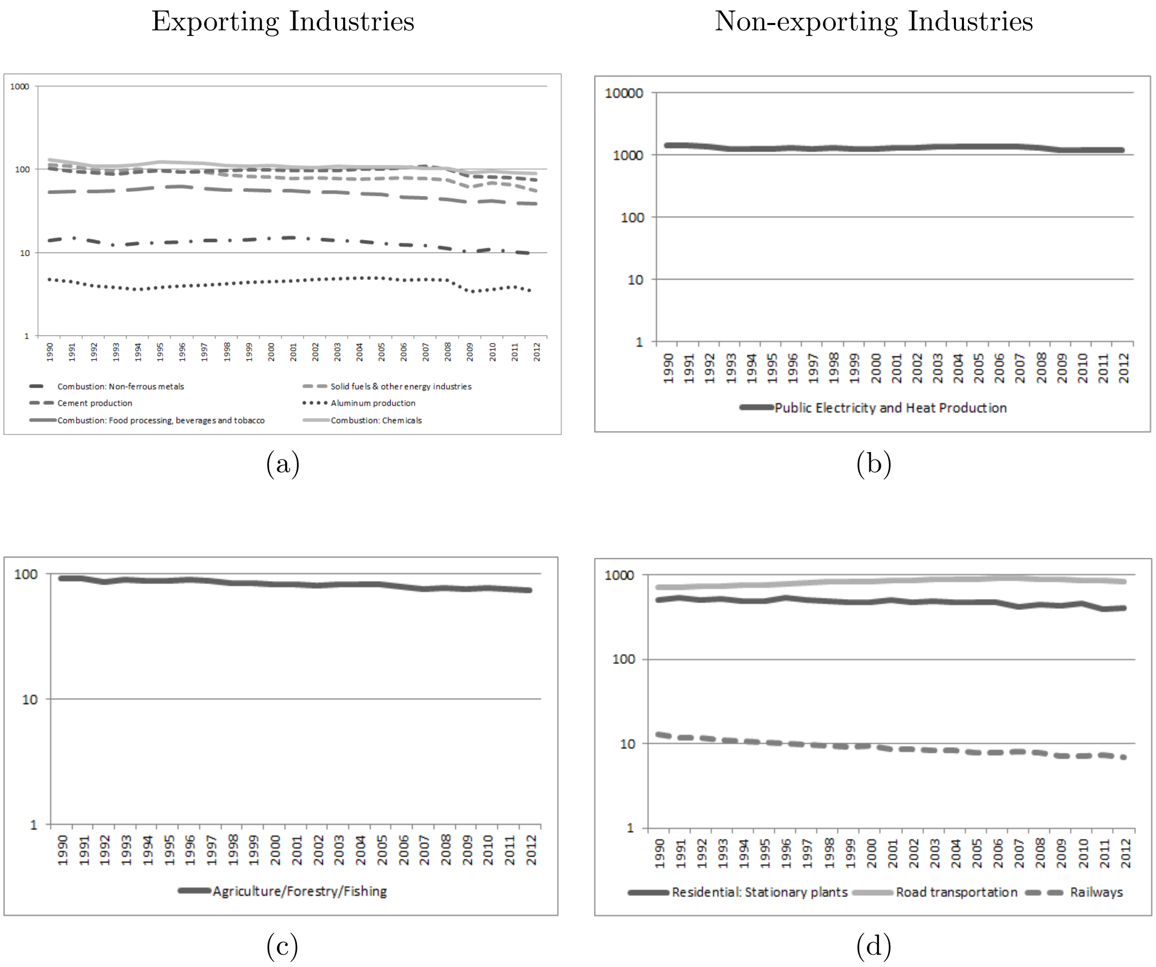
These percentages show that the above sectors have significant exporting activity. The most polluting sector that participates in the EU ETS but is not considered to be export-oriented is Public Electricity & Heat Production. As an example of an exporting sector that does not participate in the EU ETS, we present all the activities related to Agriculture/Forestry/Fishing. Finally, the three non-participants and non-export-oriented sectors presented here are the Residential Sector and the emissions from Road Transportation and Railways. In Figure 7, we place the emissions of CO_2 generated by every single sector mentioned above.

