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A Tale of Two Externalities: Environmental Policy and Market Structure

By

Ana Espinola-Arredondo
&
Felix Munoz-Garcia

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A Tale of Two Externalities:

Environmental Policy and Market Structure[*]

Ana Espínola-Arredondo[†]
School of Economic Sciences
Washington State University
Pullman, WA 99164

Félix Muñoz-García[‡]
School of Economic Sciences
Washington State University
Pullman, WA 99164

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Abstract

This paper examines the two externalities that a country's environmental regulation imposes on other country's welfare: an environmental externality, due to transboundary pollution, and a competitive advantage externality, as regulations affect domestic firms' abatement costs, which impact the profits of their foreign competitors. We first analyze the emission standards that countries independently set under different market structures and then compare them with the standards set under international environmental agreements that internalize one or both types of externalities. The paper hence disentangles the effect of each externality. We show that firms' profits increase when countries participate in international treaties if the environmental damage from pollution is relatively low and such pollution is not significantly transboundary. We hence demonstrate that international environmental agreements can serve as cooperative devices firms use to ameliorate overproduction and increase profits, without the need to form collusive agreements.

Keywords: Transboundary pollution, strategic environmental policy, international environmental agreement, market structure.

JEL classification: C72, F12 , H23, Q28.

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[†]Address: 205C Hulbert Hall, Washington State University, Pullman, WA 99164. E-mail: anaespinola@wsu.edu.

[‡]Address: 103G Hulbert Hall, Washington State University. Pullman, WA 99164-6210. E-mail: fmunoz@wsu.edu. Phone: (509) 335 8402. Fax: (509) 335 1173.

1 Introduction

Most pollution has a transboundary nature, since it affects not only the country where it is produced but also neighboring countries. In order to control pollution, governments extensively use emission standards as an environmental policy. When countries independently select emission standards, however, they impose two external effects on other countries' welfare. First, emission standards produce an environmental externality on other countries due to transboundary pollution. Second, environmental regulations can be used as a tool to support domestic firms in their international competition. Specifically, countries have incentives to set relatively lax environmental policies that reduce national firms' costs, increasing its profits relative to foreign competitors. The negative effect on foreign firms' profits can be understood as a "competitive advantage externality," or eco-dumping.[1] International Environmental Agreements (IEAs) are commonly proposed as a tool to reduce emission standards, helping internalize the environmental externality associated to transboundary pollution. Nonetheless, IEAs can *also* be used to ameliorate the negative effects of the competitive advantage externality. The benefits from IEAs would therefore be twofold: first, a mitigation of global pollution and, second, the control of eco-dumping.

In this paper we disentangle these benefits by analyzing two different market structures, where one or both of the external effects are present.[2] We investigate a monopoly where the competitive advantage externality is absent since the domestic firm does not face foreign competition. Nonetheless, less strict emission standards in one country still impose an environmental externality on other countries, due to the transboundary nature of pollution. Then, we also study the case of oligopolistic market structures, where a country's decision to relax the environmental standards to its national firms imposes two types of negative externalities on other countries: environmental and competitive advantage externalities.

The paper examines the strategic incentives countries face when selecting their environmental policies by considering a two-stage game where, first, governments independently set their domestic environmental regulations, and second, every firm decides its production level given the emission standards countries previously established. The presence of the aforementioned externalities induces countries to set lax environmental standards. In contrast, by participating in international treaties, countries are capable of internalizing one or both types of externalities. Specifically, when countries participate in an international agreement, they first jointly decide the emission levels to be included in the treaty, and second, firms respond by choosing their output levels, given the commitments signed in the international agreement.

We show that emission standards under monopoly are less stringent than under oligopoly, both when countries independently set their emission levels and when they choose their environmental regulations within an IEA. The paper also analyzes countries' free-riding incentives under different

[1] Strictly speaking, the "competitive advantage externality" is a pecuniary externality (or spillover effect), since a change in the environmental regulation in one country affects the profits of firms located in other countries.

[2] We initially assume that producers sell all their output in a third market. This assumption is relaxed in section 6, where producers sell a fraction of their total production to domestic consumers.

market structures. Specifically, these incentives are defined as the difference between the environmental standards every country independently selects and those when countries participate in international agreements that internalize either (or both) externalities. In particular, we show that countries' free-riding incentives are larger under monopoly than oligopoly, despite the fact that under monopoly only the environmental externality is present, while under oligopoly both types of externalities exist. Intuitively, more relaxed environmental regulations induce a larger increase in profits for the monopolist than for the oligopolist. Countries with monopolistic firms therefore set weakly less strict emission levels than countries with firms competing in an international oligopoly.

Besides countries' incentives to participate in international agreements, we investigate firms' interests towards these treaties. Under monopoly markets, we demonstrate that the participation in an IEA only imposes a negative effect on profits since more stringent environmental standards increase the monopolist's abatement costs. However, under oligopoly markets, setting more stringent emission standards under the treaty imposes two effects on profits: a *negative effect* due to higher abatement costs, but also a *positive effect*, since stricter emission standards in all countries participating in the IEA reduce aggregate output (ameliorating overproduction in oligopoly).

Comparing the relative size of these effects, we show that when the environmental damage is relatively high, countries set very stringent emission standards when participating in an international treaty, imposing a negative effect on profits that dominates the positive effect. Therefore, oligopoly profits are lower when countries participate in international agreements than when they do not, leading firms to *oppose* their countries' participation in the international treaty. In contrast, when the environmental damage from pollution is relatively low, countries slightly reduce their emission standards under the treaty, which imposes a positive effect on oligopoly profits (due to the reduction in output) that outweighs the negative effect that such environmental regulation imposes on costs. Hence, firms would actually *favor* their countries' participation in IEAs. Intuitively, the emission standards countries set in international agreements serve as a cooperative device firms use to ameliorate overproduction and increase profits without the need to form explicit collusive agreements. One example of firms supporting IEAs is the "e-mission 55" initiative, where more than 200 companies from around the world are grouped to favor their countries' implementation of the Kyoto protocol.[3] Similarly, several firms and industry organizations supported the Montreal protocol in order to guarantee an equal environmental regulation as their competitors; see Bernhagen (2008). An additional example is the Pew Center on Global Climate Change, where 46 companies constitute the "largest U.S.-based association of corporations focused on [...] policy solutions to climate change" promoting "targets for GHG emission reductions" including among its members Boeing, DuPont and GE.[4] Furthermore, we show that the set of environmental damages for which firms support IEAs shrinks as pollution becomes more transboundary. In particular,

[3] A firm's support of IEAs does not need to be related with that firm's green practices, since its promotion of IEAs is only oriented in reducing aggregate output. In addition, note that firms' support of international treaties could also be explained by the firm's public image towards environmentally-oriented customers. Our paper shows that, even in the absence of public image considerations, firms would still favor IEAs under certain parameter conditions.

[4] See http://www.pewclimate.org/

emission standards under the IEA are more stringent, inducing a larger negative effect on profits. Finally, we demonstrate that firms would favor countries' participation in IEAs that only internalize the environmental effects of pollution under more general conditions than if the treaty internalizes both the environmental and competitive advantage externality.

We examine two extensions to our model. First, we analyze the case in which oligopolists form a cartel agreement, and investigate how countries' environmental regulation is affected by firms' decision to collude, both when countries independently set their domestic emission standards and when they participate in IEAs. Specifically, we show that countries' marginal benefit from setting less stringent emission levels to domestic firms is larger when firms form a cartel than when they compete as oligopolists, ultimately inducing countries to set less strict emission standards, both with and without IEAs. Hence, environmental regulation becomes "softer" when regulating firms that belong to an international cartel, providing them with additional incentives to form and sustain such collusive agreements.

Second, we extend our model to the case in which countries take into account domestic consumer surplus.[5] We show that emission standards increase in the importance that countries assign to their consumers' welfare, both when countries do not participate in international treaties, and when they do. Furthermore, this result applies for different degrees of the transboundary externality, including the case where the environmental externality is absent.

Previous literature analyzes the environmental externality that local producers located in a single country impose on the country's welfare when pollution is *non-transboundary* and how emission standards can serve to eliminate this domestic externality; see Maloney and McCormick (1982), Ebert (1998) and Farzin (2003). In contrast, our paper considers a general setting in which firms interact in an international market and pollution can either be transboundary or non-transboundary. Other studies examine the competitive advantage externality that results when multiple countries independently select their environmental policies. In particular, Kennedy (1994) examines countries' incentives to strategically set environmental taxes in a context where pollution is transboundary, whereas Barrett (1994a) investigates both taxes and emission standards assuming that pollution is non-transboundary. Similarly, Ulph (1996a) uses a non-transboundary setting to study how countries' strategic environmental regulations affect firms' previous investment decision in research and development.[6] Our study hence contributes to this literature by considering not only the competitive advantage but also the environmental externality, and disentangles the separate effect of each type of externality. Unlike previous work, our paper identifies under which conditions firms favor their countries' participation in IEAs that internalize either (or both) type of exter-

[5] Setting less stringent emission standards increases domestic output, which under oligopoly increases the consumer surplus not only of domestic but also of foreign buyers of the good. Hence, higher emission standards impose a new type of externality: namely, a positive "consumer surplus" externality on foreign countries. We describe this type of externality in section 6.2.

[6] Other studies analyze countries' strategic incentives when setting environmental regulations to domestic producers. For models where firms' location is exogenous see Conrad (1993), Ulph (1996b) and Feenstra et al. (2003), and for models in which firm's location is an endogenous variable see Markusen *et al.* (1992, 1993), Rauscher (1993) and Ulph (1994).

nality. Furthermore, we study how firms' incentives to collude are affected by countries' signature of an environmental agreement. Summarizing, this paper examines emission standards and firms' equilibrium profits when both externalities are present, and how countries' participation in IEAs might serve as a tool firms use to reduce overproduction in oligopolistic market structures.

The structure of the paper is as follows. Section 2 develops the model, and section 3 describes firms' equilibrium output during the second stage of the game, under different market structures. In section 4, we analyze emission standards under monopoly markets, and how they are affected by countries' participation in international agreements. Section 5 examines emission standards under oligopoly, and compares them with those under monopoly. Section 6 extends our model by analyzing cartel agreements and consumer surplus. We finally discuss the main results.

2 Model

Let us consider two countries which independently determine their environmental regulation and one firm located in each country. In particular, every country i chooses the environmental standard that regulates the emissions produced by the firm located in its jurisdiction. Pollution can either affect the country where emissions were generated alone (non-transboundary emissions), or both the country that originally produced them and the foreign country (transboundary emissions). Similarly to Kennedy (1994), let $\alpha \geq 0$ be the emissions from country i that reach country j, producing an environmental externality. Note that if $\alpha = 0$ emissions from one country do not impose any environmental externality on the foreign country, as in Ulph (1996a) and in Barrett (1994a), while if $\alpha = 1$ emissions affect both countries equally. Finally, $\alpha > 1$ represents the case where pollution imposes larger environmental damages on the foreign than on the domestic country.

