When do Firms Support Environmental Agreements?*

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Abstract

Several firms have recently supported their countries' participation in international environmental agreements where countries commit to stricter environmental regulation. This paper analyzes the rationale of this conduct by examining equilibrium emission standards with and without environmental treaties. We identify that more stringent environmental regulation produces two effects on firm profits: a negative effect due to larger abatement costs, and a positive effect that arises from the amelioration of duopoly overproduction. We describe under which conditions the positive effect dominates the negative effect, increasing firm profits, and inducing them to support their countries' participation in environmental treaties.

KEYWORDS: Transboundary pollution; Strategic environmental policy; International environmental agreement; Market structure.

JEL CLASSIFICATION: C72, F12 , H23, Q28.

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1 Introduction

Lobbyists usually oppose stricter environmental policies on the grounds that such regulation increases abatements costs, ultimately reducing their profitability and employment in the industry. However, examples abound about firms supporting their countries' participation in international environmental agreements (IEAs) that include more stringent environmental standards. One example is the "e-mission 55" initiative, where more than 200 companies from around the world favored their countries' implementation of the Kyoto protocol in 2001 including, among others, the German producer of electrical equipment AEG, the Japanese global manufacturing companies Ricoh and Kyocera, and the multinational corporation ABB Group.[1] Similarly, the Pew Center on Global Climate Change, with 46 companies, constitutes the "largest nonprofit U.S.-based association of corporations focused on addressing the challenges of climate change and supporting *mandatory* climate policy," and includes among its members the chemical company DuPont, the mining company Rio Tinto, Boeing, the oil company BP, and General Electric. In addition, in their guiding principles firms agree that the international climate framework after the Kyoto protocol "must establish [...] binding commitments for all developed and major developing economies."[2]

In this paper we show that these firms' conduct can be explained by the reduction in aggregate output that stricter environmental standards induce.[3] In particular, we demonstrate that a country's participation in an IEA reduces emission standards, producing both a negative and positive effect on firms' profits in a duopoly market. On one hand, more stringent environmental standards increase firms' abatement costs. On the other hand, stricter emission standards in all countries participating in the IEA reduce aggregate output (ameliorating overproduction in oligopoly), thus increasing market prices and profits.

Comparing the relative size of these effects, this paper shows that when the environmental damage is relatively high and countries set very stringent emission standards when participating in an international treaty, they impose 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 is relatively low and countries slightly reduce their emission standards under the treaty, a positive effect is generated on oligopoly profits. This effect 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.

[1] Founded by the European Business Council for Sustainable Energy, the e-mission 55 initiative also includes firms such as the UK's leading supplier of liquefied petroleum gas CalorGas, the German railway company Deutsche Bahn AG, the Japanese multinational manufacturer Shimano (producer of cycling, fishing, and rowing equipment), and one of the world largest suppliers of injection molding systems, Husky.

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

[3] A firm's support of IEAs could also be explained by the firm's public image towards environmentally-oriented customers. Our paper demonstrates that, even in the absence of public image considerations, firms would still favor IEAs under certain parameter conditions.

The paper examines a two-stage game where, first, governments set their domestic environmental regulations, and second, every firm decides its production level given the emission standards countries previously established. When countries independently select emission standards they impose two external effects on other countries' welfare: first, an environmental externality when pollution is transboundary; and second, a "competitive advantage externality," or eco-dumping, since lax environmental policies reduce domestic firms' costs, increasing its profits relative to foreign competitors.[4] In contrast, by participating in international treaties, countries are capable of internalizing one or both types of externalities.

Previous literature analyzes environmental policy allowing for pollution to be transboundary and considering the competitive advantage externality that such policy generates; see Barrett (1994) and Kennedy (1994).[5] We build on this literature focusing on the effect that regulation has on firms' profits and, as a consequence, firms' support of their countries' participation in IEAs. Farzin (2003) also analyzes the positive effects of environmental regulation on firms' profits by introducing the role of demand. Specifically, he shows under which conditions the implementation of stricter environmental standards can lead to higher product quality, boosting demand, and ultimately increasing profits. Our paper provides an additional positive effect of environmental policy on firms' profits stemming from a reduction in aggregate output, which might outweigh the negative effect of more stringent environmental policies. Therefore, we present a context where firms have the incentives to actively favor their countries' participation in IEAs even if stricter environmental policies do not improve product quality. Our results are also related with those in Porter (1991) and Porter and van der Linde (1995a,b). They show that, in a dynamic setting, firms' profits can increase due to the effect that regulation has on innovation incentives. In contrast, we offer a static model where firms' profits can increase even in the absence of those incentives.