From figures 5 to 6, regarding the level of local pollution from the exporting sectors, presented in graphs (a), we can see that the overall trend since 1990 is decreasing. Around the period when the EU ETS was introduced, this trend changed: in most of the examples there is an increase in the level of local pollutants which lasts until the economic turmoil of 2008. In other words, it can be observed that the introduction of the EU ETS was followed by an inverse U-shaped trend in the level of local pollution. The increase in pollution after the introduction of the EU ETS may have been strengthened by the decrease in permit prices. The economic turmoil in 2008 decreased economic



(a) (b) (c) (d)

Figure 6: EU28 Air pollutant emissions, PM2.5 - Gg (1000 tons), (Logarithmic scale)



(a) (b)

(c) (d)

Figure 7: EU28 Air pollutant emissions, CO2 -Tg (million tons), (Logarithmic scale)

activity and as a result the level of pollution decreased in most cases, which once more decreased permit prices. The argument becomes even stronger if we observe the level of CO_2 emissions during the same period. As expected, participants in the EU ETS with an export-oriented activity decreased their CO_2 emissions after the introduction of the ETS. A slight increase in the level of CO_2 can be observed in the last couple of years of the period under study which can be explained through the increase in permit prices. Obviously the pattern of the pollutants PM_{10} and $PM_{2.5}$ does not follow the trend of the CO_2 emissions (Figure 7) for the sectors analyzed in graphs (a) of the above figures.

Different conclusions are derived if we explore what is happening in the level of local pollutants generated by sectors belonging to the remaining three categories. In the case of the industries that participate in the EU ETS, but are not export-oriented (graphs (b)), we observe that, by and large, the introduction of the permits market did not affect the generated local pollution. In general, the introduction of the permits market does not seem to have affected the volatility of pollution and therefore in this case there is no apparent effect on the regulation of local pollution. Emissions of local pollutants generated by industries that do not participate in the EU ETS (graphs (c) and (d)) have decreased over time with the probable exception of the sector Agriculture/Forestry/Fishing: Stationary, which can be attributed to sector-specific reasons. The same is true for the trend of CO_2 emissions.

Conclusion

The objective of this paper is to explore how environmental regulations could be used as an alternative tool to promote exports. More specifically, we use a model of strategic environmental policy with multiple pollutants, where the two firms compete à la Cournot in a third market. We assume the existence of two pollutants, a local and a transboundary one. The transboundary pollutant is controlled at an international level, while the local pollutant is regulated unilaterally. The focus question is whether the policy targeting the local pollutant could be used as a means to promote the exports of the competing firms under the assumption that transboundary pollution is set internationally. Our conclusion is in any case affirmative.

Our findings show that when transboundary pollution is regulated through the use of emission permits then the regulator has a stronger incentive to relax the regulation regarding local pollution, compared to the case where command and control is implemented for the reduction of transboundary pollution. This indicates a new strategic distortion due to tradable permits that leads to welfare losses. We also show that this result could be reversed in the case of a higher permit price. In this context, the higher permit price may outweigh the negative effect of the 'race to the bottom,' which in turn implies higher welfare levels. Similarly to regulation through emission permits, when emission taxes are implemented the marginal abatement costs are fixed to the given tax, and thus we expect that all the implications presented for the emission permits scenario will also carry over when the regulator selects the emission taxes to regulate local pollution.

The data extracted from the survey of the European Environmental Agency at the industry level for the EU 28 over the period 1990-2012 support our findings. More precisely, we observe that export-oriented sectors that participate in the EU Emission Trading System increased the generation of local pollutants around the period of the enforcement of the trading scheme, while this trend was followed by a gradual adjustment during the following years. This inverted U in the pattern of local pollutants is not observed in the sectors that either do not have significant exporting activities or do not participate in the European permits market. Moreover, CO_2 emissions remained constant when the EU ETS was introduced and thereafter followed a decreasing pattern for the majority of the sectors under study.

