Free-riding and cooperation in environmental games*

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Abstract

This paper examines the negotiation of an international environmental agreement in which different countries determine the (non-enforceable) promises of investment in clean technologies to be included in the agreement. Furthermore, it analyzes countries' optimal investment in emission-reducing technologies, considering that, in addition to the utility that a country perceives from an improved environmental quality, it is also concerned about the relative fulfillment of the terms specified in the international agreement either by itself or by others. I show, first, why countries may prefer to shift most promises of investment in clean technologies to other countries, despite the fact that these promises are usually non-enforceable by any international organization. Second, I determine countries' optimal investments in these technologies, and analyze how their particular investments depend on how demanding the international agreement is, and on the importance that countries assign to each others' relative fulfillment of their part of the treaty.

KEYWORDS: International environmental agreements, Non-cooperative games, Relative fulfillment.

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1 Introduction

Multiple international environmental agreements have been implemented in recent years trying to achieve greater cooperation among countries in their reduction of greenhouse gases, emissions leading to ozone layer depletion, and many other pollutants. For instance, the Montreal protocol (1987) and the Kyoto protocol (1997) establish standards for reductions in the emission (and production) of these environmental damaging products and by-products. Most of these agreements, however, have been very asymmetrically implemented by those countries signing them.

Different economic models have been used to analyze countries' behavior towards such international environmental agreements (IEA henceforth), and especially to analyze why they decide not to carry out the reduction in emissions they sign in these treaties. In particular, most of them deal with IEA as a standard public good game, in which countries incur a (private) cost in reducing emissions in their own country, but benefit from a (public) improved global environmental quality. Since, in addition, the private costs from reducing emissions are usually assumed to be higher than the per country benefits of improved world environmental standards, the amount of pollution that every country decides to reduce in the Nash equilibrium of the game is clearly below the Pareto efficient level. Hence, the individual incentives of every country to free-ride on the environmental quality that other countries provide leads to an under-provision of improved environmental standards.

Despite the fact that the equilibrium resulting from these models predicts the commonly observed practice of free-riding in environmental games, there are some observed behaviors that are difficult to rationalize. First, why do countries want to impose high commitment levels on other signatories if there is no international organization that perfectly enforces the content of the IEA? And second, why do certain countries respect the agreements they acquire in IEAs to a great extent (in spite of their non-enforceability), while others do not fulfill their agreements? This paper proposes a model that supports, first, the interest of a country in imposing high demands on other countries –in terms of the reduction of emissions the IEA specifies for them– during the negotiation stage of the IEA, in spite of the non-enforceability of such agreements. In addition, it explains why certain countries may prefer to invest in emission-reducing technologies even when other countries do not invest, and how this optimal investment depends on how demanding (or conservative) the goals of the IEA are, among other parameters.

Similar to standard public good games, this study considers that every country benefits from the global environmental quality achieved by the overall reduction in emissions, and it incurs a private cost in doing so. In addition, the paper assumes that countries benefit from the relative fulfillment of the agreement (i.e., the extent to which the goal of the IEA is fulfilled). Specifically, I consider that countries can benefit from the relative fulfillment of the IEA because of their *own* and/or because of *other countries'* relative fulfillment of the agreement.[1] In the first case, countries

[1] Both of these assumptions can simultaneously be introduced in the model. However, this generalization reduces

benefit from respecting the terms of the IEA since deviating from their environmental commitments may be severely punished by environmentally oriented citizens ("green voters"), whereas sticking to the terms of the agreement may be rewarded by these voters' support in future elections. In the second case, in contrast, countries benefit from observing that other cosigners fully carry out their promises –i.e., they infer a strong commitment with the fulfillment of the environmental standards included in the IEA— and experience disutility from such lack of commitment otherwise.

Different real life observations support the idea that countries may benefit from the relative fulfillment of the agreements in which they participate. First, regarding the positive relationship between voters and countries' relative fulfillment of its commitments, there is strong empirical evidence suggesting that voters do vote for an incumbent politician based on her past performance (relative to her initial promises), what is referred as "retrospective voting."[2] Moreover, in the specific relationship between green voters and countries' relative fulfillment of the IEA, table 1 (appendix) shows the existence of a positive correlation between the proportion of green parties in a country's parliament and that country's relative fulfillment of the commitments it signed in the Kyoto protocol. Second, regarding countries' concern for each others' fulfillment of the IEA, we can also find many real cases, where for instance, certain northern European countries such as Germany –which essentially stick to the terms of the Kyoto protocol– may feel some disappointment from observing that many other signatories do not carry out their promises as they should.[3]

In order to examine the role of these non-binding IEAs in countries' environmental policies, this paper analyzes a two-stage complete information environmental game. Countries first decide the environmental goals to be included in the IEA (negotiation game), and given these goals, they simultaneously choose how much to invest in emission-reducing technologies during the second stage of the game (investment game). In particular, this study shows that countries try to impose the most demanding environmental standards on other countries but not on themselves during the negotiation stage of the game. Indeed, when countries are concerned about either their own relative fulfillment of the IEA or about other countries' relative fulfillment, the specific commitment they sign in the treaty becomes relevant, even if these commitments are non-enforceable by any international organization. These predictions are confirmed by the effort that countries exert trying to achieve that other countries sign different non-binding international agreements, either on environmental issues or not.[4] In addition, the research identifies how the commitments involved

the intuition of the results without improving its explanatory power.

[2] For example, Francis *et al.* (1994) find that representatives whose voting records are closer to the predicted senatorial position for their state are more likely to enter a primary, which supports the hypothesis that representatives expect primary voters to choose retrospectively.

[3] Existing evidence suggests that only 15 out of the 41 countries included in Annex I of the Kyoto protocol have fulfilled their commitments in Article 3 (which specifies a 5 percent reduction in the emission of greenhouse gases from 1990 to 2008).

[4] For instance, in February 2007 the European Union insisted that they would sign a reduction in emissions by 30 percent if other heavy pollutants (e.g. U.S., China and India) sign the agreement as well. Another example is the Byrd-Hagel Resolution, passed by the U.S. Senate on July 25, 1997, which stated that the United States should not be a signatory to any protocol that did not include binding targets and timetables for developing as well as industrialized nations.

in the IEA affect countries' investment in clean technologies in a second stage of the game, despite of the fact that these commitments are non-binding. Specifically, it determines under what parameter values (and under what commitments signed during the negotiation stage) countries' reduction of pollutants is higher than what standard environmental games predict. Finally, the paper explains the case where a country would only accept an agreed level equal to zero (e.g., the case of United Kingdom in the Helsinki protocol or U.S. in the Kyoto Protocol), however it invests positive amounts in clean technologies in the investment game.

The contribution of this paper to the literature on environmental games is then twofold. First, it *endogenizes* the particular commitments that countries include and sign in the IEA, explaining also why countries care about the specific terms of the agreement despite these terms being non-enforceable. In contrast, standard environmental games assume that countries simply decide whether to participate in the IEA, whose environmental goals coincide with the Pareto-efficient level (probably determined by scientists). This makes the specific commitments included in the IEA *exogenous* to the game. Second, this paper explains the interaction between the specific terms of an agreement and countries' relative fulfillment of such agreement, which are considered to be completely independent in the existing literature. Interestingly, this model can be applied to many other settings, where players (either countries, firms, or individuals) interact with other players signing a contract in which they both engage in the provision of a certain public good. The contents of the contract are observable, but cannot be enforced by a third party, such as a court of law. Specifically, if players are concerned about the relative fulfillment of the contract by other players, or by themselves, this model predicts higher contribution levels, and lower free-riding behaviors than in standard public good games.

The paper is organized as follows. Section two comments on the game-theoretic literature that studies IEAs. In particular, it focuses on those analyses predicting higher levels of emission reduction than in standard environmental games. Section three describes the model under the assumption that countries are concerned about their own relative fulfillment of the agreement (e.g., because of the importance of green voters), and analyzes countries' best response functions in this setting. Afterwards, it examines countries' equilibrium strategies in this simultaneous move game and analyzes the optimal proposals to be made by every country during the (previous) negotiation stage of the IEA, given the above equilibrium strategies. Section four describes the model under the assumption that countries care about each others' relative fulfillment of the IEA and compares its results with those of the first model. Finally, the last section elaborates on the conclusions of the paper, as well as further areas of research.

2 Related literature

Given the relatively pessimistic prediction of the existing literature examining environmental improvement as a (global) public good, many different game-theoretic approaches have been applied to explain why cooperation is sometimes observed in international environmental policies. In the following subsection, I elaborate on the main results and assumptions of these models –grouped into four different branches– as well as their main criticisms. Additionally, subsection 2.2 summarizes the debate on treaty compliance.

2.1 Literature on environmental games predicting cooperation

In recent years, different authors have used the theory of repeated games to rationalize why certain international agreements are in fact respected along time, see Barrett (1994, 1999), Cesar (1994) and Rubio and Ulph (2007). In particular, a cooperative solution can be supported as a Nash equilibrium of the repeated game when countries' discount factor is high enough. Despite their satisfactory results in terms of cooperation among the players, the disadvantage of using repeated games to analyze such interactions among countries implementing IEAs are, among others: (1) the restriction on the sufficiently high values for the discount factor, which is difficult to reconcile with myopic politicians, and (2) the multiplicity of equilibria supported as the Nash equilibrium of the repeated game, which limits the predictive power of the model.

Similarly, another class of models considers countries' preferences for "international equality", as in game-theoretic models analyzing social preferences with inequity adverse agents, see Hoel and Schneider (1995). In this case, the equilibrium prediction also determines that countries fulfill the agreement they sign in the IEA, at least to a greater extent than in the standard models described above. That is, their reduction of pollutant emissions is more relevant when countries have social preferences among other countries than when they only have strictly individualistic preferences. Also, Jeppesen and Anderson (1998) develop Barret's model (1994) incorporating the idea of fairness introduced by Rabin (1993). They show that if countries are highly concerned about the welfare of other countries, full cooperation can be supported as an equilibrium. However, the assumption that countries are actually concerned about the payoffs that another country obtains from playing this environmental game does not seem to be very realistic.

Another class of models explaining the seeming dissonance between the standard theoretical models analyzed above –in which countries are predicted to have poor incentives to reduce emissions— and real cases –in which certain countries carry out their promises in the IEA to a great extent— uses the possibility that an international organization imposes sanctions on the "defecting" countries, see Barrett (1992, 1994).[5] Obviously, introducing the possibility of receiving a

[5] Note that Barret (1999) analyzes the theory of international cooperation in the context of repeated games where players use contingent strategies, such as grim strategies.

sanction induces every country to maintain its promises in the IEA. However, these models have also been subject to criticism in the literature, since they assume enforceable contracts. Given that most of these international agreements cannot be enforced by any legal organization, this model is probably very restrictive in its assumptions.[6]

Finally, an interesting (and productive) branch of the literature examines the possibility of "linked negotiations" on transboundary pollution with other issues such as free trade agreements, which developed countries may use to achieve greater reductions in pollution by developing countries, see Whalley (1991) and Folmer *et al* (1993). Importantly, these models predict a limitation of the free-riding practices when the countries' interests are sufficiently complementary. In spite of their interest, these models have also been criticized because of: (1) the coercion they seem to recommend from developed nations to underdeveloped ones in order to induce better environmental practices among the latter, and (2) because of the difficulty to implement such limitations on real free-trade agreements, given the last advances of the World Trade Organization.