In addition, assume that firms are symmetric both in their production and abatement costs. Production costs are $\frac{q_i}{\theta}$, where a high parameter $\theta > 0$ represents an efficient production process. Using an approach similar to Ulph (1996a), let every unit of output q_i be associated to one unit of pollution.[7] Hence, the amount of pollution that firm i must abate given the emission standard e_i is

$$A_i \equiv q_i - e_i$$

represented by the difference between the firm's pollution (associated to output) and the emission standard to be observed. Intuitively, an emission standard is more stringent the lower the emission level e_i is, since it induces the firm to further abate its emissions. Following the functional forms used by Barrett (1994b) and Ulph (1996a), let abatement costs be $\frac{2A_i^2}{\theta}$, which decrease as the firm becomes more efficient (higher θ), and are increasing and convex in the abatement level, A_i. Assuming an inverse linear demand $P(Q) = a - Q$, where Q denotes aggregate output, firm's profits

[7] In the case that every unit of output generates *less* than one unit of emissions, firms' abatement costs would be reduced, resulting in an increase in both monopoly and duopoly output. Nonetheless, the qualitative features of the model would be unaffected.

are given by

$$\pi_i(q_i, q_j, e_i) = (a - Q)q_i - \frac{q_i}{\theta} - \frac{2(q_i - e_i)^2}{\theta}$$

It is straightforward to verify that the marginal cost of producing one additional unit of q_i, $\frac{1-4e_i}{\theta} + \frac{4}{\theta}q_i$, is decreasing in e_i, i.e., less stringent emission standards decrease firms' marginal costs. We assume that demand satisfies $a > \frac{1}{\theta}$.[8]. We analyze two market structures: monopoly, whereby a single producer supplies a good to the international market, and duopoly, where firms located in both countries sell the same product competing in quantities in the international market.

Finally, country i's social welfare is $W_i(q_i, q_j, e_i, e_j) = \pi_i(q_i, q_j, e_i) - d \times (e_i + \alpha e_j)$, which increases in firm i's profits and decreases in the environmental damage associated to domestic and foreign emissions.[9] The environmental damage of an additional unit of domestic emissions is $d > 0$, and that of foreign emissions is $\alpha d \geq 0$. In addition, note that profits of firm i only depend on the emission standards from country i when the firm is a monopolist, whereas profits depend on the emission levels set by both countries if it is a duopolist.[10] The time structure of the game is as follows:

1. In the first stage of the game, every country i determines its own equilibrium emission standard. For comparison, we consider the following scenarios:

   (a) Countries do not participate in an international environmental agreement. Hence, every country independently selects its own emission standard under no treaty, NT, e_i^{NT};

   (b) Countries participate in an international *environmental* treaty that reduces the environmental damage caused from transboundary pollution. Thus, emission standards selected under the environmental treaty internalize the environmental externality, EE, (e_i^{EE}, e_j^{EE});

   (c) Countries participate in an international treaty that internalizes *both* types of externalities: the environmental externality and the competitive advantage externality. We refer to the emission standards that internalize both externalities as (e_i^{BE}, e_j^{BE}).

2. In the second stage of the game, given the emission standard set by every country, firms choose their production levels $q_i(e_i, e_j)$ and $q_j(e_j, e_i)$, either as monopolists selling their products to separate international markets, or as duopolists competing in the same international market.

[8] This condition guarantees existence when firms compete as Cournot duopolists, as shown in the proof of Lemma 1 below, given that the marginal willingness to pay for the first unit, $p(0) = a$, exceeds the marginal cost associated with its production, $\frac{1-4e_i}{\theta}$, for all emission standards $e_i \geq 0$.

[9] For simplicity, we assume that the marginal environmental damage from pollution, d, is constant in emission levels. Nonetheless, considering an increasing marginal environmental damage does not affect the implications of our results.

[10] Similarly to Barrett (1994a) and Ulph (1996a), we initially assume that every firm sells its production to the international market, and that consumers located in country i are a negligible share of all consumers in the international market. As a consequence, country i's social welfare does not include consumer surplus. This assumption is relaxed in section 6, where we investigate how emission standards are affected by the share of national customers in the international demand for the good. The qualitative results of the paper are unaffected.

3 Equilibrium Output

Let us describe firms' production decision during the second stage of the game when they take emission standards as given. In particular, when firms compete as Cournot duopolists every firm i's best response function is given by

$$q_i^C(q_j, e_i) = \begin{cases} \frac{(a\theta-1)+4e_i}{2(2+\theta)} - \frac{\theta}{2(2+\theta)} q_j & \text{if } q_j < \frac{a\theta-1+4e_i}{\theta} \\ 0 & \text{otherwise} \end{cases}$$

Specifically, $q_i^C(q_j, e_i)$ is increasing in the emission standard e_i (producing an outward shift in firm i's best response function). Intuitively, a less stringent environmental standard reduces firm i's marginal costs, inducing it to produce larger amounts, which leads firm j to produce lower output levels. Hence, setting less strict emission standards serves as a strategic pre-commitment, as in Fudenberg and Tirole (1984), affecting firms' competitiveness in the posterior stage of the game.[11,12] Next we analyze equilibrium output, both under monopolistic and duopolistic markets.

Lemma 1. *Equilibrium output under monopoly is* $q_i^M(e_i) = \frac{(a\theta-1)+4e_i}{2(2+\theta)}$, *and under Cournot duopoly is*

$$q_i^C(e_i, e_j) = \begin{cases} \frac{(a\theta-1)+4e_i}{2(2+\theta)} & \text{if } \overline{e_i} \leq e_i, \\ \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)} & \text{if } \underline{e_i} \leq e_i < \overline{e_i}, \text{ and} \\ 0 & \text{if } e_i < \underline{e_i} \end{cases}$$

where $\overline{e_i} \equiv \frac{(a\theta-1)(4+\theta)+(2+\theta)8e_j}{4\theta}$ *and* $\underline{e_i} \equiv \frac{4+\theta[1+4e_j+a(4+\theta)]}{8(2+\theta)}$.

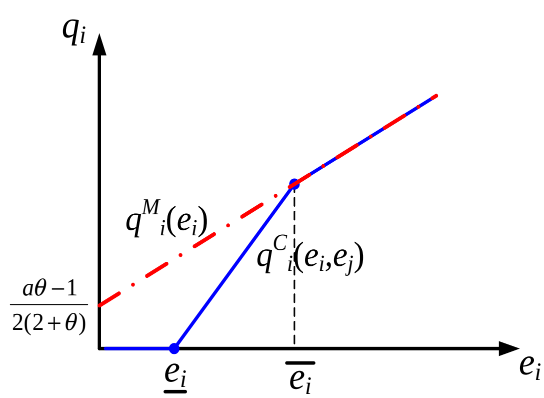

Figure 1. Equilibrium output.

[11] In particular, this strategic setting corresponds to the "Top Dog" case in Fudenberg and Tirole's (1984) classification of strategic pre-commitment decisions. Brander and Spencer (1985) use a similar strategic setting to analyze governmental subsidy programs to exporters, improving their competitiveness with respect to foreign competitors.

[12] Note that this result also holds for different demand and cost functions. In particular, it is satisfied if every firm's best response function when competing as a Cournot duopolist is negatively sloped and experiences an upward shift when countries set less stringent environmental regulations to their domestic firms.

As figure 1 illustrates, firm i's output is zero when country i's emission standards are low relative to those of country j, i.e., $e_i < \underline{e_i}$. In contrast, when country i's emission standards are relatively high, $e_i > \overline{e_i}$, firm j produces zero units, and firm i becomes a monopoly. Finally, when both countries' environmental regulation is relatively similar, both firm i and j produce a positive output. Comparing monopoly and duopoly output, observe that the former is less sensitive to a given increase in emission standards than the latter. Intuitively, the monopolist fully takes into account the price decrease that results from producing a larger output, whereas the duopolist does *not* fully internalize such price reduction. This leads the duopolist to increase more its production as a result of less strict emission standards than the monopolist does.

4 Emission Standards under Monopoly

We next examine the first stage of the game in which countries set emission standards. In this section, we analyze the case where every country has a firm that operates as a monopolist, selling its production to separate international markets. Regulating a monopoly imposes an environmental externality (EE) on the welfare of other countries. It produces, however, no competitive advantage externality (CAE) since less stringent environmental regulations in one country do not affect the foreign firm's profits (given its monopoly power). In the following section, we investigate emission standards under duopoly, where both EE and CAE effects are present.

Let us first examine countries' trade-offs from marginally increasing emissions. On the one hand, a marginal increase in the emission standard e_i allowing firms to emit more pollutants, has an associated marginal environmental cost of $MEC_i = d$ to country i, and a social marginal environmental cost of $SMEC = (1 + \alpha)d$ to both countries, as depicted in figure 2. On the other hand, a marginal increase in e_i raises the profits of the domestic monopoly.[13] In particular, the marginal benefit of increasing e_i under monopoly is

$$MB_i^M(e_i) = \begin{cases} \frac{2(a\theta-1)}{\theta(2+\theta)} - \frac{4}{2+\theta}e_i & \text{if } e_i < \frac{a\theta-1}{2\theta}, \text{ and} \\ 0 & \text{otherwise} \end{cases}$$

[13] Alternatively, a marginal *decrease* in e_i (more stringent emission standards) has an associated marginal environmental *benefit* of d, due to less pollution, but produces a marginal *loss* in monopoly profits.

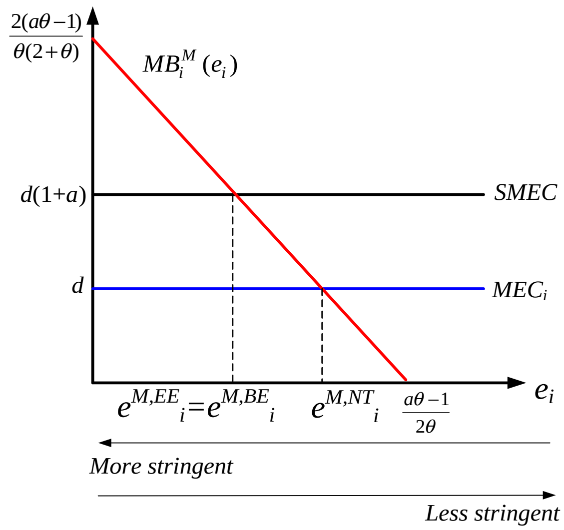

Figure 2. Emission standards under monopoly.

Starting at $e_i = 0$, a marginal increase in e_i raises monopoly profits by a relatively large amount, but the additional profits from raising e_i decrease as emission standards become larger (i.e., less stringent emission standards exhibit decreasing marginal benefits). Let us next analyze country i's equilibrium emission standards.