Acknowledgements: We thank Helmut Bester, Jessica Coria, Bård Harstad and Roland Strausz for valuable comments and suggestions. We also thank the participants of the 15^{th} ETSG and of the WCERE 2014 Conferences, as well as the members of the CREW project and those of the Microeconomics chair at Humboldt University Berlin. The usual disclaimer applies.

Appendix

Proof of Proposition 1

a) In order to determine this sign of $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT}$ we can differentiate the profit maximizing conditions of the firms with respect to outputs and solve for the comparative statics:

$$\begin{bmatrix} \pi_{xx} & \pi_{xX} \\ \Pi_{Xx} & \Pi_{XX} \end{bmatrix} \begin{bmatrix} dx^* \\ dX^* \end{bmatrix} = \begin{bmatrix} -\pi_{x\bar{e}_1} d\bar{e}_1 \\ 0 \end{bmatrix} \Leftrightarrow \begin{bmatrix} \frac{dx^*}{d\bar{e}_1} \\ \frac{dX^*}{d\bar{e}_1} \end{bmatrix} = \begin{bmatrix} \pi_{xx} & \pi_{xX} \\ \Pi_{Xx} & \Pi_{XX} \end{bmatrix}^{-1} \begin{bmatrix} -\pi_{x\bar{e}_1} \\ 0 \end{bmatrix} \Leftrightarrow$$

$$\begin{bmatrix} \frac{dx^*}{d\bar{e}_1} \\ \frac{dX^*}{d\bar{e}_1} \end{bmatrix} = \begin{bmatrix} -\frac{\Pi_{XX}\pi_{x\bar{e}_1}}{\Delta^{NT}} \\ \frac{\Pi_{Xx}\pi_{x\bar{e}_1}}{\Delta^{NT}} \end{bmatrix}, \tag{A1}$$

where $\Delta^{NT} = \pi_{xx}\Pi_{XX} - \pi_{xX}\Pi_{Xx}$ is the determinant of the Hessian matrix and the condition for stability implies $\Delta^{NT} > 0$ (Dastidar, 2000). Note that $\Pi_{Xx} < 0$ and $\pi_{x\bar{e}_1} = ac_{x\bar{e}_1}(\cdot) = \gamma + c_{1x\bar{e}_1}(\cdot) = \gamma + c_{1xx}(\cdot) \gtreqless 0$. Thus, the overall sign depends on the sign of $\pi_{x\bar{e}_1}$:

$$\pi_{x\bar{e}_1} = \begin{cases} < 0 \text{ if } \gamma > -c_{1xx}(\cdot) \\ = 0 \text{ if } \gamma = -c_{1xx}(\cdot) \\ > 0 \text{ if } \gamma < -c_{1xx}(\cdot) \end{cases} \Rightarrow \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} = \begin{cases} < 0 \text{ if } \gamma > -c_{1xx}(\cdot) \\ = 0 \text{ if } \gamma = -c_{1xx}(\cdot) \\ > 0 \text{ if } \gamma < -c_{1xx}(\cdot) \end{cases}.$$

b) Similarly to Scenario 1 we determine $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{T}$. Differentiating the profit maximizing conditions in (3) it follows:

$$\begin{bmatrix} \pi_{xx} & \pi_{xX} & \pi_{xe_2} & 0 \\ \Pi_{Xx} & \Pi_{XX} & 0 & \Pi_{XE_2} \\ \pi_{e_2x} & 0 & \pi_{e_2e_2} & 0 \\ 0 & \Pi_{E_2X} & 0 & \Pi_{E_2E_2} \end{bmatrix} \begin{bmatrix} dx^* \\ dX^* \\ de_2^* \\ dE_2^* \end{bmatrix} = \begin{bmatrix} -\pi_{x\bar{e}_1} \\ 0 \\ -\gamma \\ 0 \end{bmatrix} d\bar{e}_1 \Leftrightarrow$$