In order to overcome some of the shortcomings of the existing literature, in this paper I propose a model that limits countries' free-riding practices in certain cases (while it allows them under some parameter values) without the need to repeat the environmental game during different periods and without relying on social preferences among the countries. In addition, I do not need to allow the possibility of legal sanctions (or coercion in terms of trade agreements) to be enforced by the countries or by any international organization. These elements permit an easier analysis and complementary interpretations to the ones in the above models.

2.2 Literature on treaty compliance

There is substantial debate in the literature about how countries achieve compliance in international agreements. Chayes and Chayes (1995) argue that countries spend a lot of energy and time in preparing, drafting, negotiating and monitoring treaty obligations, which leads them to usually comply with their part of the treaty. Even though they recognize that noncompliance exists, they justify it by ambiguity of the treaty, the capacity limitation of status and uncontrollable social or economic changes. Moreover, they consider that sanctions are not necessary to ensure compliance. On the other hand, Downs et al. (1996) defend the idea that sanctions are an important element on treaty compliance. They argue that the evidence suggests that high levels of compliance and infrequent use of enforcement result from the low requirements of the agreement. Barret (1999) attempts to disentangle the debate. He concludes that the main constraint on international cooperation is free-riding deterrence, not compliance enforcement. This paper recognizes the fact that noncompliance plays an important role in the IEA, however the extreme case of complete

[6] Schelling (2006) provides arguments about why there is no obvious formula to make the punishment fit the crime in IEAs.

violation of a treaty obligation is not observed in the equilibrium. Additionally, the absence of the full cooperative outcome in the results can mainly be explained by free-riding as in Barret (1999).

3 Model when countries care about their own fulfillment

Consider a two-stage complete information game. In the first stage of the game, the negotiation stage, countries decide their agreed levels (in terms of investment in clean technology) in the IEA. In the second stage, the investment game, countries privately decide how much investment to make on emission-reducing technologies. Each country is endowed with w monetary units (e.g. governmental budget). Let x_i denote country i's monetary investments in clean technologies (alternatively in reduction of pollutant emissions), and let z_i represent its consumption of private goods. These private goods can be interpreted, generally, as the tax revenue raised by the government, which can now be kept for alternative uses in other expenditure programs not related with the IEA. Additionally, we consider that the marginal utility country i derives from alternative expenditure programs (private good) is one.

Specifically, let us use the following quasilinear utility function, where private goods (money) enter linearly, while both total investments in clean technologies by country i and j, $G = x_i + x_j$, and country i's relative fulfillment of the terms in the IEA, f_i, are included in the nonlinear function $v(\cdot)$.

$$U_i(z_i, G, f_i) = z_i + v(G, f_i)$$

In particular, I assume that the difference between country i's actual investment in cleaner technologies, x_i, and the agreed level of investment that country i specified in the treaty, $c_i \geq 0$[7] (which is endogenously determined in the first stage of the game, section 3.3), represents the relative fulfillment of country i's commitment in the agreement. This difference can also be understood as the noncompliance cost. That is,

$$f_i = \alpha_i(x_i - c_i)$$

First, note that country i improves its opinion among green voters if its investment in cleaner technologies, x_i, is higher or equal than its commitment level, c_i; otherwise, if country i invests less than what it was supposed to, $x_i < c_i$, green voters of country i perceive lack of commitment to the agreement, which could lead them to penalize the incumbent party in future elections.[8] In addition, this difference is scaled by $\alpha_i \in [0, +\infty)$. In short, α_i indicates the importance of green voters in country i. For instance, α_i can be interpreted as the percentage of politicians from green parties in the Senate or the percentage of population who belongs to environmental organizations. The

[7] Zero represents the case in which country i does not sign the agreement.

[8] This study assumes that green voters care about the total investment in clean technologies, G, and the compliance of their countries' agreement, f_i, but not about the commitment level signed in the IEA, c_i, since that level is not relevant per se in terms of achieving the objectives of the IEA.

higher is this percentage, the more negative is the impact of a lack of fulfillment of the agreement in the governments' utility. Finally, given that this is a game of complete information, country i can correctly conjecture whether $x_i > c_i$ or $x_i < c_i$, where c_i is the given commitment agreed upon during the first stage of the game. In further sections, I consider an extension of this model, where countries are assumed to be concerned about each others' relative fulfillment of the IEA (instead of its own fulfillment).

For simplicity, let us assume the nonlinear (concave) function $v(G, f_i) = \ln[mG + f_i]$. Therefore, the representative country's maximization problem is given by

$$\max_{z_i, G} U_i(z_i, G, f_i) = z_i + \ln[mG + \alpha_i(x_i - c_i)]$$

$$\begin{aligned} \text{subject to } z_i + x_i &= w \\ x_i + x_j &= G \\ x_i, x_j &\geqslant 0 \end{aligned}$$

Using $z_i = w - x_i$, we can simplify the above program to

$$\max_{x_i} \quad w - x_i + \ln[m(x_i + x_j) + \alpha_i(x_i - c_i)]$$

In particular, the first term, $w - x_i$, represents the utility derived from the consumption of the remaining monetary units that have not been invested in clean technologies, i.e., that have not been invested in the public good. In the second term, m represents the return from the environmental good and $m(x_i + x_j)$ denotes the total utility that country i obtains from the consumption of a higher level of environmental quality given its own investments, x_i, and the ones of country j, x_j. Finally, $\alpha_i(x_i - c_i)$ represents the utility that country i derives from relatively fulfilling its commitment c_i in the environmental agreement or the cost that it incurs from the noncompliance of its agreements.

Intuitively, an increase in country i's investment, x_i, imposes both a positive direct and indirect effect on its utility level. The positive *direct* effect from x_i on its own utility is just that arising from the benefit of investing on emission-reducing technologies. Country i's investments, additionally, impose a positive *indirect* effect since these investments increase the relative commitment that voters perceive from their countries' actions, i.e., x_i increases $\alpha_i(x_i - c_i)$, for any given commitment c_i.

3.1 Best response function

In order to gain a clearer intuition of the results, this subsection introduces country i's best response function, and the next section analyzes the optimal investment level. Henceforth, all proofs are included in the appendix.

Lemma 1

In the simultaneous environmental game of investment in emission-reducing technologies with concerns about green voters, country i's best response function, $x_i(x_j)$, is

$$x_i(x_j) = \begin{cases} 1 + \frac{1}{m+\alpha_i}\left[\alpha_i c_i - m x_j\right] \text{ if } x_j \in [0, \frac{\alpha_i(1+c_i)+m}{m}] \\ 0 \text{ if } x_j > \frac{\alpha_i(1+c_i)+m}{m} \end{cases}$$

Let us compare the best response function $x_i(x_j)$ of a country which assigns a positive importance to the noncompliance cost, $\alpha_i > 0$, to that of a country which is *not* concerned about it, $x_i^{NC}(x_j)$, as in standard environmental models. In particular, when country i assigns no importance to the population who cares about the relative fulfillment of IEA, $\alpha_i = 0$, country i's best response function becomes

$$x_i^{NC}(x_j) = \begin{cases} 1 - x_j \text{ if } x_j \in [0, 1] \\ 0 \text{ if } x_j > 1 \end{cases}$$

This expression is represented in figure 1, which helps in the comparison of the reaction functions. Specifically, note that $x_i(x_j)$ is always above $x_i^{NC}(x_j)$ for any x_j.[9] In other words, country i will always have higher levels of investment in emission-reducing technologies when it is concerned about green voters' punishment than otherwise, for any investments of country j, x_j.

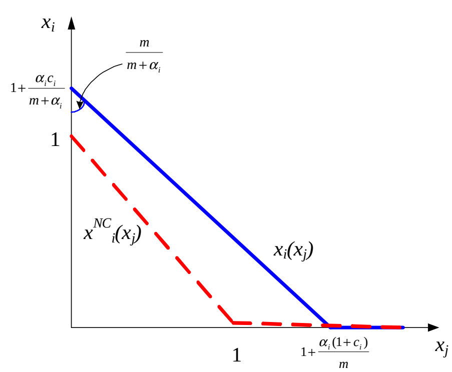


Figure 1. $x_i(x_j)$ and $x_i^{NC}(x_j)$.

[9]Note that $1 + \frac{\alpha_i(1+c_i)}{m} > 1$ for any parameter values, and any $c_i \geq 0$.

3.2 Non-cooperative equilibrium investments

Let us now examine the equilibrium strategies in the simultaneous Nash equilibrium resulting from both countries i and j applying lemma 1. The following proposition states the main result, and below I elaborate on its intuition and comparative statics.

Proposition 1

In the simultaneous environmental game, every country i's Nash equilibrium investment in emission-reducing technologies is

$$x_i^* = \begin{cases} 1 + \frac{\alpha_i c_i}{m+\alpha_i} \ \text{if} \ \alpha_i > \bar{\alpha}_i \\ \frac{\alpha_i(1+c_i)(\alpha_j+m)-\alpha_j m c_j}{\alpha_j m+\alpha_i(\alpha_j+m)} \ \text{if} \ \alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i] \\ 0 \ \text{if} \ \alpha_i \in (0, \hat{\alpha}_i] \end{cases}$$

where $\bar{\alpha}_i = \frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}$ *and* $\hat{\alpha}_i = \frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m}$

In particular, country i's investment in clean technologies is at its maximum level when its concern about green voters, α_i, is sufficiently high, i.e., $\alpha_i > \bar{\alpha}_i$. When the importance that country i assigns to green voters, α_i, decreases below $\bar{\alpha}_i$, its optimal investment also decreases, as the above proposition shows. That is, country i is not highly concerned about its own relative fulfillment of the IEA because it does not perceive the group of green voters as being relevant in future elections. Finally, if α_i drops below the threshold $\hat{\alpha}_i$, then its concerns about green voters' punishment are not strong enough to support any positive investment in clean technologies from country i. Hence, from proposition 1 we can conclude that the full free-riding outcome is not a solution of this game when the weight that the country assigns to green voters is above a particular threshold, as the following corollary specifies.

Corollary 1

In the simultaneous environmental game, every country i's Nash equilibrium investment in emission-reducing technologies, x_i^*, is strictly positive, if and only if $\alpha_i > \hat{\alpha}_i$.

Additionally, the following lemma indicates under what parameter values we can expect countries' *aggregate* investment in clean technologies to be higher than their investment when countries are not concerned about their own relative fulfillment of the IEA.

Lemma 2

In the simultaneous environmental game, when one of the countries is sufficiently concerned about green voters' punishment, i.e., $\alpha_i > \hat{\alpha}_i$ or $\alpha_j > \hat{\alpha}_j$, the aggregate Nash equilibrium investment in emission-reducing technologies , G, is greater than one for any parameter values.

Thus, as long as at least one of the countries is sufficiently concerned about the noncompliance cost, i.e., $\alpha_i > \hat{\alpha}_i$ or $\alpha_j > \hat{\alpha}_j$, the total optimal investment in the simultaneous environmental game,

$G = x_i^* + x_j^*$, is higher than the total investment obtained in standard environmental games in which countries do not assign any weight to the relative fulfillment of the IEA. Let us now examine how country i's optimal investment in clean technologies changes in the different parameters of the model. The following lemma summarizes these comparative statics about x_i^*, while the discussion below elaborates on its intuition.