The structure of the paper is as follows. Section 2 develops the model. Section 3 describes equilibrium emission standards under different market structures and its consequence on firms' profits. Section 4 examines emission standards when firms collude in cartel agreements. We finally discuss the main results.

2 Model

Let us consider two countries that independently determine their environmental regulation, where a single firm exists 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

[4] Strictly speaking, the "competitive advantage externality" is a pecuniary externality (or a spillover effect), since a change in the environmental regulation in one country affects the profits of firms located in other countries. In addition, when countries participate in IEAs that internalize the competitive advantage externality, they set more stringent emission standards and, as a consequence, firms competing under duopoly benefit from the amelioration of overproduction.

[5] 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 firms' location is an endogenous variable see Markusen et al. (1992, 1993), Rauscher (1993) and Ulph (1994).

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). Let $\alpha \geq 0$ be the emissions from country i that reach country j, producing an environmental externality. Note that this embodies the setting in Ulph (1996a) and Barrett (1994), where emissions do not impose environmental externalities ($\alpha = 0$) as a special case.

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 with one unit of pollution.[6] Hence, the amount of pollution that firm i must abate given the emission standard e_i is $A_i \equiv q_i - e_i$, representing the difference between the firm's pollution (associated with 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. 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 are given by

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

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 $a > \frac{1}{\theta}$.[7] 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 $W_i(q_i, q_j, e_i, e_j) = \pi_i\left(q_i, q_j, e_i\right) - d \times (e_i + \alpha e_j)$, which increases in firm i's profits[8] and decreases in the environmental damage associated with domestic and foreign emissions, $d \times (e_i + \alpha e_j)$. Intuitively, an increase in domestic emissions produces a marginal environmental damage measured by d, whereas an increase in foreign emissions generates a marginal environmental damage of αd, where $\alpha \geq 0$ represents the extent of the transboundary externality of pollution.[9] The time structure of the game is as follows:

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

[6] 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.

[7] This condition guarantees that firms have incentives to produce a positive output level, even when emission standards are zero, both under monopoly and Cournot duopoly.

[8] We assume that every firm sells its production to the international market, and that consumers located in country i are a negligible share of the market. As a consequence, country i's social welfare does not include consumer surplus. Appendix 1 shows, however, that the qualitative results of the paper are unaffected if consumer surplus is included in the social welfare function.

[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.

(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 this treaty internalize the environmental externality, EE, (e_i^{EE}, e_j^{EE}); or

(c) Countries participate in an international treaty that internalizes *both* types of externalities: the environmental 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, either as monopolists selling their products to separate international markets, or as duopolists competing in the same international market.

3 Equilibrium Emission Standards

Operating by backward induction, we find the equilibrium output levels under monopoly and duopoly for any given emission standards. The following lemma describes the emission standards that maximize social welfare under different market structures, with and without IEAs. In particular, without treaties, the social planner chooses the welfare-maximizing emission standard $e_i^{K,NT}$, only considering firm i's profits and the environmental damage that firm i's pollution causes on country i, where $K = \{M, C\}$ denotes the market structure, either monopoly (M) or Cournot duopoly (C). When countries participate in an IEA that internalizes the EE effect (both EE and CAE effects), the regulator sets an emission standard $e_i^{K,EE}$ ($e_i^{K,BE}$, respectively) that considers firm i's profits (both firms' profits) and the environmental damage that firm i's pollution causes on both countries. All proofs are relegated to the appendix.

Lemma 1. *Emission standards satisfy* $e_i^{M,NT} \geq e_i^{M,EE} = e_i^{M,BE}$ *under monopoly, and* $e_i^{C,NT} \geq e_i^{C,EE} \geq e_i^{C,BE}$ *under Cournot duopoly. In addition,* $e_i^{M,BE} \geq e_i^{C,NT}$.

Under monopoly, the emission standard that only internalizes the environmental externality coincides with that internalizing both externalities, i.e., $e_i^{M,EE} = e_i^{M,BE}$, since the competitive advantage externality (CAE) is absent. Moreover, emission standards under the treaty are weakly below those with no treaty, $e_i^{M,NT}$, since countries internalize the EE effect. 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 emphasized when countries sign a treaty that considers both externalities (EE and CAE), i.e., $e_i^{C,EE} \geq e_i^{C,BE}$. Furthermore, emission standards under no treaty are independent on the extent of the transboundary externality, α, in both market structures. In contrast, standards become more stringent in α when countries participate in either type of treaty. Finally, emission standards are decreasing in the environmental damage from pollution. Nonetheless, they are more sensitive to a given increase in environmental damage when countries participate in a treaty than otherwise; as shown in the appendix.