$$\begin{bmatrix} \frac{dx^*}{d\bar{e}_1} \\ \frac{dX^*}{d\bar{e}_1} \\ \frac{de_2^*}{d\bar{e}_1} \\ \frac{dE_2^*}{d\bar{e}_1} \end{bmatrix} = \begin{bmatrix} \pi_{xx} & \pi_{xX} & \pi_{xe_2} & 0 \\ \Pi_{Xx} & \Pi_{XX} & 0 & \Pi_{XE_2} \\ \pi_{e_2x} & 0 & \pi_{e_2e_2} & 0 \\ 0 & \Pi_{E_2X} & 0 & \Pi_{E_2E_2} \end{bmatrix}^{-1} \begin{bmatrix} -\pi_{x\bar{e}_1} \\ 0 \\ -\gamma \\ 0 \end{bmatrix} \Leftrightarrow$$

$$\begin{bmatrix} \frac{dx^*}{d\bar{e}_1} \\ \frac{dX^*}{d\bar{e}_1} \\ \frac{de_2^*}{d\bar{e}_1} \\ \frac{dE_2^*}{d\bar{e}_1} \end{bmatrix} = \begin{bmatrix} -\frac{\delta^F\left(\pi_{x\bar{e}_1}\pi_{e_2e_2} - \gamma\pi_{e_2x}\right)}{\Delta^T} \\ \frac{\Pi_{Xx}\Pi_{E_2E_2}\left(\pi_{x\bar{e}_1}\pi_{e_2e_2} - \gamma\pi_{e_2x}\right)}{\Delta^T} \\ \frac{\left(\pi_{x\bar{e}_1}\pi_{e_2x} - \pi_{xx}\gamma\right)\delta^F + \Pi_{Xx}\pi_{xX}\Pi_{E_2E_2}}{\Delta^T} \\ -\frac{\Pi_{Xx}\Pi_{E_2X}\left(\pi_{x\bar{e}_1}\pi_{e_2e_2} - \gamma\pi_{e_2x}\right)}{\Delta^T} \end{bmatrix}, \tag{A2}$$

where $\Delta^T \equiv \delta^H\delta^F - \pi_{e_2e_2}\Pi_{Xx}\pi_{xX}\Pi_{E_2E_2}$is the determinant of the Hessian matrix. Following Bulow et al. (1985) in order to ensure stability of the equilibrium, the Hessian matrix must be negative definite which implies that $\Delta^T > 0$. Moreover, the conditions for uniqueness of the equilibrium in this setup are satisfied as long as $ac_{xx}(a_i, a_{-i}) \geq 0$ (see Meunier, 2011). We know that $\Pi_{Xx}\Pi_{E_2E_2} > 0$ and remains to determine the sign of $\pi_{x\bar{e}_1}\pi_{e_2e_2} - \gamma\pi_{e_2x} = \gamma^2 - c_{1xx}(\cdot)c_{2xx}(\cdot)$. We define as $\gamma_1 \equiv \sqrt{c_{1xx}(\cdot)c_{2xx}(\cdot)}$. Then:

$$\pi_{x\bar{e}_1}\pi_{e_2e_2} - \gamma\pi_{e_2x} = \begin{cases} < 0 \text{ if } \gamma \in (-\gamma_1, \gamma_1) \\ = 0 \qquad\quad \text{if } \gamma = \pm\gamma_1 \\ > 0 \qquad\quad \text{if } |\gamma| > \gamma_1 \end{cases} \Rightarrow \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T = \begin{cases} < 0 \text{ if } \gamma \in (-\gamma_1, \gamma_1) \\ = 0 \qquad\quad \text{if } \gamma = \pm\gamma_1 \\ > 0 \qquad\quad \text{if } |\gamma| > \gamma_1 \end{cases}.$$

Q.E.D.