Lemma 3

In the environmental game of investment in emission-reducing technologies, country i's optimal investment level, x_i^*, is weakly increasing (decreasing) in c_i (c_j), for any parameter values.

Hence, country i's equilibrium investment, x_i^*, is increasing in the (non-enforceable) own commitment, c_i, that country i accepts when signing the IEA. The increase in x_i^* is due to country i's own obligation to fulfill the contract, given that its lack of fulfillment can be punished by voters with strong environmental concerns. Interestingly, an increase in country j's commitment of investment in the IEA, i.e., an increase in c_j, reduces country i's optimal investment in clean technologies, x_i^*. This result can be explained by the fact that a higher commitment of country j in the IEA "relaxes" country i's incentives to invest in clean technologies. Let us now examine how x_i^* varies in country i and j's concerns about green voters.

Lemma 4

In the environmental game of investment in emission-reducing technologies, country i's optimal investment level, x_i^*, is weakly increasing (decreasing) in α_i (α_j).

First, note that country i's Nash equilibrium level of investment, x_i^*, is increasing in its own concern about green voters, α_i. Thus, if green voters represent an important proportion of the population who can affect the future elections results, then country i will invest higher levels of x_i in order to fulfill its commitment, c_i. On the other hand, country i decreases its investment, x_i, if the importance of green voters in other countries, α_j, increases. Clearly, country i knows that an increase in α_j induces country j to achieve a greater fulfillment of its own commitments, increasing x_j, what ultimately reduces country i's investment since country i's best response function is negatively sloped.

3.3 Equilibrium proposals

The previous section analyzed the optimal investment levels of each country, *given* a specific commitment of investing in clean technologies specified in the IEA for every country, c_i and c_j. This section goes one step back and, using sequential rationality, examines what are the optimal investment levels that every country accepts for itself and the other country –the pair (c_i, c_j)– in the subgame perfect Nash equilibrium (SPNE) of the game describing the negotiation and posterior implementation of the IEA. The following proposition specifies countries' incentives in this negotiation stage of the game, and below I discuss the SPNE strategies of the signatory countries in the IEAs.

Proposition 2

Every country i's equilibrium payoff from playing the investment game, with the optimal investments $\left(x_i^*, x_j^*\right)$ *determined in proposition 1, is weakly decreasing (increasing) in* c_i (c_j).

Hence, in the negotiation stage of the game –where countries determine the investment levels (c_i, c_j) to be included in the text of the IEA– every country i has strong incentives to set low environmental standards for itself (low c_i), but high requirements for other countries (high c_j). This result has important consequences in the optimal proposals of the pair (c_i, c_j) to be voted during the negotiation stage under any voting procedure, since countries want to shift the greatest burden of the IEA to other countries.

Ideally, the determination of the commitment levels that each country signs in the agreement should be obtained through the Nash bargaining solution concept. However, it cannot be applied in the model because the model's payoff structure is not well-behaved. In other words, the inverse of the utility function is not convex and strictly increasing, which are two requirements to apply the Nash bargaining solution concept.

Therefore, the negotiation stage is represented by the standard ultimatum bargaining game. In particular, the following proposition analyzes what is the SPNE strategies resulting from a fairly simple voting procedure, in which country i proposes a pair of investment levels (c_i, c_j) and country j is allowed to either accept or reject such proposal.

Proposition 3

If the voting procedure is represented by the ultimatum bargaining game, the optimal investment level for every country i is,

$$\begin{aligned}
&\text{if } \alpha_i > \bar{\alpha}_i \text{ and } \alpha_j \in (0, \hat{\alpha}_j] \\
&(c_i^*, c_j^*) = \left(\frac{2^{\frac{2}{3}} B^2 - 2(3+\alpha_i)m + F}{6B}, \frac{2^{\frac{2}{3}} B^2 E + FE + 2\alpha_i Bm(1-(4+\alpha_i)e^w m)}{e^w \alpha_j (2^{\frac{2}{3}} B^2 - 2\alpha_i Bm + F)}\right) \\
&(x_i^*, x_j^*) = \left(1 + \alpha_i - \frac{6\alpha_i B}{2^{\frac{2}{3}} B^2 + F - 2\alpha_i Bm}, 0\right) \\
&\text{or} \\
&\text{if } \alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i] \text{ and } \alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j] \\
&(c_i^*, c_j^*) = \left(c_i, \frac{\alpha_j m(-1+w) - \alpha_j \alpha_i + \alpha_i \Gamma w + (\alpha_j m + \alpha_i \Gamma)\log \Gamma}{\alpha_j(\alpha_i + m)}\right) \\
&(x_i^*, x_j^*) = \left(\frac{\alpha_i + w - mw - m\log\Gamma)}{(\alpha_i + m)}, w + \log\Gamma\right)
\end{aligned}$$

Interestingly, country i exerts all its proposing power, since country j accepts any proposal leading to positive payoffs. Indeed, note that country j's acceptance does not mean that country j

keeps a zero payoff. Unlike the ultimatum bargaining game, the investment proposals accepted by country j in this game are only promises (non-binding commitments) included in the international agreement, which may or may not be implemented by country j in the next stage of the game, as described in proposition 1. Additionally, the negotiation process can be represented by three different cases which depend on the concern levels of the proposing country and the country receiving the offer. Therefore, the agreed commitment levels vary in each case, for instance, they depend in what the concern level of the first mover is (which has all the bargaining power) and how important the noncompliance cost is for the country which accept or reject such offer.

Of course, in more elaborated settings, such as the voting procedures developed in different international organizations, country i cannot take full advantage of its proposing power. Instead, it may propose less extreme investment pairs (c_i, c_j), since the possibility of playing some cooperative-punishment strategy in this repeated game might induce higher payoffs for country i. In spite of other considerations, the model that this paper analyzes can clearly capture countries' incentives during the negotiation of the IEA, which emphasizes countries efforts in shifting the greatest possible burden of the (non-binding) commitments included in the IEA to other countries. Moreover, proposition 3 suggests that even in the extreme case where country i's commitment level is zero (it can be interpreted as not signing the treaty), it will still invest in clean technologies as long as country i is concerned enough about green voters.[10]

Corollary 2

In the negotiation stage of the environmental game where country i proposes a pair $(0, c_j)$ *and country i is very concerned about the noncompliance cost, country i's optimal investment in clean technologies is strictly positive.*

Hence, the extreme situation where country i exerts all its bargaining power in the negotiation stage (zero commitment level) is compensated in the investment game. Since, when country i's concern level is strictly positive it invests positive amounts in clean technologies.

Corollary 3

In the negotiation stage of the environmental game where country i proposes a pair (c_i, c_j) *and country i is very (relatively) concerned about the noncompliance cost and country j is not (relatively) concerned,* c_j *is increasing in* α_i*.*

The above corollary represents country i's interest in imposing high commitment levels on country j. If the proposer suffers a high political cost when it does not fulfill its environmental

[10] Note the connection of these results with those in the literature on strategic pre-commitment, as in Fudenberg and Tirole (1984) and Balboa et al. (2004). Indeed, in this literature players choose the level of an irreversible variable, such as physical capital or tax, during the first stage with the objective to influence the strategic environment of the game played during the second stage. Similarly, in this model every country i uses the negotiation stage of the IEA to reduce its own commitment level (since this reduces its non-compliance costs in the second stage), and increases the other country's commitment level (given that this leads the other country to invest more in clean technologies during the second stage). In summary, every country uses the negotiation stage in order to shift most of the burden of the public good provision to the other country in the second stage.

agreements, then it has incentives in offering a positive c_j (even though the responder does not comply its agreement in the second stage of the game).

Corollary 4

In the negotiation stage of the environmental game where country i proposes a pair (c_i, c_j) and country i and j are relatively concerned about the noncompliance cost , G^* is increasing in α_j.

In other words, when signatory countries are concerned about the noncompliance cost, the total investment in clean technology obtained in the investment game increases. That is, if countries which participate in the negotiation of the IEA have high political costs, in terms of noncompliance of their environmental agreements, it positively affect the results of the treaty.

Finally, figure 2 depicts the relationship between country i and j's concern levels. Specifically, region 2 shows that every country tries to impose the most demanding environmental standard on the other country but not on themselves during the negotiation stage.

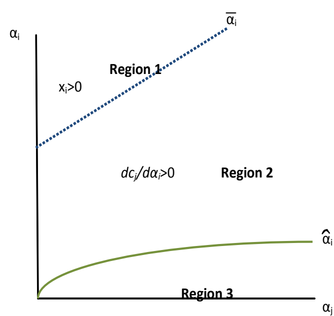


Figure 2.

4 A model when countries care about each others' fulfillment

Let us now consider the model presented in section 3, but assuming that country i's concerns about the relative fulfillment of the IEA depends on the extent to which country j fulfills its commitment in the agreement, $c_j \in [0, 1]$. That is, country i's maximization problem is now defined as

$$\max_{x_i} \quad w - x_i + \ln\left[m(x_i + x_j) + \alpha_i\left(x_j - c_j\right)\right]$$

where country i improves his perception of country j's serious commitment of carrying out the treaty if country j's investment in cleaner technologies, x_j, is higher than or equal to his commitment level, c_j; otherwise, if country j invests less than what it was supposed to, $x_j < c_j$, country i perceives a lack of commitment in the fulfillment of the agreement, which leads to a negative perception from country j's actions. Additionally, α_i indicates the importance that country i assigns to country j's fulfillment of its part of the agreement, where as before $\alpha_i \in [0, +\infty)$.

Intuitively, note that in this model an increase in country j's investment, x_j, imposes both a positive direct and indirect effect on country i's utility level. The positive *direct* effect from x_j on country i's utility is just the usual one arising from the public good nature of country j's investment on emission-reducing technologies. Country j's investments, additionally, impose a positive *indirect* effect on country i since these investments increase the relative commitment that country i perceives from country j's actions, i.e., higher x_j increases $\alpha_i (x_j - c_j)$, for any given commitment level c_j. The following lemma describes country i's best response function in this context.

Lemma 5

In the simultaneous environmental game of investment in emission-reducing technologies with concerns about the each others' fulfillment of the international agreement, country i's best response function, $x_i(x_j)$, is

$$x_i(x_j) = \begin{cases} \frac{1}{m}\left[\alpha_i c_j + m - (\alpha_i + m)x_j\right] \text{ if } x_j \in [0, \frac{\alpha_i c_j + m}{\alpha_i + m}] \\ 0 \text{ if } x_j > \frac{\alpha_i c_j + m}{\alpha_i + m} \end{cases}$$

A comparison between the best response function $x_i(x_j)$ of a country concerned about other country's fulfillment of the agreement, $\alpha_i > 0$, with respect to that of a country which is *not* concerned about the other country's commitment with the treaty, $x_i^{NC}(x_j)$ will give us more intuition about the countries' strategic behavior.