Proposition 1. *Emission standards of country i under monopoly, $e_i^{M,NT}$, are*

$$e_i^{M,NT} = \begin{cases} \frac{a\theta-1}{2\theta} - \frac{2+\theta}{4}d & \text{if } d < d^M, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^M \equiv \frac{2(a\theta-1)}{\theta(2+\theta)}$.

Notice that $e_i^{M,NT}$ is decreasing in d, since a higher environmental damage induces every country to set more stringent emission standards on its firms. This result is also illustrated in figure 2, where an increase in $MEC_i = d$ reduces $e_i^{M,NT}$. For values of d above d^M, the marginal environmental damage of emissions is sufficiently high to support an emission standard equal to zero.

4.1 Emission Standards under Treaty

This section analyzes the pair of emission standards that countries select when they participate in an international treaty.[14]

Proposition 2. *Emission standards of country i under monopoly when participating in international treaties that internalize the environmental externality, $e_i^{M,EE}$, or both externalities, $e_i^{M,BE}$,*

[14] For simplicity, we consider that both countries have the same bargaining power in the international treaty.

are

$$e_i^{M,EE} = e_i^{M,BE} = \begin{cases} \frac{a\theta-1}{2\theta} - \frac{(2+\theta)(1+\alpha)}{4}d & \textit{if } d < \frac{1}{1+\alpha}d^M, \textit{ and} \\ 0 & \textit{otherwise.} \end{cases}$$

First, note that as suggested above the CAE effect is absent under monopoly. Hence, the emission standard that only internalizes the environmental externality coincides with that internalizing both externalities, i.e., $e_i^{M,EE} = e_i^{M,BE}$. Second, emission standards under the treaty are weakly below those with no treaty, $e_i^{M,NT}$, since countries internalize the EE effect. In particular, note that at a zero environmental damage, $d = 0$, emission standards with and without the treaty coincide. A given increase in the environmental damage from pollution, however, induces a larger reduction in the emission standard under the treaty than under no treaty. In addition, emission standards under the treaty are weakly decreasing in α. Specifically, when pollution is non-transboundary ($\alpha = 0$) the EE effect is absent, and emission standards under the treaty coincide with those under no treaty, i.e., $e_i^{M,NT} = e_i^{M,EE} = e_i^{M,BE}$. In contrast, when pollution becomes more transboundary (higher α), the EE effect is more significant. Therefore, emission standards under the treaty become more stringent since they must internalize larger environmental damages.

The difference between emission standards without and with treaty, $e_i^{M,NT} - e_i^{M,EE}$, provides a measure of how much a country fails to fully internalize the environmental externality it imposes on other countries. For simplicity, we denote this difference as countries' free-riding behavior, FR^M, given that countries do not consider the EE effect that their independent environmental regulations impose on other countries. Specifically, under monopoly markets,

$$FR^M \equiv \begin{cases} \frac{\alpha(2+\theta)}{4}d & \text{for any } d \leq \frac{1}{1+\alpha}d^M, \\ \frac{(a\theta-1)}{2\theta} - \frac{2+\theta}{4}d & \text{for any } \frac{1}{1+\alpha}d^M < d \leq d^M, \\ 0 & \text{for any } d > d^M \end{cases}$$

When the environmental damage from pollution is zero, countries set the highest (least stringent) environmental standards to their national firms, both with and without the treaty. A similar argument is applicable when d is relatively high, $d > d^M$, since now countries need to impose the most stringent environmental standards to their domestic firms, with and without the treaty. For intermediate values of d, the difference in emissions first increases and then decreases. First, when $d \leq \frac{1}{1+\alpha}d^M$, a given increase in the environmental damage d induces emission standards under an environmental treaty to become more stringent than under no treaty, increasing the difference FR^M. Second, for values of d exceeding $\frac{1}{1+\alpha}d^M$, countries participating in the IEA cannot further reduce their emission standards, but emission standards under no treaty decrease in the environmental damage of pollution, thus reducing the difference FR^M.

Furthermore, FR^M is weakly increasing in the transboundary nature of pollution, α. Specifically, from lemma 1 and proposition 1 emission standards under no treaty, $e_i^{M,NT}$, are constant in α, while those under the treaty, $e_i^{M,EE}$, are decreasing in α. Hence, an increase in α enlarges the difference $e_i^{M,NT} - e_i^{M,EE}$, reflecting the presence of a more significant environmental externality.[15]

[15] In the case that $\alpha = 0$ free-riding is absent because there are no EE effects. Hence, non-transboundary pollution

5 Emission Standards under Duopoly

In this section, we analyze countries' emission standards when firms compete as Cournot duopolists in the international market. Using the equilibrium output chosen by these firms in the second stage of the game, we examine countries' equilibrium regulations under no treaty, $e_i^{C,NT}$, under the treaty that internalizes the EE effect, $e_i^{C,EE}$, and under the agreement that internalizes both externalities, $e_i^{C,BE}$.

First, when countries participate in a treaty that internalizes the CAE effect, they consider the negative externality they impose on foreign firms. As a consequence, the marginal benefit from setting less stringent emission standards when countries internalize both externalities, $MB_i^{C,BE}(e_i, e_j)$, is lower than when they do not, $MB_i^C(e_i, e_j)$, as figure 3 below shows. Second, country i's marginal benefit from increasing its own emission standards decreases in the emission standards set by country j, both under no treaty and under either type of treaty. Intuitively, an increase in e_j reduces the additional benefits that firm i can obtain from less strict environmental regulations. Graphically, an increase in e_j produces a parallel inward shift both in $MB_i^C(e_i, e_j)$ and in $MB_i^{C,BE}(e_i, e_j)$.

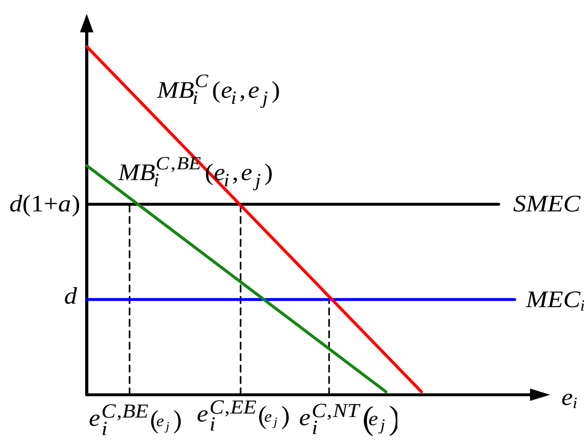

Figure 3. Emission standards under duopoly.

Third, the additional profits from less strict emission standards are higher for the monopolist than that for the duopolist, i.e., $MB_i^M(e_i) \geq MB_i^C(e_i, e_j)$ for given emissions e_i and e_j. Specifically, a given increase in e_i induces a larger increase in output for this duopolist than for the monopolist, since the duopolist does not fully internalize the price-effect of its additional production. This causes a larger decrease in prices for the duopolist than for the monopolist. Ultimately, less stringent environmental regulations induce a smaller increase in profits for the duopolist than for the monopolist.[16] We next characterize equilibrium emissions under no treaty, $e_i^{C,NT}$.

induces countries to set the *same* environmental policy under monopoly markets, both with and without the treaty.

[16] This argument also applies to the analysis of an international oligopoly with more than two firms. In particular, setting less stringent emission standards to a domestic oligopolist induces a marginal increase in profits which is decreasing in the number of firms competing in the international oligopoly.

Proposition 3. *Emission standards under duopoly and no treaty,* $e_i^{C,NT}$*, are*

$$e_i^{C,NT} = \begin{cases} \frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]} - \frac{(4+\theta)(4+3\theta)^2}{4[48+\theta(44+9\theta)]}d & \text{if } d < d^{C,NT}, \text{ and} \\ 0 & \text{otherwise} \end{cases}$$

where $d^{C,NT} \equiv \frac{16(2+\theta)^2(a\theta-1)}{\theta(4+\theta)(4+3\theta)^2}$.

5.1 Emission Standards under treaty

Let us investigate countries' emissions standards when their agreement internalizes the environmental externality, $e_i^{C,EE}$, and when it internalizes both externalities, EE and CAE, $e_i^{C,BE}$.

Proposition 4. *Emission standards under duopoly when countries participate in an international treaty that internalizes the EE effect,* $e_i^{C,EE}$*, are*

$$e_i^{C,EE} = \begin{cases} \frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]} - \frac{(1+\alpha)(4+\theta)(4+3\theta)^2}{4[48+\theta(44+9\theta)]}d & \text{if } d < \frac{1}{1+\alpha}d^{C,NT}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

And emission standards when countries participate in a treaty that internalizes both externalities, $e_i^{C,BE}$*, are*

$$e_i^{C,BE} = \begin{cases} \frac{2(2+\theta)(a\theta-1)}{\theta(16+9\theta)} - \frac{(1+\alpha)(4+3\theta)^2}{64+36\theta}d & \text{if } d < d^{C,BE}, \text{ and} \\ 0 & \text{otherwise} \end{cases}$$

where $d^{C,BE} \equiv \frac{8(2+\theta)(a\theta-1)}{(1+\alpha)\theta(4+3\theta)^2}$.

Similarly to monopoly, the internalization of the EE effect under duopoly weakly reduces emission standards, from $e_i^{C,NT}$ to $e_i^{C,EE}$, and this reduction is increasing in the extent of the transboundary externality, α. The following corollary describes the ranking among emission levels, under different market structures, with and without IEAs.

Corollary 1. *Emission standards satisfy* $e_i^{K,NT} \geq e_i^{K,EE} \geq e_i^{K,BE}$ *for a given market structure* $K = \{M, C\}$*, and* $e_i^{M,BE} \geq e_i^{C,NT}$.

Therefore, the above corollary establishes a complete ranking among all emission levels, where emission standards under monopoly are weakly higher than under duopoly for all treaty/no treaty scenarios, as the figures below illustrate. Intuitively, the marginal increase in profits from setting less stringent environmental standards to a monopolist is higher than that to a duopolist, which leads countries to set less stringent environmental regulations to the former than to the latter. Figure 4, additionally, represents the reduction in emission standards under different treaties, and for a given market structure: first, when countries only internalize the EE effect (reducing emissions from

$e_i^{K,NT}$ to $e_i^{K,EE}$), and second, when countries internalize both the EE and CAE effects[17] (weakly decreasing emissions to $e_i^{C,BE}$).