Proof of Corollary 1

In order to obtain and compare the sign of the strategic effect under the two senarios (NT, T), we need to compare the different levels of the degree of compementarity derived in Proposition 1. More specifically, if $-c_{1xx} < -\gamma_1 \Rightarrow -c_{1xx} < -\sqrt{c_{1xx}c_{2xx}} \Rightarrow (c_{1xx})^2 > (c_{1xx}c_{2xx}) \Rightarrow c_{1xx} > c_{2xx}$.

(a) For $c_{1xx} > c_{2xx}$:

- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^i > 0$, for $\gamma < -c_{1xx}$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} = 0 < \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T$, for $\gamma = -c_{1xx}$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} < 0 < \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T$, for $\gamma \in (-c_{1xx}, -\gamma_1)$ and $\gamma > \gamma_1$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} < 0 = \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T$, for $\gamma = -\gamma_1,\ \gamma_1$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^i < 0$, for $\gamma \in (-\gamma_1, \gamma_1)$.

(b) For $c_{1xx} < c_{2xx}$:

- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^i > 0$, for $\gamma < -\gamma_1$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T = 0 < \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT}$, for $\gamma = -\gamma_1$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T < 0 < \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT}$, for $\gamma \in (-\gamma_1, -c_{1xx})$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T < 0 = \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT}$, for $\gamma = -c_{1xx}$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^i < 0$, for $\gamma \in (-c_{1xx}, \gamma_1)$.
- $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T > 0 > \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT}$, for $\gamma > \gamma_1$.

Q.E.D.

Proof of Proposition 2

When $\gamma = 0$ it is trivial to show that the strategic effect in scenario 2 can be expressed either by the formula in (A2) or by the formula in (A1) given that the last two first order conditions in (3) are introduced in the first two profit maximizing conditions with respect to output. Given that the numerator of $\frac{dX^*}{d\bar{e}_1} = \frac{\Pi_{Xx}\pi_{x\bar{e}_1}}{\Delta^{NT}}$ is the same across the two scenarios, in order to illustrate that $\left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} - \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^T > 0$ it is sufficient to show that $\Delta^T_{\gamma=0} < \Delta^{NT}_{\gamma=0}$ where the sub-index $\gamma = 0$

stands for the corresponding determinants of the Hessian matrices. Therefore:

$$\begin{aligned}\Delta^{NT}_{\gamma=0} - \Delta^{T}_{\gamma=0} &= c_{2xx}(X-\overline{E}_2)\left[c_{1xx}(x-\overline{e}_1) - r_{xx}(\cdot)\right] + c_{2xx}(x-\overline{e}_2)\left[c_{1xx}(X-\overline{E}_1) + c_{2xx}(X-\overline{E}_2) - R_{xx}(\cdot)\right] > \\ \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} &> \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}.\end{aligned}$$

By continuity there must exist an $|\varepsilon| \to 0$ such that $\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$. Q.E.D.

Proof of Proposition 3

Taking the difference of the two strategic effects in (5) we get:

$$\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} - \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T} = -\frac{b(g_2+\gamma)\omega}{(b+g_1+g_2+2\gamma)(3b+g_1+g_2+2\gamma)(3bg_2+g_1g_2-\gamma^2)\left[(b+g_1)\,g_2-\gamma^2\right]},$$

where $\omega \equiv \left[3b^2 g_2\gamma - (g_1g_2-\gamma^2)(4bg_2+g_2^2+3g_2\gamma+\gamma^2+g_1(2g_2+\gamma))\right]$.

For $\gamma < 0$, given that $|\gamma| < g_1, g_2$ it follows directly that $\omega < 0 \Rightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} - \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T} > 0$.

For $\gamma > 0$ the sign of ω is ambiguous. If $\gamma = 0$ then $\omega < 0 \Rightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$. By continuity follows that there must exist $\varepsilon > 0$ such that $\omega < 0 \Rightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$. It can be shown that $\omega_{\gamma\gamma} > 0$ for $\gamma > 0$. As $\gamma = 0 \Rightarrow \omega > 0$ and $\gamma = \gamma_1 \Rightarrow \omega > 0$ there must exist a $\overline{\gamma} \in (0, \gamma_1)$ such that $\left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} = \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$. For $\gamma > \overline{\gamma} \Rightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} < \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$ and for $\gamma \in [0, \overline{\gamma}) \Rightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} < \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T}$. Q.E.D.