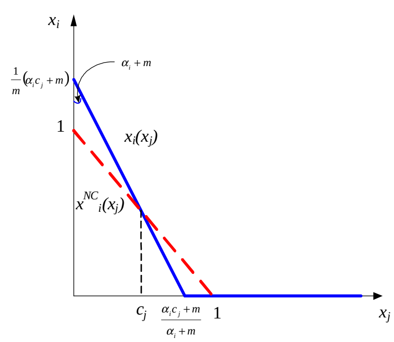


Figure 3. $x_i(x_j)$ and $x_i^{NC}(x_j)$.

Figure 3 shows that $x_i(x_j)$ is steeper than $x_i^{NC}(x_j)$ for any x_j. In particular, $x_i(x_j)$ is above $x_i^{NC}(x_j)$ for any $x_j < c_j$, and below otherwise. In other words, country i compensates country j's investments when it is below its country's commitment in the IEA, c_j. Specifically, note that when country j's actual investment in emission-reducing technologies is lower than the level it signed in the IEA, $x_j < c_j$, country i experiences a disutility from the lack of commitment it interprets from country j's actions. Hence, in order to compensate for such low level of investment country i invests more than it would in the case of not being concerned about the fulfillment of the contract. In contrast, when $x_j > c_j$, country i experiences an increase in its utility level given the strong commitment with the IEA from country j. In this case, country i makes an optimal investment in clean technologies below that it would carry out when not being concerned about the performance of the contract.

Let us now examine the equilibrium strategies in the simultaneous Nash equilibrium resulting from both countries i and j applying the above best response function. The following proposition states the main result, and below I elaborate on its intuition.

Proposition 4

In the simultaneous environmental game, every country i's Nash equilibrium investment in emission-reducing technologies is

$$x_i^* = \begin{cases} \frac{\alpha_i c_j + m}{m} \text{ if } \alpha_i > \bar{\alpha}_i \\ \frac{\alpha_j c_i m + \alpha_i(\alpha_j c_i + m - c_j m)}{\alpha_j m + \alpha_i(\alpha_j + m)} \text{ if } \alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i] \\ 0 \text{ if } \alpha_i \in (0, \hat{\alpha}_i] \end{cases}$$

where $\bar{\alpha}_i = \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)}$ *and* $\hat{\alpha}_i = \frac{\alpha_j c_i m}{m(c_j - 1) - \alpha_j c_i}$

In particular, country i's investment in clean technologies is at its maximum level when country i's concerns about other countries fulfillment of the agreement, α_i, is sufficiently high, i.e., when $\alpha_i > \bar{\alpha}_i$. However, if the importance that country i assigns to country j's commitment with the contract, α_i, decreases below $\bar{\alpha}_i$, its optimal investment also decreases, as the above proposition shows. Finally, when α_i drops below the threshold $\hat{\alpha}_i$, then its concerns about country j honoring the IEA are not strong enough to support any positive investment in clean technologies from country i. Let us now analyze under what parameter values the aggregate investments in clean technologies are above those in standard environmental games.

Lemma 6

In the simultaneous environmental game, the aggregate Nash equilibrium investment in emission-reducing technologies, G, is greater than one if and only if either $\alpha_i > \bar{\alpha}_i$ *or* $\alpha_j > \bar{\alpha}_j$. *Additionally, when neither* $\alpha_i > \bar{\alpha}_i$ *nor* $\alpha_j > \bar{\alpha}_j$ *are satisfied, G is greater than one if and only if* $c_i + c_j > 1$.

As in the previous model, the total optimal investment in the simultaneous environmental game, $G = x_i^* + x_j^*$, is greater than one when at least one of the countries is highly concerned about each others' relative fulfillment, i.e., $\alpha_i > \bar{\alpha}_i$ or $\alpha_j > \bar{\alpha}_j$. However, when both countries are not highly concerned about each others' fulfillment, total investments are only higher than those in standard environmental games when the total environmental goals specified in the IEA are relatively demanding, i.e., when $c_i + c_j > 1$. Regarding the comparative statics of the Nash equilibrium investment levels, x_i^*, the following lemma confirms that we can extend our intuitions from the previous section.

Lemma 7

In the simultaneous environmental game in which countries are concerned about each others' relative fulfillment of the IEA, both corollary 1 and lemma 3 hold.

Hence, in this setting lemma 3 can be interpreted as follows. Country i's equilibrium investment, x_i^*, is increasing in the (non-enforceable) own commitment, c_i, that it accepts when signing the IEA. Interestingly, the increase in x_i^* is not due to country i's own obligation to fulfill the contract (as in previous sections), but instead, because a higher commitment of country i in the IEA "relaxes" country j's incentives to invest in clean technologies. Indeed, since now country i is supposed to invest more (higher c_i), country j invests less (lower x_j^*), which ultimately leads country i to increase its investment to compensate country j's lack of investment in emission-reducing technologies. Similarly, an increase in country j's agreed level of investment in the IEA –i.e., an increase in c_j, as in the second result of the above lemma– reduces country i's optimal investment in clean technologies, x_i^*. In the following lemma I examine how x_i^* varies in country i and j's concerns about each others' fulfillment of the environmental agreement.

Lemma 8

In the environmental game of investment in emission-reducing technologies, country i's optimal investment level, x_i^*, is weakly decreasing (increasing) in α_i (α_j), if and only if $c_j > 1 - c_i$.

First, note that country i's Nash equilibrium level of investment, x_i^*, is *decreasing* in its own concern about country j's fulfillment of the contract's requirements, α_i, if and only if $c_j > 1 - c_i$. This result is opposed to that we obtained in lemma 4. In particular, it specifies that if the commitment of investment in emission-reducing technologies that country j signs in the IEA is sufficiently high, then country i perceives its investment as less necessary, similarly to the above discussion about the effects of an increase in c_j. Otherwise, if $c_j < 1 - c_i$, then country i increases its investment as α_i increases, since it considers that country i must compensate country j's lack of investment in clean technologies.

An alternative interpretation of this result would focus on how "demanding" are the environmental goals included in the IEA. When the investment objectives specified in the IEA are extremely demanding, i.e., $c_i + c_j > 1$, then country i's optimal investment in emission-reducing technologies decreases in their own concern, α_i, about country j's fulfillment of the contract. In contrast, international agreements with conservative goals, $c_i + c_j < 1$, make country i's investment in clean technologies to be increasing in α_i.[11]

Let us finally analyze what happens with country i's optimal investment, x_i^*, when the importance that country j assigns to country i's fulfillment of the contract requirements, α_j, increases. In

[11] This interpretation is related to the results obtained by Barrett (1994) and Downs et. al. (1996). When the agreement establishes low requirements (or gains to cooperate are small) free riding behavior is less preeminent. Therefore, a highly concerned country will exert higher efforts to achieve the compliance of the agreement.

particular, an increase in α_j raises country i's equilibrium investment, x_i^*, if and only if $c_j > 1 - c_i$. Clearly, now if country j assigns a greater importance to country i's fulfillment of the contract and the investment level that country i specified in the IEA is relatively high (i.e., $c_j > 1 - c_i$ is equivalent to $1 - c_j < c_i$) leads country j to reduce x_j, increasing x_i^* as a consequence.

Similarly to the previous intuition, if we interpret these results in terms of how demanding are the goals of the IEA, one can conclude that when the IEA is very demanding (conservative) country i's investments in emission-reducing technologies are increasing (decreasing) in the importance that other countries assign to country i's fulfillment of the contract, α_j. Finally, we can briefly analyze the negotiation stage of the IEA given the above optimal investment levels for every country.

Proposition 5

Every country i's equilibrium payoff from playing the investment game, with the optimal investments $\left(x_i^*, x_j^*\right)$ *determined in proposition 3, is weakly decreasing (increasing) in* c_i *(*c_j*).*

The above proposition is indeed equivalent to proposition 2, and in this context it emphasizes countries' incentives to shift most of the burden of the IEA to other countries, trying to make certain that the IEA specifies high commitment levels for other countries, c_j, and low for themselves, c_i. Finally, the following proposition defines the subgame perfect Nash equilibrium of the game under the assumption that countries are concerned about each others' relative fulfillment of the IEA.

Proposition 6

If the voting procedure is represented by the ultimatum bargaining game, the optimal investment level for every country i is,

if $\alpha_i \in (0, \hat{\alpha}_i]$ and $\alpha_j > \bar{\alpha}_j$

$$(c_i^*, c_j^*) = \left(\frac{\alpha_j m c_j - m\Gamma + \sqrt{4\alpha_j^2\Gamma^2 + m^2(\Gamma - \alpha_j c_j)^2}}{2\alpha_j\Gamma}, c_j\right)$$

$$(x_i^*, x_j^*) = \left(0, \frac{\alpha_j m c_j + m\Gamma + \sqrt{4\alpha_j^2\Gamma^2 + m^2(\Gamma - \alpha_j c_j)^2}}{2m\alpha_j\Gamma}\right)$$

or

if $\alpha_i > \bar{\alpha}_i$ and $\alpha_j \in (0, \hat{\alpha}_j]$

$$(c_i^*, c_j^*) = \Bigg(\frac{e^{-w}(-Am\Gamma + e^w(\alpha_i\alpha_j^3 + 2A\alpha_j^2 m - (-2+\alpha_i)\alpha_j m^2 + (-1+\alpha_i)m^3) - B}{2\alpha_j m A\Gamma}$$

$$\frac{e^{-w}(-Am\Gamma + e^w(-\alpha_i\alpha_j^3 + (2+5\alpha_i)\alpha_j m^2 + (1+3\alpha_i)m^3) + B}{2\alpha_i A\Gamma^2}\Bigg)$$

$$(x_i^*, x_j^*) = \left(1 + \frac{e^{-w}(-Am\Gamma + e^w(-\alpha_i\alpha_j^3 + (2+5\alpha_i)\alpha_j m^2 + (1+3\alpha_i)m^3) + B)}{m}, 0\right)$$

5 Discussion and Applications

5.1 Discussion on countries' asymmetric fulfillment of IEAs

Both of the models presented in this paper clearly predict that countries invest (weakly) higher levels in emission-reducing technologies than in standard environmental games. Interestingly, in the first model, the increase in country's investment is due to its concern about its own relative fulfillment of the IEA, whereas in the second model this increase is due to the country's concern about other countries' relatively fulfillment of the agreement. Notwithstanding their differences, their similar predictions can explain why certain countries fulfill to a great extent the commitments they acquire when signing IEAs, even if these commitments are relatively informal and not perfectly enforceable.

Additionally, both models predict that a country's optimal investment decision, x_i, increases in the country's own commitment level, c_i, and decreases in other countries' commitments, c_j. This result indicates that both countries "relax" their optimal investments when other countries' commitments in the IEA increase, this can rationalize why different countries condition their investment decisions on other cosigners' particular commitments in the IEA, despite knowing that such commitments are non-binding and may not be implemented by the cosigners of the treaty.

Finally, note that the main difference between the results of both models is on the comparative statics of countries' equilibrium investment, x_i^*, with respect to α_i and α_j. In the case that countries are concerned about their own relative fulfillment of the agreement, their equilibrium investments are clearly increasing in the importance that they assign to their own fulfillment of the IEA, α_i, and decreasing in the weight that the other country assigns, α_j. In contrast, when countries are concerned about each others' relative fulfillment of the environmental agreement, their equilibrium investments move in opposite directions: decreasing in the importance every country assigns to other countries fulfillment of the IEA, α_i , and increasing in the weight that other countries assign, α_j, if and only if the agreement is extremely demanding.