The above lemma 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 figure below illustrates. 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 1, 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 $e_i^{K,EE}$ where $K = \{M, C\}$), and second, when countries internalize both the EE and CAE effects[10] (weakly decreasing emissions to $e_i^{C,BE}$).

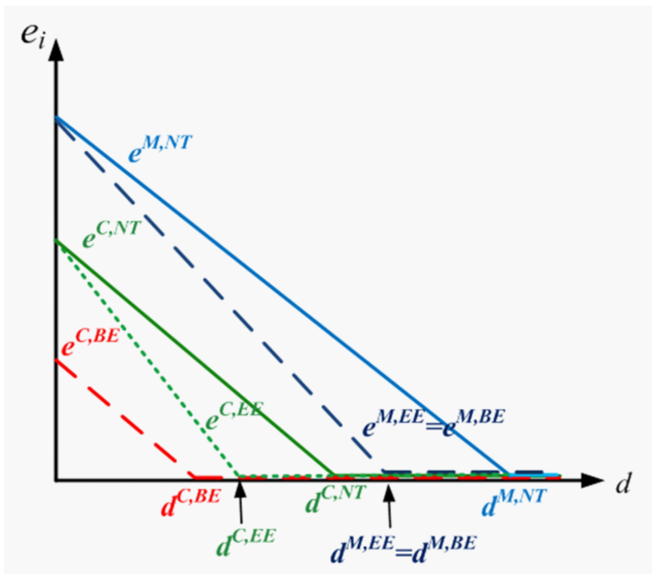

Figure 1: Emission standards for $\alpha \geq 0$.

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.

[10]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.

Proposition 1. *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.

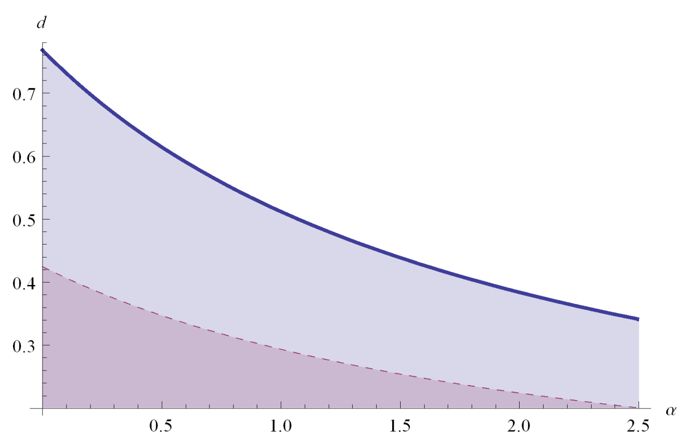

Figure 2. Cutoffs d^{EE} (solid) and d^{BE} (dashed).

Figure 2 above depicts cutoffs d^{EE} (solid line) and d^{BE} (dashed line) where, for simplicity, we consider[11] $a = 5$ 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'

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

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 shift upwards as market demand increases since a higher demand raises the positive effect that more stringent environmental standards produces on firms' profits.

4 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, thereby maximizing their joint profits. In addition, we analyze how countries' signature of IEAs modifies firms' incentives to maintain the cartel agreement.

Proposition 2. *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 with 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.

5 Conclusions

This paper analyzes two externalities that domestic environmental regulation imposes on foreign countries' welfare —environmental and competitive advantage externalities— under different market structures. The paper demonstrates that the 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. Hence, our theoretical predictions can be empirically tested from an observation of firms' stand on IEAs.

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 their abatement costs. In such context, environmental regulation would not necessarily coincide across countries, both if they 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. In addition, we consider that information about production costs is common knowledge among players. In a different setting, however, every firm would be privately informed about its marginal production costs, but not about those of its rival. In contrast, governments might have accurate information about domestic firms' marginal costs after years of regulation. In this context, a government's environmental regulation signals information about the efficiency of national firms to their foreign competitors, thus affecting their entry decision.

6 Appendix

6.1 Appendix 1 - Consumer surplus

Let us now consider the case in which the population of every country i represents a (non-negligible) share $\gamma \in [0,1]$ 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. We denote the international treaty that internalizes the three types of externalities by the superscript TE.