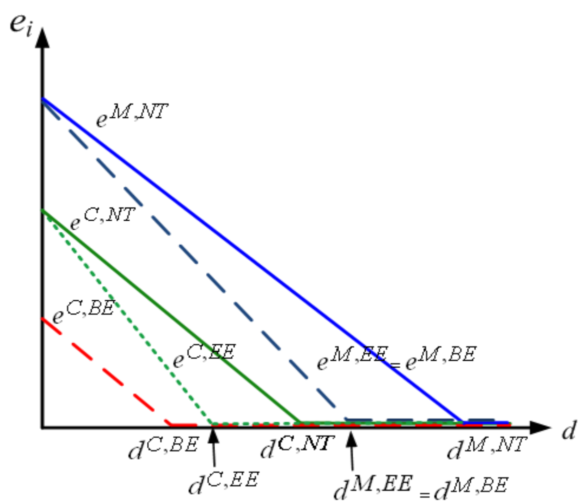

Figure 4(a): Emission standards for $\alpha > 0$.

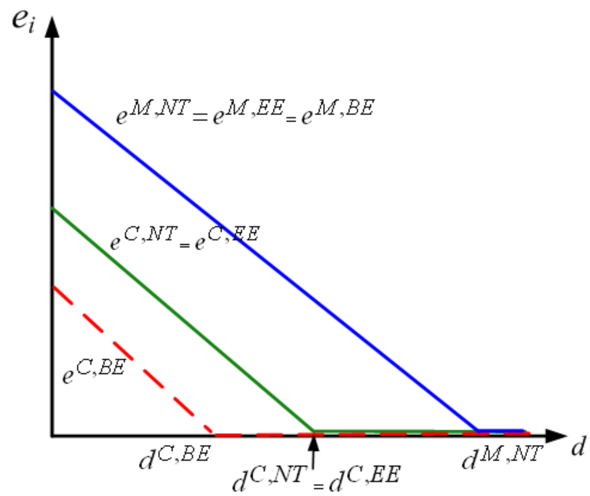

Figure 4(b): Emission standards for $\alpha = 0$.

Under non-transboundary pollution ($\alpha = 0$, see Figure 4b), the EE effect is absent and emission standards to a domestic monopoly coincide, $e_i^{M,NT} = e_i^{M,EE} = e_i^{M,BE}$. The CAE effect is still present under duopoly, nonetheless, inducing countries to independently set lax emission standards to their national duopolists, in order to improve their competitive advantage, $e_i^{C,NT} \geq e_i^{C,BE}$.

Let us next analyze to what extent countries' independent choice of emission standards fails to internalize the EE and CAE effects. In the next figure we depict $FR^{C,BE} = e_i^{C,NT} - e_i^{C,BE}$, which represents the difference between countries' emission standards under no treaty and under the treaty that internalizes both the EE and CAE effects. The figure also represents $FR^{C,EE} = e_i^{C,NT} - e_i^{C,EE}$, which measures the deviation of the emission standard under no treaty from that only internalizing the EE effect. As figure 5 indicates, $FR^{C,BE}$, is larger than $FR^{C,EE}$. Furthermore, the distance in emission standards is weakly larger under monopoly than duopoly. This implies that allowing countries to independently set environmental regulations to their national monopolists leads them to larger environmental inefficiencies, relative to the optimal level of emission standards. Nonetheless, when the environmental damage is sufficiently high, the difference in emission standards is zero, both under duopoly and monopoly.

[17] The emission standard under an international treaty that internalizes both types of externalities coincides with that in the Pareto optimal pair of emission standards. That is, given countries' social welfare function, there is no other pair of emission standards for which one of the countries could be made better off without reducing the social welfare of another country.

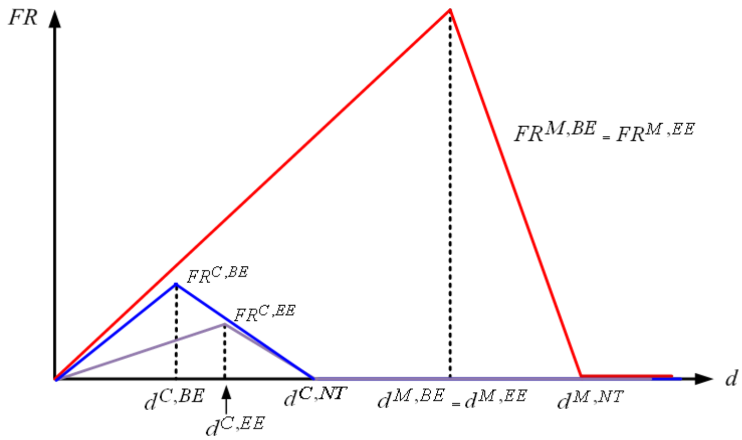

Figure 5. Comparison of FR between monopoly and duopoly.

5.2 Firms' profits

Let us now examine how countries' participation in international agreements affects firms' profits. Under monopoly, countries set more stringent emission standards when participating in international agreements, reducing their profits. Specifically, because monopolists fully internalize the price effect of their production decision, countries' participation in IEAs reduce firms' profits, relative to no treaty. Under duopoly, however, firms do not fully internalize the price effect of their output decisions. This leaves room for environmental regulations to serve as a cooperative device firms use to ameliorate overproduction in duopoly and increase profits without the need to form collusive agreements. The next proposition analyzes under which conditions firms' equilibrium profits can actually increase as a result of countries' participation in international agreements.

Proposition 5. *Under duopoly, firms' equilibrium profits with an international treaty that internalizes the EE effect exceed those with no treaty if and only if* $d < d^{EE}$*. Similarly, equilibrium profits under an international treaty that internalizes both the* EE *and* CAE *effects are larger than those with no treaty if and only if* $d < d^{BE}$*. Furthermore,* $d^{BE} < d^{EE}$ *for all parameter values, where*

$$d^{BE} \equiv \frac{8(2+\theta)(a\theta-1)}{\alpha[48\alpha+44\alpha\theta+9(2+\alpha)\theta^2+16(7+6\theta)]} \quad \textit{and} \quad d^{EE} \equiv \frac{16(2+\theta)(a\theta-1)}{(2+\alpha)\theta(4+\theta)(16+9\theta)}$$

Participation in international agreements induces countries to reduce their emission standards, which imposes two effects on firms' profits. First, a *negative effect*, since more stringent emission standards increase firms' abatement costs, which raises their marginal cost of production. Second, it provides a *positive effect* on profits, since more stringent emission standards lead firms to lower production levels, increasing profits.

The relative size of the two effects depends, nonetheless, on the environmental damage of pollution. In particular, when environmental damage is relatively low, IEAs induce countries to moderately reduce their emission levels. A reduction in both countries' emission standards induces a positive effect on firms' profits that outweighs the negative effect, ultimately *increasing* profits. When environmental damage is relatively high, however, countries set stringent emission standards under the treaty. A significant decrease in emission standards now *decreases* firms' profits, because the positive effect is counterbalanced by the negative effect that more stringent environmental regulation imposes on firms' profits.

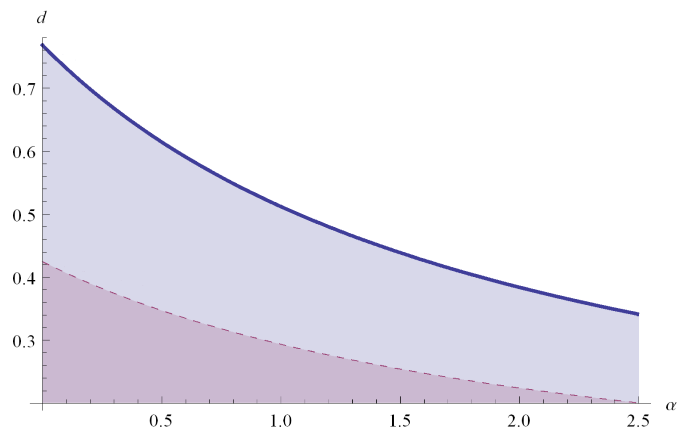

Figure 6. Cutoffs d^{EE} (solid) and d^{BE} (dashed).

Figure 6 above depicts cutoffs d^{EE} (solid line) and d^{BE} (dashed line) where, for simplicity, we consider[18] $a = 5$ and $\theta = 1$. The shaded area below every cutoff illustrates pairs of environmental damage, d, and extent of transboundary pollution, α, for which firms support their countries' participation in IEAs which internalize the EE effect alone, or both external effects, respectively. Furthermore, the fact that $d^{BE} < d^{EE}$ implies that the set of environmental damages for which firms support their countries' participation in IEAs that internalize the EE effect, $d < d^{EE}$, is larger than those in treaties internalizing both the EE and CAE effects, $d < d^{BE}$. Intuitively, the signature of IEAs internalizing both effects imposes more stringent emission standards on firms, increasing abatement costs. As a consequence, the negative effect on profits described above is larger when both externalities are taken into account.

Both cutoffs are decreasing in α, reflecting that the set of environmental damages for which firms favor IEAs shrinks as pollution becomes more transboundary. That is, more transboundary pollution leads to more stringent treaties, increasing the aforementioned negative effect on profits. As a consequence, firms support IEAs if and only if the environmental damage from pollution is relatively low *and* such pollution is not significantly transboundary. Finally, both cutoffs are increasing in market demand, a, since higher demand increases the positive effect that more stringent

[18] A change in these parameters shifts cutoffs d^{BE} and d^{EE}, without altering the ranking between them.

environmental standards produces on firms' profits.

6 Extensions

6.1 Cartel agreements

We next study the case in which duopolists form a cartel agreement, and investigate how countries' environmental regulation is affected by firms' decision to collude. In addition, we analyze how countries' signature of IEAs modifies firms' incentives to maintain the cartel agreement.

Proposition 6. *Emission standards are less stringent when duopolists form a cartel than when they compete in quantities, for a given NT/EE/BE scenario. Furthermore, equilibrium output under the cartel agreement is weakly lower than under duopolistic competition, for any treaty/no treaty scenario. In addition,* $e_i^{cartel,NT} \geq e_i^{cartel,EE} \geq e_i^{cartel,BE}$.

Intuitively, the increase in profits resulting from a marginal increase in emission standards is larger for a firm participating in a cartel agreement than for a Cournot duopolist. This induces countries to set less strict emission standards to the former than to the latter, both when countries participate in international treaties and when they do not.

Firm's profits are higher under the cartel agreement than under Cournot competition for a *given* environmental regulation. However, environmental regulation does *not* remain constant when firms collude, relative to when they compete in quantities. Instead, emission standards become less stringent, thus further increasing the profits of the firms participating in the cartel. Countries therefore become "softer" when regulating a domestic firm that belongs to an international cartel. Hence, environmental policy does not necessarily reduce the market power of the cartel, but rather, provides additional incentives to duopolists to form cartel agreements in order to face less stringent environmental regulations. Furthermore, note that the increase in production associated to setting less strict emission standards to the cartel participants does not overcome the reduction in output due to the collusive agreement. Thus, cartel output is lower than that under duopoly. Finally, and similarly to our previous results, countries' environmental regulations become weakly more stringent when they sign international agreements that internalize either the EE effect alone, or both the EE and CAE effects.