The last result may explain the perspective on compliance of Downs et al. (1996), (see section 2.2). They argue that when countries sign low commitments levels in the IEA, it is very likely to observe that signatories fulfill their compromises. Hence, in this model, low agreed levels will induce countries which are concerned about other's countries fulfillment to comply its commitment levels. The findings rationalize why countries prefer to adopt agreements that state feasible and realistic commitment levels.

5.2 Applications to international environmental negotiations

Regarding the negotiation stage, I first show that countries' equilibrium payoff from playing the investment game is weakly increasing in c_j and decreasing in c_i, for both models developed in this paper. Hence, regardless of the voting procedure which finally decides which levels of c_i and c_j

are included in the IEA, countries clearly prefer to shift most of the commitments of investment in clean technologies to other countries. Additionally, in the particular case in which the voting procedure is similar to the ultimatum bargaining game, I show that country i uses its proposer power to reduce c_i (and increase c_j) as much as possible. Ex ante, this could make us conclude that countries are leading their negotiations towards a situation in which they all want to free-ride each other's efforts in emission-reducing technologies, without bearing any costs. However, this is not the case, as previous sections show. Specifically, every country's optimal investment in clean technologies is strictly higher than zero (both when countries are concerned enough about green voters' punishment and when they are concerned about each others' fulfillment), and increases in certain parameters. In particular, this is true for the country which proposed the investment pair (c_i, c_j) specified in the international agreement, as well as for the country which accepted such proposal.

Hence, the behavior initially predicted for the voting stage –which one could describe as free-riding of the country with the greatest bargaining power– is then compensated by the second stage of the game, where countries decide how much to invest in emission-reducing technologies, since no country decides to operate as a pure free-rider given their mutual concerns about the fulfilling of the IEA, $\alpha_i, \alpha_j > 0$, as opposed to the prediction of the model when countries do not assign any importance to such fulfillment of the agreement, $\alpha_i = \alpha_j = 0$. The negotiation process can rationalize some cases that are observed in current IEAs. For instance, it reflects the EU interest in requiring the participation of India or China in the Kyoto protocol. In particular, the EU is willing to increase its commitment level (30% reduction in emissions) if and only if countries which are considered heavy pollutants sign the agreement. Finally, the results can explain the United States' case in the Kyoto protocol, where in terms of the model, U.S. commitment level is zero (U.S. did not ratify the protocol in the Senate). However, any positive investment in clean technologies would be interpreted by U.S. concerns about green voters.

These results can shed some light on some relatively surprising real-life cases of IEAs, where different countries first need long periods of time in order to reach an agreement about how much each country will reduce its emission of pollutants (or alternatively, how much resources to invest in clean technologies). In particular, countries usually want to impose important quotas on other countries (high values of c_j), but at the same time are reluctant to determine high quotas for themselves, c_i. If these international agreements were perfectly enforceable, countries would have a strong incentive to fight for a favorable division of environmental quotas. These agreements are, however, clearly not perfectly enforceable, what limits the possibility of rationalizing such lengthy negotiations from the perspective of perfectly enforceable quotas.

Indeed, this model predicts that countries fight for such favorable quotas not because they do not want to implement high investments in clean technology which is then benefited by other countries given its public good nature. Instead, this model predicts such negotiations because, even if the investment pair (c_i, c_j) included in the IEA is not enforceable, it enters as a reference point[12] in the countries' utility function. In particular, as previous sections show, country i's optimal investment decreases in c_j (and increases in c_i). However, since these investments are costly, countries want to specify the contents of the IEA such that it sets high environmental standards for other countries (high c_j) and low requirements for themselves (low c_i).

6 Conclusions

This paper analyzes a two-stage game where countries, first, decide the pair of investment levels (c_i, c_j) in emission-reducing technologies to be included in an international environmental agreement with no enforcing possibilities. Then, in the second stage, every country independently and non-cooperatively determines how much to invest in this technology, given its character of public good, and given the country's concern about the relative fulfillment of the international agreement, either by itself or by other countries.

The study shows that, first, every country's investment level in clean technology is nonzero for most parameter values, unlike those models analyzing environmental games in which players (countries) are not concerned about the relative fulfillment of the contract's requirements. In addition, it examines how optimal investments vary in different parameters. For instance, the country's equilibrium investment in clean technologies can actually increase in the importance (or political representation) of green voters. Similarly, this paper also shows that these investments increase in the country's concerns about other countries' relative fulfillment of the IEA if, in addition, this IEA sets relatively low emission reduction goals. In contrast, if the IEA sets high goals, it shows that a country's investment in clean technologies decrease in the country's concerns about other countries' relative fulfillment of the IEA. This result supports many real-life observations, in which countries prefer to specify low goals (instead of unrealistic levels) of environmental improvement to be included in the IEA. Finally, the study considers how countries' investment varies in the commitment that every country acquires in the IEA, discussing why this result does not necessarily depend on the agreement (since it is non-enforceable), but instead on the countries' own incentives in the environmental game.

A crucial element in this model is the negotiation stage of the game, where countries decide the investment levels to be included in the IEA. This paper analyzes the case when the voting procedure resembles that in an ultimatum bargaining game, that is, country's optimal promises prescribe that all the (non-enforceable) investment in clean technologies is carried out by other countries, leaving no investment burden for itself. The results suggest that, in spite of that these commitment levels are non-enforceable, some countries invest positive amounts in environmentally oriented technology, even those countries who suggest the radical proposal $(c_i^*, c_j^*) = (0, c_j)$ during

[12] A deeper analysis of the effect of reference points on players' strategic incentives in sequential move games can be found in Espinola-Arredondo and Munoz-Garcia (2007).

the voting stage of the game. The findings predict that is more likely that an agreement will be forthcoming if the participating countries are relatively concerned about the noncompliance cost. Additionally, increases in the advertising of countries' fulfillment of their environmental agreements by organizations such as the United Nations would raise countries' concern level.

Finally, many results of this model permits a more general rationalization of real-life practices during (and after) negotiations of IEAs. First, they support lengthy discussions during the approval stage of IEA in which every country wants to get a favorable division of the proposed investments in clean technologies that the agreement specifies, even when the IEA is clearly non-enforceable. Second, they explain why different countries do fulfill the commitment they acquired when signing an IEA, while others do not; and how this strategy depends on certain parameter values, such as how demanding is the international agreement, or the international orientation of these countries' media services.

Different extensions would clearly enrich the analysis of this general model. First, the paper develops a two stage complete information game. However, it would be interesting to analyze the case in which each country has private information about its concern level, α_i. Hence, in this setting country i can send a message about how much it cares about green voters or other countries' fulfillment of the agreement through its commitment level in the IEA, c_i. Second, countries' utility (or disutility) only comes from own or other countries' fulfillment of the contracts' requirements, while they do not consider, for example, their own bad "international image" from not fulfilling the terms of the IEA, which also could be included in a more general model. Moreover, it would be interesting to study the case where voters are represented by a different utility than that of the government. Finally, I assumed that all countries obtained the same utility from the global environmental quality, however a relaxation of this assumption allows us to analyze the role of this variable in the negotiation game, enriching the previous analysis. Further research in this area would enhance and clarify our understanding of countries' incentives in the negotiation and (partial) implementation of international agreements involving global public goods.

7 Appendix

7.1 Proof of Lemma 1

In this environmental game, both players are asked to simultaneously submit their investments in emission-reducing technologies. Fixing country j's investment, x_j, country i's utility maximization problem becomes

$$\max_{x_i} \quad w - x_i + \ln\left[m(x_i + x_j) + \alpha_i\left(x_i - c_i\right)\right]$$

And the argument that maximizes this utility function gives us the following best response function

$$x_i(x_j) = \begin{cases} \frac{1}{m}\alpha_i c_j \text{ if } x_j = 0 \\ 1 + \frac{1}{m+\alpha_i}\left[\alpha_i c_i - m x_j\right] \text{ if } x_j \in [0, \frac{\alpha_i(1+c_i)+m}{m}] \\ 0 \text{ if } x_j > \frac{\alpha_i(1+c_i)+m}{m} \end{cases}$$

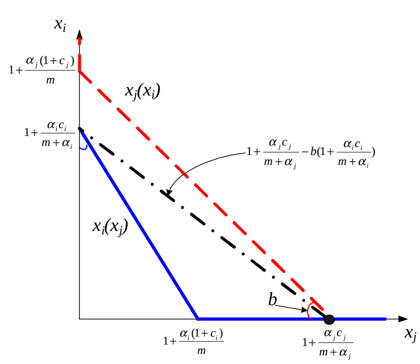
Since $1 + \frac{1}{m+\alpha_i}\left[\alpha_i c_i - m x_j\right] = 0$ exactly at $x_j = \frac{\alpha_i(1+c_i)+m}{m}$. Hence, this best response function can be more compactly expressed as

$$x_i(x_j) = \begin{cases} 1 + \frac{1}{m+\alpha_i}\left[\alpha_i c_i - m x_j\right] \text{ if } x_j \in [0, \frac{\alpha_i(1+c_i)+m}{m}] \\ 0 \text{ if } x_j > \frac{\alpha_i(1+c_i)+m}{m} \end{cases}$$

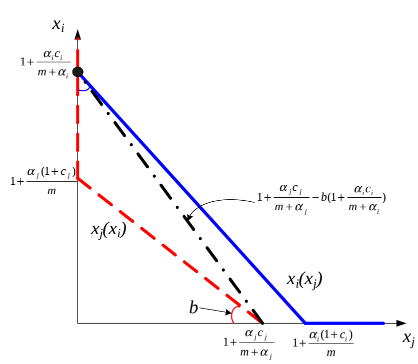
■

7.2 Proof of Proposition 1

Let us take country i's best response function, $x_i(x_j)$, from lemma 1, and analyze the different forms in which country i and j's best response functions can cross each other. The corner solutions (cases 1 and 2 below) are illustrated in the following figures, to clarify the following steps of the proof.