Proof of Lemma 1

Define as $\overline{e}_1^{*i}$, $i = T$, NT the pollution level in equilibrium under each scenario. To show that $\overline{e}_1^{*T} > \overline{e}_1^{*NT}$ it is sufficient to show that the strategic component in (6) is larger in the first case, i.e., $\left(\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T} > \left(\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT} \Leftrightarrow \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{T} < \left(\frac{\partial X^*}{\partial \overline{e}_1}\right)^{NT}$ since $\left(\frac{\partial \pi^*}{\partial X^*}\right)^{T} = \left(\frac{\partial \pi^*}{\partial X^*}\right)^{NT}$. Q.E.D.

Proof of Proposition 4

Define as aggregate welfare the sum of welfare levels in the two countries for each scenario: $(w^c)^i \equiv w + W$, $i = T$, NT. The first order conditions for a maximum are the following:

$$\begin{aligned}\left(\frac{dw^c}{d\overline{e}_1}\right)^{i} &= \frac{\partial \pi^*}{\partial \overline{e}_1} + \frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}_1} + \frac{\partial \Pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}_1} - \frac{\partial d}{\partial \overline{e}_1} = 0 \\ \overline{e}_1^{*} &= \overline{E}_1^{*}.\end{aligned}$$

It is important to note that, by construction, $(w^c)^T = (w^c)^{NT}$ in the non-strategic case. Irrespective of the scenario $\frac{\partial x^*}{\partial \overline{e}_1} > \left|\frac{\partial X^*}{\partial \overline{e}_1}\right|$. Therefore, $\overline{e}_1^{c*} < \overline{e}_1^{*}$ where the index stands for pollution in the aggregate case. For values of pollution which are higher than $\overline{e}_1^{c*}$ it follows that $\frac{dw^c}{d\overline{e}_1} < 0$. To show that in the strategic case $(w^{c*})^{NT} > (w^{c*})^{T}$ it suffices that $\left(\frac{dw^c}{d\overline{e}_1}\right)^{NT} > \left(\frac{dw^c}{d\overline{e}_1}\right)^{T}$ for values of $\overline{e}_1$ close to the non-strategic equilibrium. This is true iff $\left(\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}_1} + \frac{\partial \Pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}_1}\right)^{NT} > \left(\frac{\partial \pi^*}{\partial X^*}\frac{\partial X^*}{\partial \overline{e}_1} + \frac{\partial \Pi^*}{\partial x^*}\frac{\partial x^*}{\partial \overline{e}_1}\right)^{T} \Leftrightarrow$

$\left(\frac{\partial X^*}{\partial \bar{e}_1} + \frac{\partial x^*}{\partial \bar{e}_1}\right)^{NT} < \left(\frac{\partial X^*}{\partial \bar{e}_1} + \frac{\partial x^*}{\partial \bar{e}_1}\right)^{T} \Leftrightarrow \left[\frac{\partial X^*}{\partial \bar{e}_1}\left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)\right]^{NT} < \left[\frac{\partial X^*}{\partial \bar{e}_1}\left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)\right]^{T}$. Given that $\left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)^{NT} = \left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)^{T} < 0 \Rightarrow \left[\frac{\partial X^*}{\partial \bar{e}_1}\left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)\right]^{NT} < \left[\frac{\partial X^*}{\partial \bar{e}_1}\left(1 + \left(\frac{\partial X^*}{\partial x^*}\right)^{-1}\right)\right]^{T}$ $\Leftrightarrow \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{NT} > \left(\frac{\partial X^*}{\partial \bar{e}_1}\right)^{T}$ which given Proposition 2 holds true for $|\gamma| \leq \varepsilon$. Q.E.D.

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