6.2 Consumer surplus

Let us now consider the case in which the population of every country i represents a (non-negligible) share $\gamma > 0$ of the international demand for the good. Under this assumption, governments consider national consumer surplus when determining emission standards, both with and without international treaties. In particular, country i's social welfare becomes $W_i(\cdot) = \gamma CS(q_i, q_j) + \pi_i(q_i, q_j, e_i) - d(e_i + \alpha e_j)$. Under duopoly, a given increase in emission standards by country i imposes, in addition to the EE and CAE effects, a positive externality on other countries due to the increase in consumer surplus resulting from larger production levels (and lower prices) that are not only enjoyed by domestic but also by foreign consumers of the good. This consumer surplus externality is present under duopoly but not under monopoly, since producers sell their product in separate international markets.

We assume, however, that the positive effect of the consumer surplus externality does not dominate the negative effect of the EE and CAE externalities. That is, less stringent emission standards from one country still impose an overall negative externality on other countries' welfare,[19] and for this reason international treaties prescribe a reduction in emission levels.[20] We denote the international treaty that internalizes the three types of externalities by the superscript *TE*.

Proposition 7. *Let $\gamma > 0$ be the weight every country assigns to its domestic consumer surplus. Emission standards are weakly increasing in γ, both under monopoly and duopoly, and under a given NT/EE/TE scenario. Furthermore, emission levels satisfy $e_i^{K,NT} \geq e_i^{K,EE} \geq e_i^{K,TE}$, for $K = \{M, C\}$.*

Hence, as countries assign a larger importance γ to their national consumer surplus, they set less strict environmental regulations to its corresponding firm in order to induce larger production levels (and lower prices). This result holds both for the case in which countries do not participate in international agreements and in the case they do.[21] Alternatively, weight γ could be interpreted as consumer's representation in the political process that determines emission standards. Under this interpretation, a larger political representation of consumers' interests would favor less stringent emission standards. Finally, note that we consider γ to be exogenous. However, firms might have incentives to spend resources into lobbying activities in order to increase the weight that policymakers assign to consumers' welfare, strategically inducing less stringent emission standards (as shown in proposition 7).

7 Conclusions

This paper analyzes two externalities that domestic environmental regulation imposes on foreign countries' welfare —environmental and competitive advantage externalities— under different market structures. In particular, under monopoly only environmental externalities are present, whereas under duopoly both types of externalities exist. The paper hence disentangles the effect of these externalities.

[19] For simplicity, we assume that $\gamma < 2$, which guarantees that the negative externalities from higher emissions (EE and CAE) dominate the positive consumer surplus externality. This assumption still allows countries to assign different weights to their consumers' welfare, either higher or lower than the importance countries assign to their domestic firm's profits, if $\gamma > 1$ and $\gamma < 1$, respectively.

[20] Note that, otherwise, less stringent emission standards from one country would impose an overall positive externality on other countries' welfare, and therefore international agreements should call for an increase in countries' emissions.

[21] Our results extend to other social welfare functions in which countries assign different weights to consumer surplus, profits and environmental damage from pollution. Specifically, the results hold when emissions standards are strategic substitutes, i.e., more stringent standards in one country lead other countries to relax the emission levels they set to domestic producers. Therefore, emission standards maintain their nature of global public goods.

We compare the emission standards independently selected by every country with respect to those they choose as members of an international environmental agreement, internalizing one or both types of externalities. The paper demonstrates that emission standards countries sign in international treaties that consider both types of externalities are more stringent than those internalizing only one externality. Furthermore, we show that firms' profits increase as a result of countries' participation in international agreements if the environmental damage from pollution is sufficiently low and pollution is not significantly transboundary. Hence, firms would actually favor their countries' participation in IEAs under certain conditions. This result provides an additional benefit from environmental agreements: to serve as a cooperative tool duopolists use to mitigate overproduction and increase profits, without the need to form collusive agreements.

The paper assumes that duopolists are symmetric in their cost structure. The model could be modified to consider the case in which firms are asymmetric. In such case, environmental regulation would not necessarily coincide across countries, both if countries participate in an IEA and if they do not. Asymmetric environmental regulations in equilibrium might induce firms to shift their production decision towards those countries with the least stringent emission standards. This could promote, for instance, acquisitions of firms located in countries with different environmental regulations, thus modifying the market structure.

Information about production costs is common knowledge among other firms and countries. In a different model, however, every firm would be privately informed about its marginal production costs, but not about rivals' costs. In contrast, governments might have relatively accurate information about their domestic firms' marginal costs after years of regulation. In this context, a government's environmental regulation to domestic firms signals information about the efficiency of national firms to their foreign competitors, which affects their entry decision.

8 Appendix

8.1 *Proof of Lemma 1*

Differentiating the monopolist's profit with respect to q_i and solving for q_i we obtain the monopolist output as a function of emission standard e_i,

$$q_i^M(e_i)=\frac{(a\theta-1)+4e_i}{2(2+\theta)}$$

In the case that firms i and j compete in quantities, firm i's best response function is,

$$q_i^C(q_j,e_i)=\begin{cases} \frac{(a\theta-1)+4e_i}{2(2+\theta)}-\frac{\theta}{2(2+\theta)}q_j & \text{if } q_j<\frac{a\theta-1+4e_i}{\theta} \\ 0 & \text{otherwise} \end{cases}$$

Note that, first, when $\frac{(a\theta-1)+4e_i}{2(2+\theta)} > \frac{(a\theta-1)+4e_j}{\theta}$ (i.e., if $e_i > \frac{(a\theta-1)(4+\theta)+(2+\theta)8e_j}{4\theta} \equiv \overline{e_i}$) we have that $q_i^C = \frac{(a\theta-1)+4e_i}{2(2+\theta)}$ and $q_j^C = 0$ (graphically, firms' best response functions intersect at the vertical intercept). Second, when $\frac{(a\theta-1)+4e_j}{2(2+\theta)} > \frac{(a\theta-1)+4e_i}{\theta}$ (i.e., if $e_i < \frac{4+\theta[1+4e_j+a(4+\theta)]}{8(2+\theta)} \equiv \underline{e_i}$), we have that $q_i^C = 0$ and $q_j^C = \frac{(a\theta-1)+4e_j}{2(2+\theta)}$ (in this case, firms' best response functions intersect at the horizontal intercept). Third, when $\frac{(a\theta-1)+4e_i}{2(2+\theta)} < \frac{(a\theta-1)+4e_j}{\theta}$ (i.e., if $\underline{e_i} < e_i < \overline{e_i}$), we have that $q_i^C(e_i,e_j) = \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)}$ (interior solution), which is positive if and only if $\underline{e_i} < e_i$, which is satisfied since $\underline{e_i} < e_i < \overline{e_i}$. Therefore, equilibrium output when firms compete a la Cournot is

$$q_i^C(e_i,e_j) = \begin{cases} \frac{(a\theta-1)+4e_i}{2(2+\theta)} & \text{if } \overline{e_i} \leq e_i, \\ \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)} & \text{if } \underline{e_i} \leq e_i < \overline{e_i}, \text{ and} \\ 0 & \text{if } e_i < \underline{e_i} \end{cases}$$

Note that existence of the Cournot equilibrium is satisfied: first, the inverse demand curve satisfies $p(0) = a$, which exceeds the marginal cost evaluated at $q_i = 0$, $\frac{1-4e_i}{\theta}$. Second, firm j's best response function, $q_j^C(q_i)$, evaluated at $q_i = 0$, $\frac{a\theta-1+4e_i}{\theta}$, exceeds the monopoly output $\frac{a\theta-1+4e_i}{2(2+\theta)}$, which holds for all parameter values. In addition, uniqueness of the Cournot equilibrium output is also satisfied since the absolute value of the slope of every firm's best response function, $\frac{\theta}{2(2+\theta)}$, is lower than one for all parameter values.

In the case where both countries set symmetric emission standards in the first stage of the game, $e_i = e_j$, we have that $\frac{(a\theta-1)+4e_i}{2(2+\theta)} < \frac{(a\theta-1)+4e_i}{\theta}$, as in the third case indicated above. Hence, the equilibrium output is an interior solution of the problem and $q_i^C(e_i,e_j) = \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)}$.

8.2 *Proof of Proposition 1*

Every country i maximizes its own social welfare by selecting e_i:

$$\max_{e_i} \; \Pi_i\left(q_i^M(e_i),e_i\right) - d(e_i+\alpha e_j)$$

where $\Pi_i \left(q_i^M(e_i), e_i\right)$ represents firm i's equilibrium profits under monopoly, for a given emission standard e_i. Differentiating with respect to e_i we obtain,

$$\underbrace{\frac{2(a\theta-1)}{\theta(2+\theta)}-\frac{4}{(2+\theta)}e_i}_{MB_i^M(e_i)}-\ d \leq 0$$

and solving for e_i,

$$e_i^{M,NT} = \begin{cases} \frac{a\theta-1}{2\theta} - \frac{2+\theta}{4}d & \text{if } d < d^M \text{, and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^M = \frac{2(a\theta-1)}{\theta(2+\theta)}$

8.3 *Proof of Proposition 2*

When countries maximize their joint welfare (internalizing both externalities, BE), they select e_i and e_j such that,

$$\max_{e_i\ ,e_j} \Pi_i \left(q_i^M(e_i), e_i\right) -d(e_i+\alpha e_j) + \Pi_j \left(q_j^M(e_j), e_j\right) -d(e_j+\alpha e_i)$$

differentiating with respect to e_i we obtain,

$$\underbrace{\frac{2(a\theta-1)}{\theta(2+\theta)}-\frac{4}{(2+\theta)}e_i}_{MB_i^M(e_i)}-d(1+\alpha) \leq 0$$

and similarly for e_j. Solving for e_i we have,

$$e_i^{M,BE} = \begin{cases} \frac{a\theta-1}{2\theta} - \frac{(2+\theta)(1+\alpha)}{4}d & \text{if } d < \frac{1}{(1+\alpha)}d^M \text{, and} \\ 0 & \text{otherwise.} \end{cases}$$

Finally, note that if countries only internalize the EE effect,

$$\max_{e_i}\ \Pi_i \left(q_i^M(e_i), e_i\right) -d(e_i+\alpha e_j) - d\alpha e_i$$

differentiating with respect to e_i we obtain the same first order conditions as in the BE case,

$$\frac{2(a\theta-1)}{\theta(2+\theta)}-\frac{4}{(2+\theta)}e_i-d(1+\alpha) \leq 0$$

Hence $e_i^{M,EE} = e_i^{M,BE}$.