Case 1



Case 2

Case 1: $x_i^* = 0$

Note that $x_i^* = 0$ if and only the following two conditions are satisfied: (1) the horizontal intercept of country i's best response function is lower than that of country j, and (2) the slope of country j's best response function is small enough to make that $x_j(x_i)$ does not cross $x_i(x_j)$. That is, the first condition is satisfied if

$$\frac{\alpha_i(1+c_i)}{m}+1<\frac{\alpha_j c_j}{\alpha_j+m}+1$$

Manipulating this inequality, we obtain

$$\alpha_i<\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}$$

On the other hand, the second condition holds if, b, the slope of country j's best response function, satisfies

$$0<1+\frac{\alpha_j c_j}{m+\alpha_j}-b(1+\frac{\alpha_i c_i}{m+\alpha_i})$$

$$\Longleftrightarrow b<\frac{[m+\alpha_j(1+c_j)][m+\alpha_i]}{[m+\alpha_i(1+c_i)][m+\alpha_j]}$$

and since the slope of $x_j(x_i)$ is $\frac{m}{\alpha_j+m}$, we need that

$$\begin{aligned}\frac{m}{m+\alpha_j} &< \frac{[m+\alpha_j(1+c_j)][m+\alpha_i]}{[m+\alpha_i(1+c_i)][m+\alpha_j]}\\ [m+\alpha_i(1+c_i)][m+\alpha_j]m &< [m+\alpha_j(1+c_j)][m+\alpha_i][m+\alpha_j]\end{aligned}$$

and manipulating, and solving for α_i, we obtain the threshold of α_i below which all values of α_i support a zero investment in clean technologies by country i,

$$\alpha_i\le\frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m}$$

Case 2: $x_i^*=1+\frac{\alpha_i c_i}{m+\alpha_i}$

Let us now analyze the case in which country i sets the maximum investment $(1+\frac{\alpha_i c_i}{m+\alpha_i})$, while country j does not invest. Firstly, we need that country i's horizontal intercept is above that of country j's, what simply implies

$$\begin{aligned}\frac{\alpha_i(1+c_i)}{m}+1 &> \frac{\alpha_j c_j}{\alpha_j+m}+1\Longleftrightarrow\alpha_i>\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}\\ \Longleftrightarrow &\quad \alpha_i>\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}=\bar{\alpha}_i\end{aligned}$$

Secondly, we need that b, the slope of country j's best response function, satisfies

$$0>1+\frac{\alpha_j c_j+m}{m+\alpha_j}-b(1+\frac{\alpha_i c_i}{m+\alpha_i})$$

and operating similarly as in the previous case, we have

$$\alpha_i>\frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m}=\hat{\alpha}_i$$

Case 3: $x_i^* = \frac{\alpha_i(1+c_i)(\alpha_j+m)-\alpha_j m c_j}{\alpha_j m+\alpha_i(\alpha_j+m)}$

Finally, the equilibrium is interior when first, country i's horizontal intercept is below that of country j's, what simply implies,

$$\frac{\alpha_i(1+c_i)}{m}+1<\frac{\alpha_j c_j}{\alpha_j+m}+1 \Longleftrightarrow \alpha_i<\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}=\bar{\alpha}_i$$

and second, when b, the slope of country j's best response function, satisfies

$$0>1+\frac{\alpha_j c_j+m}{m+\alpha_j}-b(1+\frac{\alpha_i c_i}{m+\alpha_i}) \Longleftrightarrow \alpha_i>\frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m}=\hat{\alpha}_i$$

Finally, we must check that $\bar{\alpha}_i>\hat{\alpha}_i$. Indeed,

$$\begin{aligned}\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}-\frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m} &> 0\\ \alpha_j &> -\frac{m}{(1+c_j)}, \text{ since } m \text{ and } c_j \text{ are positive this inequality holds}\end{aligned}$$

for any parameter values. Hence, we can summarize the above three cases as follows:

$$x_i^*=\begin{cases} 1+\frac{\alpha_i c_i}{m+\alpha_i} \text{ if } \alpha_i>\bar{\alpha}_i \\ \frac{\alpha_i(1+c_i)(\alpha_j+m)-\alpha_j m c_j}{\alpha_j m+\alpha_i(\alpha_j+m)} \text{ if } \alpha_i\in(\hat{\alpha}_i,\bar{\alpha}_i] \\ 0 \text{ if } \alpha_i\in(0,\hat{\alpha}_i] \end{cases}$$

where $\bar{\alpha}_i=\frac{\alpha_j c_j m}{(1+c_i)(\alpha_j+m)}$ and $\hat{\alpha}_i=\frac{mc_j+\alpha_j(1+c_j)(m+c_j)}{(1+c_i)m}$ ■

7.3 Proof of Lemma 2

In order to obtain a higher investment level than in the case of unconcerned countries, we need to show that the total sum of the optimal investment in clean technologies of country i and j is greater than one. Notice that there are three possible combinations, which depend of the parameter α_i or α_j.

	x_i	x_j
Case 1	$\alpha_i\in(0,\hat{\alpha}_i]$	$\alpha_j>\bar{\alpha}_j$
Case 2	$\alpha_i\in(\hat{\alpha}_i,\bar{\alpha}_i]$	$\alpha_j\in(\hat{\alpha}_j,\bar{\alpha}_j]$
Case 3	$\alpha_i>\bar{\alpha}_i$	$\alpha_j\in(0,\hat{\alpha}_j]$

Case 1 and 3 are trivial because when $\alpha_i>\bar{\alpha}_i$ ($\alpha_j>\bar{\alpha}_j$) the optimal investment is $x_i^*=1+\frac{\alpha_i c_i}{m+\alpha_i}$ ($x_j^*=1+\frac{\alpha_j c_j}{m+\alpha_j}$) which clearly is greater than one.

In case 2 the optimal investments in clean technologies are $x_i^*=\frac{\alpha_i(1+c_i)(\alpha_j+m)-\alpha_j m c_j}{\alpha_j m+\alpha_i(\alpha_j+m)}$ and $x_j^*=\frac{\alpha_j(1+c_j)(\alpha_i+m)-\alpha_i m c_i}{\alpha_i m+\alpha_j(\alpha_i+m)}$, therefore:

$$
\begin{aligned}
x_i^* + x_j^* &> 1 \\
\frac{\alpha_i(1+c_i)(\alpha_j+m) - \alpha_j m c_j}{\alpha_j m + \alpha_i(\alpha_j+m)} + \frac{\alpha_j(1+c_j)(\alpha_i+m) - \alpha_i m c_i}{\alpha_i m + \alpha_j(\alpha_i+m)} &> 1 \\
\frac{\alpha_j m + \alpha_i(m + \alpha_j(2 + c_i + c_j))}{\alpha_j m + \alpha_i(\alpha_j+m)} &> 1 \\
c_i + c_j &> -1
\end{aligned}
$$

and given that c_i and c_j are positive numbers the above inequality holds.

Therefore the sum of the optimal investments in case 2 is greater than one ■

7.4 Proof of Lemma 3

Differentiating x_i^* with respect to c_i,

$$\frac{\partial x_i^*}{\partial c_i} = \frac{\alpha_i\left(\alpha_j + m\right)}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is positive for any parameter values. Similarly, differentiating x_i^* with respect to c_j,

$$\frac{\partial x_i^*}{\partial c_j} = -\frac{\alpha_j m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is negative for any parameter values. ■

7.5 Proof of Lemma 4

Differentiating x_i^* with respect to α_i,

$$\frac{\partial x_i^*}{\partial \alpha_i} = \frac{\alpha_j m\left(c_i + c_j + 1\right)\left(\alpha_j + m\right)}{\left[\alpha_j m + \alpha_i\left(\alpha_j + m\right)\right]^2}$$

which is positive. Finally, let us differentiate x_i^* with respect to α_j,

$$\frac{\partial x_i^*}{\partial \alpha_j} = \frac{\alpha_i m^2\left(c_i + c_j + 1\right)}{\left[\alpha_j m + \alpha_i\left(\alpha_j + m\right)\right]^2}$$

which is negative. ■

7.6 Proof of Proposition 2

Inserting the results from proposition 1 for two countries with positive weight, $\alpha_i > 0$ and $\alpha_j > 0$, we obtain country i's equilibrium utility level from playing the subgame in which countries invest in emission-reducing technologies.

$$
\begin{aligned}
U_i &= w - x_i^* + \ln\left[m\left(x_i^* + x_j^*\right) + \alpha_i\left(x_i^* - c_i\right)\right] \\
&= -\frac{\alpha_i(1+c_i)(\alpha_j+m) + \alpha_j c_j m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)} + w - \ln\left[\alpha_i + m\right]
\end{aligned}
$$

Since U_i is linear in both c_i and c_j, we can determine the value of c_i and c_j that maximizes U_i by checking if U_i increases or decreases in c_i and c_j. Indeed,

$$
\frac{\partial U_i}{\partial c_i} = -\frac{\alpha_i(\alpha_j+m)}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}
$$

which is negative for all parameter values. In contrast,

$$
\frac{\partial U_i}{\partial c_j} = \frac{\alpha_j m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}
$$

which is positive for all parameter values. Hence, U_i decreases in c_i and increases in c_j.

7.7 Proof of Proposition 3

In the ultimatum bargaining game country i makes an offer and country j can accepts or reject such offer. In the model there exists 3 cases, since countries i and j can have different concern levels about green voters. The cases are represented in the following tables, notice that country i makes an offer composed by a pair of commitment levels (c_i, c_j).

First case: Country i's concern level is very small, $\alpha_i \in (0, \hat{\alpha}_i]$, and country j is very concerned about the noncompliance cost, $\alpha_j > \bar{\alpha}_j$. The solution is undefined given that the model's payoff structure is not well-behaved.

Second case: Country i's concern level is very high, $\alpha_i > \bar{\alpha}_i$, and country j's concern level is small, $\alpha_j \in (0, \hat{\alpha}_j]$.

$$
\begin{aligned}
(c_i^*, c_j^*) &= \left(\frac{2^{\frac{2}{3}}B^2 - 2(3+\alpha_i)m + F}{6B}, \frac{2^{\frac{2}{3}}B^2 E + FE + 2\alpha_i B m(1-(4+\alpha_i)e^w m)}{e^w \alpha_j (2^{\frac{2}{3}}B^2 - 2\alpha_i B m + F)}\right) \\
\text{where } B &= (A + \sqrt{A^2 + 4D^3})^{\frac{1}{3}} \, and \; A = -45\alpha_i^2 m^2 - 9\alpha_i^3 m^2 - 45\alpha_i m^3 - 2\alpha_i^3 m^3 \\
E &= (-1 + (1+\alpha_i)e^w m) \text{ and } F = 2^{\frac{4}{3}} m(3\alpha_i(2+\alpha_i) + (6+\alpha_i(6+\alpha_i))m \\
(x_i^*, x_j^*) &= (1 + \alpha_i - \frac{6\alpha_i B}{2^{\frac{2}{3}}B^2 + F - 2\alpha_i B m}, 0)
\end{aligned}
$$

Third case: Country i and j have a medium concern level, $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$.

$$
\begin{aligned}
(c_i^*, c_j^*) &= (c_i, \frac{\alpha_j m(-1+w) - \alpha_j \alpha_i + \alpha_i \Gamma w + (\alpha_j m + \alpha_i \Gamma) \log \Gamma}{\alpha_j(\alpha_i + m)}) \\
\text{where } \Gamma &= (\alpha_j + m) \\
(x_i^*, x_j^*) &= (\frac{\alpha_i + w - mw - m \log \Gamma)}{(\alpha_i + m)}, w + \log \Gamma)
\end{aligned}
$$

7.8 Corollary 2

Case when country i proposes (c_i, c_j) and $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$:

$$
\begin{aligned}
(c_i^*, c_j^*) &= (0, \frac{\alpha_j m(-1+w) - \alpha_j \alpha_i + \alpha_i \Gamma w + (\alpha_j m + \alpha_i \Gamma) \log \Gamma}{\alpha_j(\alpha_i + m)}) \\
(x_i^*, x_j^*) &= (\frac{\alpha_i + w - mw - m \log \Gamma)}{(\alpha_i + m)}, w + \log \Gamma) \\
\text{where } \Gamma &= \frac{\alpha_i + w - mw - m \log \Gamma)}{(\alpha_i + m)} > 0 \text{ iff } \alpha_i > m(w + m \log \Gamma) - w
\end{aligned}
$$