Proposition A. *Let $\gamma \in [0,1]$ 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 $K = \{M, C\}$.*

Proof. 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 the proof of 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,

$$\max_{e_i \geq 0} \ \gamma \left[\frac{1}{2} \left(a - p_i^M(e_i) \right) q_i^M(e_i) \right] + \Pi_i \left(q_i^M(e_i), e_i \right) - d(e_i + \alpha e_j)$$

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 $d^{M,NT} \equiv \frac{(a\theta-1)[4+(2+\gamma)\theta]}{\theta(2+\theta)^2}$. 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

$$\max_{e_i \geq 0} \ \gamma \left[\frac{1}{2}\left(a - p_i^M(e_i)\right) q_i^M(e_i)\right] + \Pi_i\left(q_i^M(e_i), e_i\right) - d(e_i + \alpha e_j) - d\alpha e_i$$

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 $e_i^{M,TE} = e_i^{M,EE}$. Additionally, $e_i^{M,EE}$ 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 $\gamma \leq 1$.

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

$$\max_{e_i \geq 0} \ \gamma \left[\frac{1}{2}\left(a - p^C(e_i, e_j)\right) q_i^C(e_i, e_j)\right] + \Pi_i\left(q_i^C(e_i, e_j), e_i\right) - d(e_i + \alpha e_j)$$

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 $d^{C,NT} \equiv \frac{2(a\theta-1)[32+\theta(8(4+\theta)+\gamma(12+5\theta))]}{\theta(4+\theta)(4+3\theta)^2}$. Moreover, $e_i^{C,NT}$ is weakly increasing in γ given that

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

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

$$\max_{e_i \geq 0} \ \gamma \left[\frac{1}{2}\left(a - p^C(e_i, e_j)\right) q_i^C(e_i, e_j)\right] + \Pi_i \left(q_i^C(e_i, e_j), e_i\right) - d(e_i + \alpha e_j) - d\alpha e_i$$

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

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

Furthermore, $e_i^{C,EE}$ is weakly increasing in γ given that

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

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,

$$\max_{e_i, e_j \geq 0} \ \gamma \left[\frac{1}{2}\left(a - p^C(e_i, e_j)\right) q_i^C(e_i, e_j)\right] + \Pi_i \left(q_i^C(e_i, e_j), e_i\right) - d(e_i + \alpha e_j) +$$
$$\gamma \left[\frac{1}{2}\left(a - p^C(e_i, e_j)\right) q_j^C(e_j, e_i)\right] + \Pi_j \left(q_j^C(e_j, e_i), e_j\right) - d(e_j + \alpha e_i)$$

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 $d^{C,TE} \equiv \frac{8(a\theta-1)(2+\theta+\gamma\theta)}{\alpha(1+\alpha)(4+3\theta)^2}$ In addition, $e_i^{C,TE}$ is weakly increasing in γ given that

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

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

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

which is weakly positive for all $\gamma < \frac{48+\theta(44+9\theta)}{24+10\theta}$, which holds by definition since $\gamma < 1 <$

$\frac{48+\theta(44+9\theta)}{24+10\theta}$. Similarly, $e_i^{C,EE} \geq e_i^{C,TE}$ since

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

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

6.2 *Proof of Lemma 1*

Under monopoly, firm i's profit-maximization problem is

$$\max_{q_i \geq 0} \ (a - q_i)q_i - \frac{q_i}{\theta} - \frac{2(q_i - e_i)^2}{\theta}$$

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, each firm i solves the following maximization problem

$$\max_{q_i \geq 0} \ (a - Q)q_i - \frac{q_i}{\theta} - \frac{2(q_i - e_i)^2}{\theta}$$

Differentiating with respect to q_i, we obtain firm i's best response function

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

We next describe the three cases under which firms' best-response functions intersect (solutions to the Cournot production game): (1) the corner solution where $q_i^C > 0$ and $q_j^C = 0$, (2) the corner solution in which $q_i^C = 0$ and $q_j^C > 0$, and (3) the interior solution where $q_i^C, q_j^C > 0$.

Case 1. When $\frac{(a\theta-1)+4e_i}{2(2+\theta)} > \frac{(a\theta-1)+4e_j}{\theta}$ (which, solving for e_i, yields $e_i > \frac{(a\theta-1)(4+\theta)+(2+\theta)8e_j}{4\theta} \equiv \overline{e_i}$) we can guarantee that $\frac{(a\theta-1)+4e_i}{\theta} > \frac{(a\theta-1)+4e_j}{2(2+\theta)}$ (which solving for e_i yields $e_i > \frac{4+\theta[1+4e_j - a(4+\theta)]}{8(2+\theta)} \equiv \underline{e_i}$). Furthermore, $\overline{e_i} > \underline{e_i}$ for all parameter values since $\overline{e_i} - \underline{e_i} = \frac{(4+\theta)(4+3\theta)(a\theta-1+4e_j)}{8\theta(2+\theta)}$ is strictly positive given that $a > \frac{1}{\theta}$ by definition. Therefore, condition $e_i > \overline{e_i}$ is sufficient to sustain the corner solution $q_i^C = \frac{(a\theta-1)+4e_i}{2(2+\theta)}$ and $q_j^C = 0$ (graphically, firms' best response functions intersect at the vertical axis).