8.4 *Proof of Proposition 3*

When every country independently sets e_i then,

$$\max_{e_i} \Pi_i(q_i^C(e_i, e_j), e_i) - d(e_i + \alpha e_j)$$

where $\Pi_i(q_i^C(e_i, e_j), e_i)$ denotes firm i's equilibrium profits under duopoly, for emission standards e_i and e_j. Differentiating with respect to e_i,

$$\frac{16(2+\theta)^2\left[\theta(a(4+\theta)-4e_j-1)-4\right]}{\theta(4+\theta)^2(4+3\theta)^2} - \frac{4\left[128+\theta(160+\theta(64+9\theta))\right]}{(4+\theta)^2(4+3\theta)^2}e_i - d \leq 0$$

where the first two terms represent the marginal benefit from setting less stringent emission standards to firm i, MB_i^C. In particular,

$$MB_i^C = \begin{cases} \frac{16(2+\theta)^2[\theta(a(4+\theta)-4e_j-1)-4]}{\theta(4+\theta)^2(4+3\theta)^2} - \frac{4[128+\theta(160+\theta(64+9\theta))]}{(4+\theta)^2(4+3\theta)^2}e_i & \text{if } e_i > \widehat{e_i} \\ 0 & \text{otherwise} \end{cases}$$

where $\widehat{e_i} = \frac{4(2+\theta)^2[\theta(a(4+\theta)-4e_j-1)-4]}{\theta[128+\theta(160+\theta(64+9\theta))]}$, and similarly for country j. Solving for e_i we obtain $e_i(e_j)$. By symmetry, we simultaneously solve for e_i and e_j to obtain

$$e_i^{C,NT} = \begin{cases} \frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]} - \frac{(4+\theta)(4+3\theta)^2}{4[48+\theta(44+9\theta)]}d & \text{if } d < d^{C,NT}\text{, and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^{C,NT} = \frac{16(2+\theta)^2(a\theta-1)}{\theta(4+\theta)(4+3\theta)^2}$.

8.5 *Proof of Proposition 4*

When countries internalize the EE effect, country i selects e_i to maximize,

$$\max_{e_i} \Pi_i(q_i^C(e_i, e_j), e_i) - d(e_i + \alpha e_j) - d\alpha e_i$$

differentiating with respect to e_i,

$$MB_i^C - d(1+\alpha) \leq 0$$

where MB_i^C is defined in the proof of Proposition 3. Solving for e_i, and applying symmetry we obtain,

$$e_i^{C,EE} = \begin{cases} \frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]} - \frac{(1+\alpha)(4+\theta)(4+3\theta)^2}{4[48+\theta(44+9\theta)]}d & \text{if } d < \frac{1}{(1+\alpha)}d^{C,NT}\text{, and} \\ 0 & \text{otherwise.} \end{cases}$$

When countries internalize both types of externalities, they choose e_i and e_j in order to maximize their joint welfare,

$$\max_{e_i, e_j} \Pi_i(q_i^C(e_i, e_j), e_i) - d(e_i + \alpha e_j) + \Pi_j(q_j^C(e_i, e_j), e_j) - d(e_j + \alpha e_i)$$

differentiating with respect to e_i,

$$\underbrace{\frac{d\Pi_i}{de_i}}_{(+)} + \underbrace{\frac{d\Pi_j}{de_i}}_{(-)} - d(1+\alpha) \leq 0$$

where $\frac{d\Pi_i}{de_i} + \frac{d\Pi_j}{de_i} \equiv MB_i^{C,BE}$, and in particular,

$$MB_i^{C,BE} = \begin{cases} \frac{8(2+\theta)\left[\theta(a(4+\theta)^2-16(2+\theta)e_j-\theta-8)-16\right]}{\theta(4+\theta)^2(4+3\theta)^2} - \frac{4[128+\theta(144+\theta(56+9\theta))]}{(4+\theta)^2(4+3\theta)^2}e_i & \text{if } e_i > \widetilde{e_i} \\ 0 \quad \text{otherwise} \end{cases}$$

where $\widetilde{e_i} = \frac{2(2+\theta)^2\left[\theta(a(4+\theta)^2-16(2+\theta)e_j-\theta-8)-16\right]}{\theta[128+\theta(144+\theta(56+9\theta))]}$, and similarly for country j. Solving for e_i and e_j and applying symmetry,

$$e_i^{C,BE} = \begin{cases} \frac{2(2+\theta)(a\theta-1)}{\theta(16+9\theta)} - \frac{(4+3\theta)^2}{32+18\theta}d & \text{if } d < d^{C,BE}, \text{ and} \\ 0 \quad \text{otherwise.} \end{cases}$$

where $d^{C,BE} = \frac{4(2+\theta)(a\theta-1)}{\theta(4+3\theta)^2}$.

8.6 *Proof of Corollary 1*

Under monopoly markets, $e_i^{M,NT} \geq e_i^{M,EE} = e_i^{M,BE}$ since $e_i^{M,NT} - e_i^{M,EE} \equiv FR^M$, which is weakly positive for all parameter values (see section 4.1).

Under duopoly markets, first note that $e_i^{C,NT} \geq e_i^{C,EE}$ since they both start at the same vertical intercept, $\frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]}$, and they are both linear in d, but $e_i^{C,EE}$ decreases in d faster than $e_i^{C,NT}$ does (in particular, from propositions 3 and 4, the negative slope of $e_i^{C,EE}$ is $(1+\alpha)$ times larger than that of $e_i^{C,NT}$). Similarly, $e_i^{C,EE} \geq e_i^{C,BE}$ since the vertical intercept of $e_i^{C,EE}$ is higher than that of $e_i^{C,BE}$, i.e., $\frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]} > \frac{2(2+\theta)(a\theta-1)}{\theta(16+9\theta)}$, and in addition, both expressions are linearly decreasing in d, but the horizontal intercept of $e_i^{C,EE}$, $\frac{1}{1+\alpha}d^{C,NT}$, is larger than that of $e_i^{C,BE}$, $d^{C,BE}$, i.e., $\frac{1}{1+\alpha}\frac{16(2+\theta)^2(a\theta-1)}{\theta(4+\theta)(4+3\theta)^2} > \frac{4(2+\theta)(a\theta-1)}{\theta(4+3\theta)^2}$.

Let us now show that $e_i^{M,BE} \geq e_i^{C,NT}$. From propositions 2 and 3 we know that, first, the vertical intercept of $e_i^{M,BE}$, $\frac{a\theta-1}{2\theta}$, is higher than that of $e_i^{C,NT}$, $\frac{4(2+\theta)^2(a\theta-1)}{\theta[48+\theta(44+9\theta)]}$. Second, both expressions are linear and decreasing in d, but the horizontal intercept of $e_i^{M,BE}$, $\frac{1}{1+\alpha}d^M$, is larger than that of $e_i^{C,NT}$, $d^{C,NT}$. Specifically, $\frac{1}{1+\alpha}\frac{2(a\theta-1)}{\theta(2+\theta)} > \frac{16(2+\theta)^2(a\theta-1)}{\theta(4+\theta)(4+3\theta)^2}$. We can therefore conclude that the complete ranking of emission standards under monopoly and duopoly satisfies

$$e_i^{M,NT} \geq e_i^{M,EE} = e_i^{M,BE} \geq e_i^{C,NT} \geq e_i^{C,EE} \geq e_i^{C,BE}$$

8.7 *Proof of Proposition 5*

EE treaty. We compare equilibrium profits without treaty, $\Pi_i^{C,NT}$, and with an international treaty that internalizes the EE effect alone, $\Pi_i^{C,EE}$. First, we compare profits under positive emission levels, $d < d^{C,EE}$; second under environmental damages supporting positive emission standards only under NT, $d^{C,EE} < d < d^{C,NT}$; and third, when environmental damages sustain zero emissions both under NT and EE, $d^{C,NT} < d$. When emissions are positive, we have

$$\Pi_i^{C,NT} - \Pi_i^{C,EE} = \frac{d\alpha(4+\theta)(4+3\theta)^2(32+A\theta)}{8\theta[48+\theta(44+9\theta)]^2}$$

where $A \equiv 16 - 16a(2+\theta) + d(2+\alpha)(4+\theta)(16+9\theta)$. In particular, starting at $d = 0$ we have $\Pi_i^{C,NT} - \Pi_i^{C,EE} = 0$, then the difference decreases in d (becoming negative) for all $d < \frac{1}{2}d^{EE}$, and it then increases for $d > \frac{1}{2}d^{EE}$, becoming $\Pi_i^{C,NT} - \Pi_i^{C,EE} = 0$ at exactly $d = d^{EE}$, where

$$d^{EE} \equiv \frac{16(2+\theta)(a\theta-1)}{(2+\alpha)\theta(4+\theta)(16+9\theta)}$$

Therefore, for positive emission levels, $\Pi_i^{C,NT} - \Pi_i^{C,EE} < 0$ if and only if $0 < d < d^{EE}$ (which implies $\Pi_i^{C,NT} < \Pi_i^{C,EE}$), and $\Pi_i^{C,NT} - \Pi_i^{C,EE} > 0$ otherwise (i.e., $\Pi_i^{C,NT} > \Pi_i^{C,EE}$). Furthermore, note that d^{EE} satisfies $d^{EE} < d^{C,EE} < d^{C,NT}$ for all parameter values, which implies that the result $\Pi_i^{C,NT} < \Pi_i^{C,EE}$ indeed occurs at levels of environmental damage for which countries set positive emission standards, both under NT and EE. Second, if $d^{C,EE} < d < d^{C,NT}$, then $e^{C,EE} = 0$ but $e^{C,NT} > 0$. When comparing equilibrium profits under these conditions, $\Pi_i^{C,NT} - \Pi_i^{C,EE} > 0$ starting at the lower bound of this interval $d = d^{C,EE}$ and this difference converges to zero only at the upper bound of this interval, $d = d^{C,NT}$. Third, if $d > d^{C,NT}$ then emission standards are zero both under NT and EE, and $\Pi_i^{C,NT} = \Pi_i^{C,EE}$ for all $d > d^{C,NT}$. Summarizing, $\Pi_i^{C,NT} < \Pi_i^{C,EE}$ for all $d < d^{EE}$, and $\Pi_i^{C,NT} \geq \Pi_i^{C,EE}$ for all $d > d^{EE}$.