7.9 Corollary 3

Case when country i proposes (c_i^*, c_j^*) and $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$:

$$
\begin{aligned}
U_j(\cdot) &= w + \ln [m x_i - \alpha_j c_j] \\
c_j &= \frac{(m + c_i)(m e^w - 1) + \alpha_i m c_i e^w}{\alpha_j e^w (m + c_i)}
\end{aligned}
$$

Additionally, $x_i^* = \frac{\alpha_i(1+c_i)(\alpha_j+m) - \alpha_j m c_j}{\alpha_j m + \alpha_i(\alpha_j + m)}$ when $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $x_j^* = \frac{\alpha_j(1+c_j)(\alpha_i+m) - \alpha_i m c_i}{\alpha_i m + \alpha_j(\alpha_i + m)}$ when $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$. Therefore,

$$
\begin{aligned}
U_i(\cdot) &= w - x_i^* + \ln \left[m(x_i^* + x_j^*) + \alpha_i (x_j^* - c_i) \right] \\
& \max_{c_i} U_i(\cdot)
\end{aligned}
$$

F.O.C with respect to c_i is:

$$
-\frac{\alpha_i}{\alpha_i + m} = 0
$$

Therefore $(c_i, c_j) = (0, \frac{\alpha_j m(-1+w) - \alpha_j \alpha_i + \alpha_i \Gamma w + (\alpha_j m + \alpha_i \Gamma) \log \Gamma}{\alpha_j(\alpha_i + m)})$

Finally, country j's commitment level increases in α_i.

$$\frac{\partial c_j}{\alpha_i} = \frac{m^2(w+\log\Gamma)}{\alpha_j(\alpha_i+m)^2} > 0$$

Case when country i proposes (c_i^*, c_j^*) and $\alpha_i > \bar{\alpha}_i$ and $\alpha_j \in (0, \hat{\alpha}_j]$:

$$\begin{aligned} U_j(\cdot) &= w + \ln\left[mx_i - \alpha_j c_j\right] \\ c_j &= \frac{(m+c_i)(me^w - 1) + \alpha_i m c_i e^w}{\alpha_j e^w (m+c_i)} \end{aligned}$$

Additionally, $x_i^* = 1 + \frac{\alpha_i c_i}{m+\alpha_i}$ when $\alpha_i > \bar{\alpha}_i$ and $x_j^* = 0$ when $\alpha_j \in (0, \hat{\alpha}_j]$. Therefore,

$$\begin{aligned} U_i(\cdot) &= w - 1 + \frac{\alpha_i c_i}{m+\alpha_i} + \ln\left[m(1 + \frac{\alpha_i c_i}{m+\alpha_i}) + \alpha_i (1 + \frac{\alpha_i c_i}{m+\alpha_i} - c_i)\right] \\ & \max_{c_i} w - 1 + \frac{\alpha_i c_i}{m+\alpha_i} + \ln\left[m(1 + \frac{\alpha_i c_i}{m+\alpha_i}) + \alpha_i (1 + \frac{\alpha_i c_i}{m+\alpha_i} - c_i)\right] \end{aligned}$$

F.O.C with respect to c_i is:

$$-1 - \frac{\alpha_i c_i}{c_i + m} + w + \frac{\log c}{\log(\alpha_i + m + \frac{\alpha_i(\alpha_i - c_i)c_i}{c_i+m})} = 0$$

Therefore $(c_i, c_j) = (c_i, \frac{(m+c_i)(me^w-1)+\alpha_i m e^w}{\alpha_j e^w (m+c_i)})$
Finally, country j's commitment level increases in α_i.

$$\frac{\partial c_j}{\partial \alpha_i} = \frac{c_i m}{\alpha_j(c_i+m)} > 0$$

7.10 Corollary 4

The total investment in clean technology, G, obtained when $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$ is:

$$\begin{aligned} G^* &= x_i^* + x_j^* = \frac{\alpha_i + w - mw - m\log\Gamma}{(\alpha_i + m)} + w + \log\Gamma \\ \frac{\partial G^*}{\partial \alpha_j} &= \frac{\alpha_i}{(\alpha_i+m)(\alpha_j+m)} > 0 \end{aligned}$$

7.11 Proof of Lemma 5

In this environmental game, both players are asked to simultaneously submit their investments in emission-reducing technologies. Fixing country j's investment, x_j, country i's utility maximization problem becomes

$$\max_{x_i} \quad w - x_i + \ln\left[m(x_i + x_j) + \alpha_i\left(x_j - c_j\right)\right]$$

And the argument that maximizes this utility function gives us the following best response function

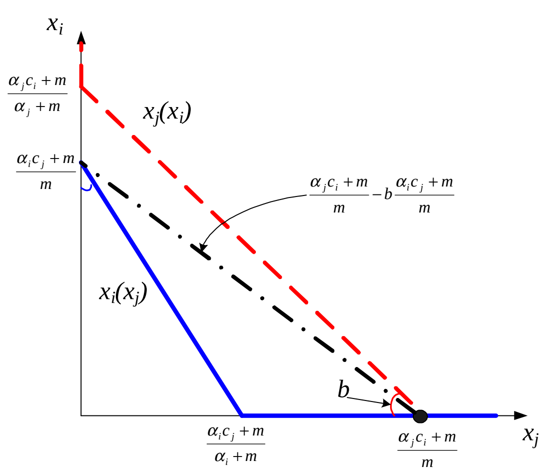
$$x_i(x_j) = \begin{cases} \frac{1}{m}\left[\alpha_i c_j + m\right] \text{ if } x_j = 0 \\ \frac{1}{m}\left[\alpha_i c_j + m - (\alpha_i + m)x_j\right] \text{ if } x_j \in (0, \frac{\alpha_i c_j + m}{\alpha_i + m}] \\ 0 \text{ if } x_j > \frac{\alpha_i c_j + m}{\alpha_i + m} \end{cases}$$

Since $\frac{1}{m}\left[\alpha_i c_j + m - (\alpha_i + m)x_j\right] = 0$ exactly at $x_j = \frac{\alpha_i c_j + m}{\alpha_i + m}$. Hence, this best response function can be more compactly expressed as

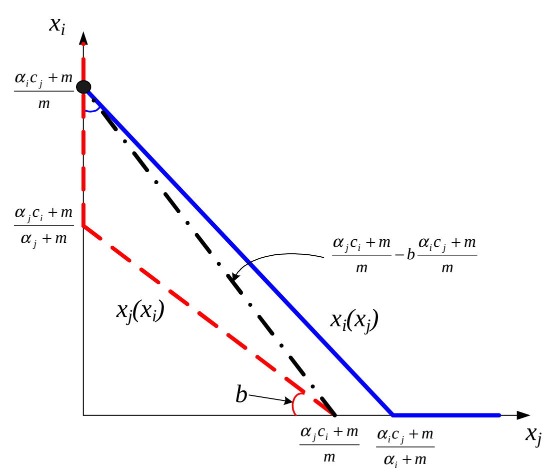
$$x_i(x_j) = \begin{cases} \frac{1}{m}\left[\alpha_i c_j + m - (\alpha_i + m)x_j\right] \text{ if } x_j \in [0, \frac{\alpha_i c_j + m}{\alpha_i + m}] \\ 0 \text{ if } x_j > \frac{\alpha_i c_j + m}{\alpha_i + m} \end{cases} \quad \blacksquare$$

7.12 Proof of Proposition 4

Let us take country i's best response function, $x_i(x_j)$, from lemma 1, and analyze the different forms in which country i and j's best response functions can cross each other. The corner solutions (cases 1 and 2 below) are illustrated in the following figures, to clarify the following steps of the proof.



Case 1



Case 2

Case 1: $x_i^* = 0$

Note that $x_i^* = 0$ if and only the following two conditions are satisfied: (1) the horizontal intercept of country i's best response function is lower than that of country j., and (2) the slope of country j's best response function is small enough to make that $x_j(x_i)$ does not cross $x_i(x_j)$. That is, the first condition is satisfied if

$$\frac{\alpha_i c_j + m}{\alpha_i + m} < \frac{\alpha_j c_i + m}{m}$$

Manipulating this inequality, we obtain

$$\alpha_i < \frac{\alpha_j c_i m}{m\,(c_j - 1) - \alpha_j c_i}$$

and since $c_i \leq 1$ by definition, the term in the right-hand side is negative for any $c_i < 1$, what implies that the above inequality is always satisfied for any $\alpha_i = 0$.

On the other hand, the second condition holds if, b, the slope of country j's best response function, satisfies

$$0 < \frac{\alpha_j c_i + m}{m} - b\frac{\alpha_i c_j + m}{m}$$
$$\Longleftrightarrow b < \frac{\alpha_j c_i + m}{\alpha_i c_j + m}$$

and since the slope of $x_j(x_i)$ is $\alpha_j + m$, we need that

$$\begin{aligned} -(\alpha_j + m) \quad &> \quad -\left(\frac{\alpha_j c_i + m}{\alpha_i c_j + m}\right) \\ (\alpha_j + m) \quad &< \quad \frac{\alpha_j c_i + m}{\alpha_i c_j + m} \end{aligned}$$

and manipulating, and solving for α_i, we obtain the threshold of α_i below which all values of α_i support a zero investment in clean technologies by country i,

$$\alpha_i < \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)} = \bar{\alpha}_i$$

Case 2: $x_i^* = \frac{\alpha_i c_j + m}{m}$

Let us now analyze the case in which country i sets the maximum investment $\frac{\alpha_i c_j + m}{m}$, while country j does not invest. Firstly, we need that country i's horizontal intercept is above that of country j's, what simply implies

$$\begin{aligned} \frac{\alpha_i c_j + m}{\alpha_i + m} \quad &> \quad \frac{\alpha_j c_i + m}{m} \Longleftrightarrow \alpha_i > \frac{\alpha_j c_i m}{m\,(c_j - 1) - \alpha_j c_i} \\ \Longleftrightarrow \quad & \alpha_i > \frac{\alpha_j c_i m}{m\,(c_j - 1) - \alpha_j c_i} = \hat{\alpha}_i \end{aligned}$$

Secondly, we need that b, the slope of country j's best response function, satisfies

$$0 > \frac{\alpha_j c_i + m}{m} - b\frac{\alpha_i c_j + m}{m}$$

and operating similarly as in the previous case, we have

$$\alpha_i > \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)} = \bar{\alpha}_i$$

Case 3: $x_i^* = \frac{\alpha_j c_i m + \alpha_i(\alpha_j c_i + m - c_j m)}{\alpha_j m + \alpha_i(\alpha_j + m)}$

Finally, the equilibrium is interior when first, country i's horizontal intercept is below that of country j's, what simply implies,

$$\frac{\alpha_i c_j + m}{\alpha_i + m} > \frac{\alpha_j c_i + m}{m} \Longleftrightarrow \alpha_i < \frac{\alpha_j c_i m}{m\,(c_j - 1) - \alpha_j c_i} = \hat{\alpha}_i$$

and second, when b, the slope of country j's best response function, satisfies

$$0 > \frac{\alpha_j c_i + m}{m} + b\frac{\alpha_i c_j + m}{m} \Longleftrightarrow \alpha_i > \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)} = \bar{\alpha}_i$$