Case 2. When $\frac{(a\theta-1)+4e_j}{2(2+\theta)} > \frac{(a\theta-1)+4e_i}{\theta}$ (which, solving for e_i, yields $e_i < \underline{e_i}$), we can guarantee that $\frac{(a\theta-1)+4e_j}{\theta} > \frac{(a\theta-1)+4e_i}{2(2+\theta)}$ (which, solving for e_i, yields $e_i < \overline{e_i}$). Furthermore, $\overline{e_i} > \underline{e_i}$, ensuring that condition $e_i < \underline{e_i}$ is sufficient to support the corner solution $q_i^C = 0$ 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).

Case 3. When $\frac{(a\theta-1)+4e_i}{2(2+\theta)} < \frac{(a\theta-1)+4e_j}{\theta}$ and $\frac{(a\theta-1)+4e_j}{2(2+\theta)} < \frac{(a\theta-1)+4e_i}{\theta}$ hold, conditions $e_i < \overline{e_i}$ and $e_i > \underline{e_i}$ are respectively satisfied, i.e., emission standard e_i must satisfy $\underline{e_i} < e_i < \overline{e_i}$. We obtain an interior solution, where $q_i^C(e_i,e_j) = \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)}$ for every firm $i = \{1,2\}$. Note that this output level is positive if and only if $\underline{e_i} < e_i$, which holds since $\underline{e_i} < e_i < \overline{e_i}$.

Therefore, equilibrium output when firms compete a la Cournot is

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

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 $q_i^C(e_i,e_j) = \frac{\theta[a(4+\theta)-1-4e_j]+8e_i(2+\theta)-4}{(4+\theta)(4+3\theta)}$.

Monopoly, No treaty. Every country i maximizes its own social welfare by solving $\max_{e_i} \Pi_i\left(q_i^M(e_i),e_i\right) - d(e_i+\alpha e_j)$, 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 and solving, we obtain,

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

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

Monopoly, BE treaty. 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 and e_j, and solving, we obtain

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

Finally, note that if countries only internalize the EE effect, every country i maximizes $\max_{e_i} \Pi_i\left(q_i^M(e_i),e_i\right) - d(e_i+\alpha e_j) - d\alpha e_i$. Differentiating with respect to e_i we obtain the same first order conditions as in the BE case. Hence $e_i^{M,EE} = e_i^{M,BE}$.

Duopoly, No treaty. Every country i maximizes its own social welfare by solving $\max_{e_i} \Pi_i(q_i^C(e_i,e_j),q_j^C(e_i,e_j),e_i) - d(e_i+\alpha e_j)$, where $\Pi_i(q_i^C(e_i,e_j),q_j^C(e_i,e_j),e_i)$ denotes firm i's equilibrium profits under duopoly, for given emission standards e_i and e_j. Differentiating with respect to e_i,

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

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

Duopoly, EE treaty. When countries internalize the EE effect, every country i selects e_i to maximize,

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

Differentiating with respect to e_i,

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

By symmetry, we simultaneously solve for e_i and e_j to obtain

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

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

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

differentiating with respect to e_i, we obtain

$$\frac{1}{4}\left[\frac{4\left[8a(2+\theta)-(2e_i+2e_j-1)(16+9\theta)\right]}{(4+3\theta)^2}-\frac{8(e_i-e_j)\theta}{(4+\theta)^2}-\frac{4}{\theta}-4d(1+\alpha)\right]\leq 0$$

By symmetry, we simultaneously solve for e_i and e_j to obtain

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

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

Ranking. Under monopoly markets, $e_i^{M,NT}\geq e_i^{M,EE}=e_i^{M,BE}$. 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 our above results of duopoly with and without treaty, 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., $\frac{1}{1+\alpha}\frac{16(2+\theta)^2(a\theta-1)}{\theta(4+\theta)(4+3\theta)^2} > \frac{8(2+\theta)(a\theta-1)}{(1+\alpha)\theta(4+3\theta)^2}$.

Let us now show that $e_i^{M,BE} \geq e_i^{C,NT}$. From our above results of monopoly with treaty and duopoly without treaty, 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

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

6.3 *Proof of Proposition 1*

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 in 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.

6.4 *Proof of Proposition 2*

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

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

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

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

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

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

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

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

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.

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

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,

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

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.

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