BE treaty. Let us now compare equilibrium profits without treaty, $\Pi_i^{C,NT}$, and with an international agreement that internalizes both the EE and CAE effects, $\Pi_i^{C,BE}$. In the case of positive emission levels, $d < d^{C,BE}$,

$$\Pi_i^{C,NT} - \Pi_i^{C,BE} = \frac{(4+3\theta)^2[16+\theta(8-8a(2+\theta)+dB][\theta((8a(2+\theta)-8+dC)-16]}{8\theta^2(16+9\theta)[48+\theta(44+9\theta)]^2}$$

where $B = 48\alpha + 44\alpha\theta + 9(2+\alpha)\theta^2 + 16(7+6\theta)$ and $C = \alpha[48+\theta(44+9\theta)] - 8(2+\theta)$. Specifically, starting at $d = 0$ we have that $\Pi_i^{C,NT} - \Pi_i^{C,BE} = -\frac{8(2+\theta)^2(a\theta-1)^2(4+3\theta)^2}{\theta^2(16+9\theta)[48+\theta(44+9\theta)]^2} < 0$, then the difference increases in d for all $d < d^{C,BE}$, becoming zero only at $d = d^{BE}$, where

$$d^{BE} \equiv \frac{8(2+\theta)(a\theta-1)}{\alpha[48\alpha+44\alpha\theta+9(2+\alpha)\theta^2+16(7+6\theta)]}$$

Note that the difference $d^{BE} - d^{C,BE}$ is decreasing α, and becomes zero at $\alpha = -\frac{3[32+3\theta(8+\theta)]}{4(8+5\theta)} < 0$. Therefore, $d^{BE} < d^{C,BE}$ for all parameter values. The ranking $d^{BE} < d^{C,BE}$ implies that the above result $\Pi_i^{C,NT} < \Pi_i^{C,BE}$ indeed occurs at levels of environmental damage for which countries set positive emission standards, both under NT and BE. Second, if $d^{C,BE} < d < d^{C,NT}$, then $e^{C,BE} = 0$ but $e^{C,NT} > 0$. When comparing equilibrium profits under these conditions, $\Pi_i^{C,NT} - \Pi_i^{C,BE} > 0$ starting at the lower bound of this interval, $d = d^{C,BE}$, and this difference converges to zero only at the upper bound of this interval, $d = d^{C,NT}$. Third, if $d > d^{C,NT}$ then emission standards are zero both under NT and BE, and $\Pi_i^{C,NT} = \Pi_i^{C,BE}$ for all $d > d^{C,NT}$. Summarizing, $\Pi_i^{C,NT} < \Pi_i^{C,BE}$ for all $d < d^{BE}$, and $\Pi_i^{C,NT} \geq \Pi_i^{C,BE}$ for all $d > d^{BE}$.

Finally, note that the difference between the two cutoffs identified in this proof, $d^{BE} - d^{EE}$, is decreasing in α, and becomes zero at $\alpha = -\frac{2(48+48\theta+9\theta^2)}{32+36\theta+9\theta^2} < 0$. Therefore $d^{BE} < d^{EE}$ for all parameter values.

8.8 *Proof of Proposition 6*

If both oligopolists form a cartel in which they choose q_i and q_j in order to maximize their *joint* profits,

$$q_i^{cartel}(e_i, e_j) = \begin{cases} \frac{(a\theta-1)+4e_i}{2(2+\theta)} & \text{if } e_i > \frac{(a\theta-1)+2(2+\theta)e_j}{2\theta}, \\ \frac{\theta[a(4+\theta)-1-8e_j]+4e_i(4+3\theta)-4}{(4+\theta)(4+5\theta)} & \text{if } \frac{(a\theta-1)+2\theta e_j}{4+2\theta} < e_i < \frac{(a\theta-1)+2(2+\theta)e_j}{2\theta}, \text{ and} \\ 0 & \text{if } \frac{(a\theta-1)+2\theta e_j}{4+2\theta} > e_i \end{cases}$$

Note that in the case that both countries set symmetric emission standards in the first stage of the game, $e_i = e_j$, equilibrium output $q_i^{cartel}(e_i, e_j)$ is an interior solution of the problem.

1. **Cartel with no treaty.** When every country i maximizes its own social welfare by selecting e_i

$$\max_{e_i} \ \Pi_i(q_i^{cartel}(e_i, e_j), e_i) - d(e_i + \alpha e_j)$$

differentiating with respect to e_i, solving for e_i, and applying symmetry, we obtain

$$e_i^{cartel,NT} = \begin{cases} \frac{(a\theta-1)[16+\theta(32+13\theta)]}{\theta[48+\theta(88+25\theta)]} - \frac{(4+\theta)(4+5\theta)^2}{4[48+\theta(88+25\theta)]}d & \text{if } d \leq d^{cartel,NT} \\ 0 & \text{otherwise} \end{cases}$$

where $d^{cartel,NT} \equiv \frac{4(a\theta-1)[16+\theta(32+13\theta)]}{\theta(4+\theta)(4+5\theta)^2}$. Note that

$$e_i^{cartel,NT} - e_i^{C,NT} = \frac{(4+\theta)(a\theta-1-d\theta)[16+\theta(40+17\theta)]}{[48+\theta(44+9\theta)][48+\theta(88+25\theta)]}$$

which is positive for all $d < \frac{a\theta-1}{\theta}$. Since $d^{C,NT} < d^{cartel,NT} < \frac{a\theta-1}{\theta}$ for all parameters values, we can conclude that, for all strictly positive emission standards under the cartel ($d < d^{cartel,NT}$) emission standards satisfy $e_i^{cartel,NT} > e_i^{C,NT}$.

2. **Cartel considering the EE effect.** When countries internalize the EE effect, country i selects e_i to maximize

$$\max_{e_i} \ \Pi_i(q_i^{cartel}(e_i, e_j), e_i) - d(e_i + \alpha e_j) - d\alpha e_i$$

differentiating with respect to e_i, solving for e_i, and applying symmetry, we obtain

$$e_i^{cartel,EE} = \begin{cases} \frac{(a\theta-1)[16+\theta(32+13\theta)]}{\theta[48+\theta(88+25\theta)]} - \frac{(1+\alpha)(4+\theta)(4+5\theta)^2}{4[48+\theta(88+25\theta)]} d \text{ if } d \leq \frac{1}{1+\alpha} d^{cartel,NT} \\ 0 \quad \text{otherwise} \end{cases}$$

Note that

$$e_i^{cartel,EE} - e_i^{C,EE} = \frac{a\theta - 1 - (1+\alpha)d\theta}{a\theta - 1 - d\theta} \times (e_i^{cartel,NT} - e_i^{C,NT})$$

which is positive for all $d < \frac{a\theta-1}{(1+\alpha)\theta}$. Since, $d^{C,NT} < d^{cartel,NT} < \frac{a\theta-1}{\theta}$, then $\frac{1}{1+\alpha} d^{C,NT} < \frac{1}{1+\alpha} d^{cartel,NT} < \frac{a\theta-1}{(1+\alpha)\theta}$ for all parameter values. We can therefore conclude that for all strictly positive emission standards under the cartel ($d \leq \frac{1}{1+\alpha} d^{cartel,NT}$) emission levels satisfy $e_i^{cartel,EE} \geq e_i^{C,EE}$.

3. **Cartel considering the EE and CAE effects.** When countries internalize both types of externalities, they choose e_i and e_j in order to maximize their joint welfare.

$$\max_{e_i, e_j} \ \Pi_i(q_i^{cartel}(e_i, e_j), e_i) - d(e_i + \alpha e_j) + \Pi_j(q_j^{cartel}(e_i, e_j), e_i) - d(e_j + \alpha e_i)$$

differentiating with respect to e_i, solving for e_i, and applying symmetry,

$$e_i^{cartel,BE} = \begin{cases} \frac{2(a\theta-1)(2+3\theta)}{\theta(16+25\theta)} - \frac{(1+\alpha)(4+5\theta)^2}{64+100\theta} d \text{ if } d \leq d^{cartel,BE} \\ 0 \text{ otherwise} \end{cases}$$

where $d^{cartel,BE} \equiv \frac{8(a\theta-1)(2+3\theta)}{\theta(1+\alpha)(4+5\theta)^2}$. Note that

$$e_i^{cartel,BE} - e_i^{C,BE} = \frac{4\theta(a\theta - 1 - (1+\alpha)d\theta)}{(16+9\theta)(16+25\theta)} \times (e_i^{cartel,NT} - e_i^{C,NT})$$

which is positive for all $d < \frac{a\theta-1}{(1+\alpha)\theta}$. Since, $d^{C,BE} < d^{cartel,BE} < \frac{a\theta-1}{(1+\alpha)\theta}$. Therefore, for all strictly positive emission standards under the cartel ($d \leq d^{cartel,BE}$) emission standards satisfy $e_i^{cartel,BE} \geq e_i^{C,BE}$.

4. **Ranking.** First, note that, $e_i^{cartel,NT} - e_i^{cartel,EE} = \frac{d(4+\theta)(4+5\theta)^2}{\theta[48+\theta(88+25\theta)]} > 0$. Second, note that

$$e_i^{cartel,EE} - e_i^{cartel,BE} = \frac{(4+7\theta)(4+5\theta)^2(a\theta - 1 - (1+\alpha)d\theta)}{\theta(16+25\theta)[48+\theta(88+25\theta)]} > 0$$

which is positive for all strictly positive emission levels under cartel, as shown above, i.e., $d < \frac{a\theta-1}{(1+\alpha)\theta}$. Therefore, $e_i^{cartel,NT} \geq e_i^{cartel,EE} \geq e_i^{cartel,BE}$.

5. **Output comparison.** Under no treaty, cartel output satisfies

$$q_i^{cartel,NT} = \frac{(4+\theta)(4+5\theta)[a\theta-1-d\theta]}{\theta[48+\theta(88+25\theta)]} \leq \frac{(4+\theta)(4+3\theta)[a\theta-1-d\theta]}{\theta[48+\theta(44+9\theta)]} = q_i^{C,NT}$$

for all parameter values. Under the treaty internalizing the EE effect alone, cartel output

$$q_i^{cartel,EE} = \frac{(4+\theta)(4+5\theta)[a\theta-1-d(1+\alpha)\theta]}{\theta[48+\theta(88+25\theta)]} \leq \frac{(4+\theta)(4+3\theta)[a\theta-1-d(1+\alpha)\theta]}{\theta[48+\theta(44+9\theta)]} = q_i^{C,EE}$$

for all parameter values. Finally, under the treaty internalizing both the EE and CAE effects, cartel output satisfies

$$q_i^{cartel,BE} = \frac{(4+5\theta)[a\theta-1-d(1+\alpha)\theta]}{\theta(16+25\theta)} \leq \frac{(4+3\theta)[a\theta-1-d(1+\alpha)\theta]}{\theta(16+9\theta)} = q_i^{C,BE}$$

for all parameter values.

8.9 *Proof of Proposition 7*

First note that firms' maximization problem is unaffected, relative to the case in which consumer surplus was not considered. Hence, for given emission standards e_i and e_j, both monopoly output $q_i^M(e_i)$ and duopoly output $q_i^C(e_i, e_j)$ coincide with that specified in Lemma 1. Let us next examine equilibrium emission standards.