Finally, we must check that $\bar{\alpha}_i > \hat{\alpha}_i$. Indeed,

$$\bar{\alpha}_i - \hat{\alpha}_i = \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)} - \frac{\alpha_j c_i m}{m\,(c_j - 1) - \alpha_j c_i} > 0$$

for any parameter values. Hence, we can summarize the above three cases as follows:

$$x_i^* = \begin{cases} \frac{\alpha_i c_j + m}{m} \text{ if } \alpha_i > \bar{\alpha}_i \\ \frac{\alpha_j c_i m + \alpha_i(\alpha_j c_i + m - c_j m)}{\alpha_j m + \alpha_i(\alpha_j + m)} \text{ if } \alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i] \\ 0 \text{ if } \alpha_i \in (0, \hat{\alpha}_i] \end{cases}$$

where $\hat{\alpha}_i = \frac{\alpha_j c_i m}{m(c_j - 1) - \alpha_j c_i}$ and $\bar{\alpha}_i = \frac{\alpha_j(c_i - m) + m - m^2}{c_j(\alpha_j + m)}$ ■

7.13 Proof of Lemma 6

In order to obtain a higher solution than in the case of unconcerned countries, we need to show that the total sum of the optimal investment in clean technologies of the country i and j is greater than one. Notice that there are four possible combinations, which depend of the parameter α_i or α_j.

	x_i	x_j
Case 1	$\alpha_i > \bar{\alpha}_i$	$\alpha_j > \bar{\alpha}_j$
Case 2	$\alpha_i > \bar{\alpha}_i$	$\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$
Case 3	$\alpha_i > \bar{\alpha}_i$	$\alpha_j \in (0, \hat{\alpha}_j]$
Case 4	$\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$	$\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$

Case 1, 2 and 3 are trivial because when $\alpha_i > \bar{\alpha}_i$ the optimal investment is $x_i^* = 1 + \frac{\alpha_i c_j}{m}$ which is greater than one.

In case 4 the optimal investments in clean technologies are $x_i^* = \frac{\alpha_j c_i m + \alpha_i(\alpha_j c_i + m - c_j m)}{\alpha_j m + \alpha_i(\alpha_j + m)}$ and $x_j^* = \frac{\alpha_i c_j m + \alpha_j(\alpha_i c_j + m - c_i m)}{\alpha_i m + \alpha_j(\alpha_i + m)}$, therefore:

$$\begin{aligned} x_i^* + x_j^* &> 1 \\ \frac{\alpha_j c_i m + \alpha_i\left(\alpha_j c_i + m - c_j m\right)}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)} + \frac{\alpha_i c_j m + \alpha_j\left(\alpha_i c_j + m - c_i m\right)}{\alpha_i m + \alpha_j\left(\alpha_i + m\right)} &> 1 \\ \frac{\alpha_j m + \alpha_i(m + \alpha_j(c_i + c_j))}{\alpha_j m + \alpha_i(\alpha_j + m)} &> 1 \\ c_i + c_j &> 1 \end{aligned}$$

Therefore, the total sum of optimal investment in clean technologies is greater than one if and only if $c_i + c_j > 1$.■

7.14 Proof of Lemma 7

Differentiating x_i^* with respect to c_i,

$$\frac{\partial x_i^*}{\partial c_i} = \frac{\alpha_j\left(\alpha_i + m\right)}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is positive for any parameter values. Similarly, differentiating x_i^* with respect to c_j,

$$\frac{\partial x_i^*}{\partial c_j} = -\frac{\alpha_i m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is negative for any parameter values. ■

7.15 Proof of Lemma 8

Differentiating x_i^* with respect to α_i,

$$\frac{\partial x_i^*}{\partial \alpha_i} = -\frac{\alpha_j\left(c_i + c_j - 1\right) m^2}{\left[\alpha_j m + \alpha_i\left(\alpha_j + m\right)\right]^2}$$

which is negative if and only if $c_i + c_j > 1$. Finally, let us differentiate x_i^* with respect to α_j,

$$\frac{\partial x_i^*}{\partial \alpha_j} = \frac{\alpha_i\left(c_i + c_j - 1\right) m\left(\alpha_i + m\right)}{\left[\alpha_j m + \alpha_i\left(\alpha_j + m\right)\right]^2}$$

which is positive if and only if $c_i + c_j > 1$. ■

7.16 Proof of Proposition 5

Inserting the results from proposition 1 for two countries with positive weight, $\alpha_i > 0$ and $\alpha_j > 0$, we obtain country i's equilibrium utility level from playing the subgame in which countries invest in emission-reducing technologies.

$$\begin{aligned} U_i &= w - x_i^* + \ln\left[m\left(x_i^* + x_j^*\right) + \alpha_i\left(x_j^* - c_j\right)\right] \\ &= -\frac{\alpha_j c_i m + \alpha_i\left(\alpha_j c_i + m - c_j m\right)}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)} + w - \ln[m] \end{aligned}$$

Since U_i is linear in both c_i and c_j, we can determine the value of c_i and c_j that maximizes U_i by checking if U_i increases or decreases in c_i and c_j. Indeed,

$$\frac{\partial U_i}{\partial c_i} = -\frac{\alpha_i\alpha_j + \alpha_j m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is negative for all parameter values. In contrast,

$$\frac{\partial U_i}{\partial c_j} = \frac{\alpha_i m}{\alpha_j m + \alpha_i\left(\alpha_j + m\right)}$$

which is positive for all parameter values. Hence, U_i decreases in c_i and increases in c_j.

7.17 Proof of Proposition 6

In the ultimatum bargaining game country i makes an offer and country j can accepts or reject such offer. In the model there exists 3 cases, since countries i and j can have different concern levels about green voters. The cases are represented in the following tables, notice that country i makes an offer composed by a pair of commitment levels (c_i, c_j).

First case: Country i's concern level is very small, $\alpha_i \in (0, \hat{\alpha}_i]$, and country j is very concerned about the noncompliance cost, $\alpha_j > \bar{\alpha}_j$.

$$\begin{aligned} (c_i^*, c_j^*) &= \left(\frac{\alpha_j m c_j - m\Gamma + \sqrt{4\alpha_j^2\Gamma^2 + m^2(\Gamma - \alpha_j c_j)^2}}{2\alpha_j\Gamma}, c_j\right) \\ \text{where } \Gamma &= (\alpha_j + m) \\ (x_i^*, x_j^*) &= \left(0, \frac{\alpha_j m c_j + m\Gamma + \sqrt{4\alpha_j^2\Gamma^2 + m^2(\Gamma - \alpha_j c_j)^2}}{2m\alpha_j\Gamma}\right) \end{aligned}$$

Second case: Country i's concern level is very high, $\alpha_i > \bar{\alpha}_i$, and country j's concern level is small, $\alpha_j \in (0, \hat{\alpha}_j]$.

$$
\begin{aligned}
(c_i^*, c_j^*) &= \Big(\frac{e^{-w}(-Am\Gamma + e^w(\alpha_i\alpha_j^3 + 2A\alpha_j^2 m - (-2+\alpha_i)\alpha_j m^2 + (-1+\alpha_i)m^3) - B}{2\alpha_j m A\Gamma} \\
&\quad \frac{e^{-w}(-Am\Gamma + e^w(-\alpha_i\alpha_j^3 + (2+5\alpha_i)\alpha_j m^2 + (1+3\alpha_i)m^3) + B}{2\alpha_i A\Gamma^2}\Big) \\
\text{where } \Gamma &= (\alpha_j + m) \\
A &= 1 + \alpha_i \text{ and} \\
B &= \sqrt{\begin{array}{c}(Am\Gamma + e^w(-\alpha_i\alpha_j^3 - 2A\alpha_j^2 m + (-2+\alpha_i)\alpha_j m^2 + \\ (-1+\alpha_i)m^3))^2 + 4A\alpha_j^2 e^w m\Gamma(m + \alpha_i(m - e^w(\alpha_j - 2m)\Gamma))\end{array}} \\
(x_i^*, x_j^*) &= \Big(1 + \frac{e^{-w}(-Am\Gamma + e^w(-\alpha_i\alpha_j^3 + (2+5\alpha_i)\alpha_j m^2 + (1+3\alpha_i)m^3) + B)}{m}, 0\Big)
\end{aligned}
$$

Third case: Country i and j have a medium concern level, $\alpha_i \in (\hat{\alpha}_i, \bar{\alpha}_i]$ and $\alpha_j \in (\hat{\alpha}_j, \bar{\alpha}_j]$.The solution is undefined given that the model's payoff structure is not well-behaved.

7.18 Table 1

Parties Annex I	Quantified emission limitation or reduction commitment (percentage of base year or period)	Change from 1990 to 2004	Fulfillment of compromises (1)	Representation of green parties in parliament (percentage) (2)
Australia	-108	25.1	**No**	5%
Austria	-92	15.7	**No**	11%
Belgium	-92	1.4	**No**	3%
Belarus ***	-92	-41.6	**45%**	2%
Bulgaria* **	-92	-49.0	**53%**	34%
Canada	-94	26.6	**No**	0%
Croatia* **	-95	-5.4	**6%**	0%
Czech Republic* **	-92	-25.0	**27%**	3%
Denmark	-92	-1.1	**1%**	3%
Estonia* **	-92	-51.0	**55%**	1%
European Community	-92	-0.6	**1%**	5%
Finland	-92	14.5	**No**	7%
France	-92	-0.8	**1%**	0.54%
Germany **	-92	-17.2	**19%**	8.31%
Greece	-92	26.6	**No**	0%
Hungary* **	-94	-31.8	**34%**	0%
Iceland **	-110	-5.0	**5%**	8%
Ireland	-92	23.1	**No**	0%
Italy	-92	12.1	**No**	3%
Japan	-94	6.5	**No**	0%
Latvia* **	-92	-58.5	**64%**	12%
Liechtenstein	-92	18.5	**No**	12%
Lithuania* **	-92	-60.4	**66%**	0%
Luxembourg	-92	0.3	**No**	12%
Monaco	-92	-3.1	**3%**	0%
Netherlands	-92	2.4	**No**	5%
New Zealand	-100	21.3	**No**	3%
Norway	-101	10.3	**No**	0%
Poland* **	-94	-31.2	**33%**	0%
Portugal	-92	41	**No**	1%
Romania* **	-92	-41.0	**45%**	9%
Russian Federation* **	-100	-32.0	**32%**	0%
Slovakia* **	-92	-30.4	**33%**	0%
Slovenia*	-92	-0.8	**1%**	0%
Spain	-92	49.0	**No**	0%
Sweden	-92	-3.5	**4%**	5%
Switzerland	-92	0.4	**No**	1%
Turkey ***	-92	72.6	**No**	0%
Ukraine* **	-100	-55.3	**55%**	0%
United Kingdom of Great** Britain and Northern Ireland	-92	-14.3	**16%**	0%
United States of America	-93	15.8	**No**	0%

** Countries fulfilling article 3 #1
* Countries that are undergoing the process of transition to a market economy.
*** They are not considered in the Protocol's Annex B as they were not Parties to the Convention when the Protocol was adopted
Positive Values means emissions, negative values means removals
Correlation Between (1) and (2): +26%

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