1. **Monopoly with no treaty.** Every country i maximizes its own social welfare by independently selecting e_i,

$$\max_{e_i} \quad \gamma \left[\frac{1}{2}\left(a - p_i^M(e_i)\right) q_i^M(e_i)\right] + \Pi_i\left(q_i^M(e_i), e_i\right) - d(e_i + \alpha e_j)$$

Differentiating with respect to e_i, solving for e_i and applying symmetry,

$$e_i^{M,NT} = \begin{cases} \frac{(a\theta-1)[4+(2+\gamma)\theta]}{4\theta(2+\theta-\gamma)} - \frac{(2+\theta)^2}{4(2+\theta-\gamma)}d & \text{if } d < d^{M,NT}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^{M,NT} \equiv \frac{(a\theta-1)[4+(2+\gamma)\theta]}{\theta(2+\theta)^2}$. First, note that $e_i^{M,NT}$ is decreasing in d for all $\gamma < 2 < 2+\theta$, which is satisfied by assumption. Additionally, note that $e_i^{M,NT}$ is weakly increasing in γ since

$$\frac{\partial e_i^{M,NT}}{\partial \gamma} = \frac{(2+\theta)(a\theta - 1 - d\theta)}{4\theta(2+\theta-\gamma)^2}$$

which is weakly positive for all $d < \frac{a\theta-1}{\theta}$, which is satisfied since $d < d^{M,NT} < \frac{a\theta-1}{\theta}$.

2. **Monopoly, with a treaty considering the EE effect.** When countries consider the EE

effect that their emission impose on other countries, they select e_i such that

$$\max_{e_i} \ \gamma \left[\frac{1}{2} \left(a - p_i^M(e_i) \right) q_i^M(e_i) \right] + \Pi_i \left(q_i^M(e_i), e_i \right) - d(e_i + \alpha e_j) - d\alpha e_i$$

Differentiating with respect to e_i, solving for e_i and applying symmetry,

$$e_i^{M,EE} = \begin{cases} \frac{(a\theta-1)[4+(2+\gamma)\theta]}{4\theta(2+\theta-\gamma)} - \frac{(1+\alpha)(2+\theta)^2}{4(2+\theta-\gamma)} d & \text{if } d < \frac{1}{1+\alpha} d^{M,NT}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

Similarly for country j. Note that if countries consider all externalities,

$$\max_{e_i, e_j} \ \gamma \left[\frac{1}{2} \left(a - p_i^M(e_i) \right) q_i^M(e_i) \right] + \Pi_i \left(q_i^M(e_i), e_i \right) - d(e_i + \alpha e_j) +$$
$$\gamma \left[\frac{1}{2} \left(a - p_j^M(e_i) \right) q_j^M(e_i) \right] + \Pi_j \left(q_j^M(e_j), e_j \right) - d(e_j + \alpha e_i)$$

Differentiating with respect to e_i we obtain the same first order conditions than in the case where countries only consider the EE effect. Hence, solving for e_i we find that $e_i^{M,TE} = e_i^{M,EE}$. First, note that $e_i^{M,EE}$ is decreasing in d for all $\gamma < 2 < 2+\theta$, which is satisfied by assumption. Second, $e_i^{M,EE}$ is increasing in γ since

$$\frac{\partial e_i^{M,EE}}{\partial \gamma} = \frac{(2+\theta)^2 \left[a\theta - 1 - d(1+\alpha)\theta \right]}{4\theta(2+\theta-\gamma)^2}$$

which is positive for all $d < \frac{a\theta-1}{(1+\alpha)\theta}$ since $d < \frac{1}{1+\alpha} d^{M,NT} < \frac{a\theta-1}{(1+\alpha)\theta}$. Third, $e_i^{M,NT} \geq e_i^{M,EE} = e_i^{M,TE}$ given that

$$e_i^{M,NT} - e_i^{M,EE} = \frac{d\alpha \left(2+\theta\right)^2}{4(2+\theta-\gamma)},$$

which is positive by definition since $\gamma < 2 < 2+\theta$.

3. **Duopoly with no treaty.** When every country independently sets e_i,

$$\max_{e_i} \ \gamma \left[\frac{1}{2} \left(a - p^C(e_i, e_j) \right) q_i^C(e_i, e_j) \right] + \Pi_i \left(q_i^C(e_i, e_j), e_i \right) - d(e_i + \alpha e_j)$$

Differentiating with respect to e_i, solving for e_i, and applying symmetry, we obtain

$$e_i^{C,NT} = \begin{cases} \frac{(a\theta-1)[32+\theta(8(4+\theta)+\gamma(12+5\theta))]}{2\theta[48-2\gamma(12+5\theta)+\theta(44+9\theta)]} - \frac{(4+\theta)(4+3\theta)^2}{4[48-2\gamma(12+5\theta)+\theta(44+9\theta)]} d & \text{if } d < d^{C,NT}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^{C,NT} \equiv \frac{2(a\theta-1)[32+\theta(8(4+\theta)+\gamma(12+5\theta))]}{\theta(4+\theta)(4+3\theta)^2}$. First, note that $e_i^{C,NT}$ is decreasing in d for all $\gamma < \frac{48+\theta(44+9\theta)}{24+10\theta}$, which is satisfied by assumption since $\gamma < 2 < \frac{48+\theta(44+9\theta)}{24+10\theta}$. Second, $e_i^{C,NT}$ is weakly increasing in γ given that

$$\frac{\partial e_i^{C,NT}}{\partial \gamma} = \frac{(4+\theta)(4+3\theta)^2(12+5\theta)(a\theta-1-d\theta)}{2\theta\left[48-2\gamma(12+5\theta)+\theta(44+9\theta)\right]^2}$$

which is positive for all $d < \frac{a\theta-1}{\theta}$, which is satisfied since $d < d^{C,NT} < \frac{a\theta-1}{\theta}$.

4. **Duopoly, with treaty considering the EE effect.** When countries consider the EE effect, they select e_i

$$\max_{e_i} \ \gamma\left[\frac{1}{2}\left(a-p^C(e_i,e_j)\right)q_i^C(e_i,e_j)\right]+\Pi_i\left(q_i^C(e_i,e_j),e_i\right)-d(e_i+\alpha e_j)-d\alpha e_i$$

Differentiating with respect to e_i, solving for e_i, and applying symmetry,

$$e_i^{C,EE} = \begin{cases} \frac{(a\theta-1)[32+\theta(8(4+\theta)+\gamma(12+5\theta))]}{2\theta[48-2\gamma(12+5\theta)+\theta(44+9\theta)]} - \frac{(1+\alpha)(4+\theta)(4+3\theta)^2}{4[48-2\gamma(12+5\theta)+\theta(44+9\theta)]}d & \text{if } d < \frac{1}{1+\alpha}d^{C,NT}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

First, note that $e_i^{C,EE}$ is decreasing in d for all $\gamma < \frac{48+\theta(44+9\theta)}{24+10\theta}$, which holds by definition since $\gamma < 2 < \frac{48+\theta(44+9\theta)}{24+10\theta}$. Second, $e_i^{C,EE}$ is weakly increasing in γ given that

$$\frac{\partial e_i^{C,EE}}{\partial \gamma} = \frac{(4+\theta)(4+3\theta)^2(12+5\theta)\left[a\theta-1-d(1+\alpha)\theta\right]}{2\theta\left[48-2\gamma(12+5\theta)+\theta(44+9\theta)\right]^2}$$

which is positive for all $d < \frac{a\theta-1}{(1+\alpha)\theta}$, which is satisfied since $d < \frac{1}{1+\alpha}d^{C,NT} < \frac{a\theta-1}{(1+\alpha)\theta}$.

5. **Duopoly, with treaty considering all externalities.** When countries internalize all externalities, they choose e_i and e_j in order to maximize their joint social welfare,

$$\max_{e_i,e_j} \ \gamma\left[\frac{1}{2}\left(a-p^C(e_i,e_j)\right)q_i^C(e_i,e_j)\right]+\Pi_i\left(q_i^C(e_i,e_j),e_i\right)-d(e_i+\alpha e_j)+$$
$$\gamma\left[\frac{1}{2}\left(a-p^C(e_i,e_j)\right)q_j^C(e_j,e_i)\right]+\Pi_j\left(q_j^C(e_j,e_i),e_j\right)-d(e_j+\alpha e_i)$$

Differentiating with respect to e_i, solving for e_i and e_j, and applying symmetry,

$$e_i^{C,EE} = \begin{cases} \frac{2(a\theta-1)(2+\theta+\gamma\theta)}{\theta(16+9\theta-8\gamma)} - \frac{(1+\alpha)(4+3\theta)^2}{4(16+9\theta-8\gamma)}d & \text{if } d < d^{C,TE}, \text{ and} \\ 0 & \text{otherwise.} \end{cases}$$

where $d^{C,TE} \equiv \frac{8(a\theta-1)(2+\theta+\gamma\theta)}{\alpha(1+\alpha)(4+3\theta)^2}$ First, note that $e_i^{C,TE}$ is decreasing in d for all $\gamma < 2+\frac{9\theta}{8}$, which holds by definition since $\gamma < 2 < 2+\frac{9\theta}{8}$. Second, $e_i^{C,TE}$ is weakly increasing in γ given that

$$\frac{\partial e_i^{C,EE}}{\partial \gamma} = \frac{2(4+3\theta)^2\left[a\theta-1-d(1+\alpha)\theta\right]}{\theta(16+9\theta-8\gamma)^2}$$

which is positive for all $d < \frac{a\theta-1}{(1+\alpha)\theta}$, which is satisfied since $d < d^{C,TE} < \frac{a\theta-1}{(1+\alpha)\theta}$.

6. **Ranking.** First, note that $e_i^{C,NT} \geq e_i^{C,EE}$ since

$$e_i^{C,NT} - e_i^{C,EE} = \frac{d\alpha\left(4+\theta\right)\left(4+3\theta\right)^2}{4\left[48-2\gamma\left(12+5\theta\right)+\theta\left(44+9\theta\right)\right]}$$

which is weakly positive for all $\gamma < \frac{48+\theta(44+9\theta)}{24+10\theta}$, which holds by definition since $\gamma < 2 < \frac{48+\theta(44+9\theta)}{24+10\theta}$. Similarly, $e_i^{C,EE} \geq e_i^{C,TE}$ since

$$e_i^{C,EE} - e_i^{C,TE} = \frac{\left(4+3\theta\right)^2\left[a\theta-1-d(1+\alpha)\theta\right]\left[4(2+\theta)-\gamma(4-\theta)\right]}{2\theta(16+9\theta-8\gamma)\left[48-2\gamma\left(12+5\theta\right)+\theta\left(44+9\theta\right)\right]}$$

which is weakly positive since $d < d^{C,TE} < \frac{a\theta-1}{(1+\alpha)\theta}$, $\gamma < 2 < \frac{4(2+\theta)}{4-\theta}$, $\gamma < 2 < 2+\frac{9\theta}{8}$, and $\gamma < 2 < \frac{48+\theta(44+9\theta)}{24+10\theta}$. Therefore, $e_i^{C,NT} \geq e_i^{C,EE} \geq e_i^{C,TE}$.

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