Pushing the Tipping in International Environmental Agreements

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Abstract

This paper intends to provide an alternative approach to explain the formation of International Environmental Agreements (IEA). The existing consensus from the literature suggests that there are either too few signatories or that the emissions of signatories are almost the same as business as usual (BAU). I start from well known model (Barrett 1997), adding heterogeneity in countries' marginal abatement costs (low and high) and in damages suffered (or corresponding environmental concern). I also allow for technological transfers and border taxes. I show that using either mechanism one at a time, does not change the results. But if both are used in a 'strategic' manner, a grand (and abating) coalition can be reached, while minimizing transfers.

JEL Classification: F53, C63, C72, F18, Q58, O32.
Keywords: Self-enforcing environmental agreements, border tax, tipping.

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1 Introduction

The present paper focuses on the idea that trying to have an International Environmental Agreement (IEA) that brings together a big share of countries into joining it, is sometimes a colossal task to achieve. Barrett (1994) [2], Rubio & Ulph (2006) [15] and Eichner & Pethig (2013) [11] among others, show that the number of signatories of self-enforcing IEAs does not exceed three or four. Recent failures on reaching an effective agreement concerning climate change is a clear example of this fact. Other solutions that have been analysed in order to arrive to a successful IEA have to do with the idea of starting with a small sub-set of countries that can incorporate others as time goes by. This idea has been already explored by Heal and Kunreuther (2011) [13], where they suggest a small coalition that adds countries to it, in a cascading process. Following this line Carraro & Siniscalco (1993) [7], Hoel & Schneider (1997) [14] and Barrett (2001) [4] have analysed the set-up in where transfers has been introduced in order to induce more countries to join the IEA. Unfortunately all these papers showed that a commitment problem prevent the formation of the grand coalition or if it forms, it almost acts as Business as Usual (BAU). The commitment problem comes from the fact that the IEA set-up resembles a chicken game. Therefore signatories are better off compared to not having an IEA at all, but they would prefer to actually have others to sign and themselves to be non-signatories. Hence, when transfers are made in order to enlarge the coalition, the original signatories prefer to leave.

With all these barriers in mind, I explore a new tactic and I show that using two instruments, namely a border tax and technology transfers, it can effectively induce and sustain the grand and meaningful coalition.(1) I also show that these transfers have to be made to the least-green countries, in order to improve the chances of success, while minimizing the amount of transfers.

In order to develop this idea, I will use as a baseline the model developed by Barrett (1997) [3], and then I will add some ingredients. The first one is the possibility of transfers between countries, as in Carraro and Siniscalco (1993) [7]. The second one has to do with the idea that societies behave green, even though direct 'rational' thinking could command otherwise. This could be related to moral reasons rather than economic ones. As shown in Cerda (2013) [8], structurally similar countries (in development level, political system) can end up behaving differently with respect to the environment. This could be for historical reasons, but the point is that some countries became (quite) aware of the environmental problem at hand and started acting accordingly. This point supports the idea of having heterogeneity in countries, which departs from the two last cited pa-

(1)Meaningful in the sense that countries are actually doing an effort in abating and not behaving close to BAU.

pers. In this paper, the differences among countries are how green they are, and what abatement technology they have in place. With respect to the first point, an equivalent interpretation can be on how countries are affected by pollution. Therefore having higher marginal damages coming from emission will be treated as a synonym of being greener. On the abatement side, countries can either have a costly technology (also referred as a 'bad' technology) and an cheap technology (the good one).

With this set-up I want to check if a small initial coalition of green countries can induce the formation of the grand coalition. The idea behind is the same as the successful mechanism implemented in the Montreal protocol and its subsequent amendments (for a detailed explanation see Barrett's book [5]). It this case one country, the US, was unilaterally willing to cut emissions and consumption of ozone depleting substances. But they were well aware that first, leakage coming from trade could reduce their effort results, and secondly that if other big economies would follow suit, the gains (for them and globally) would be much better. Therefore they were willing to unilaterally ban the use and production of CFCs, but also to ban trade of these substances. This second component, plus the fact that they were also willing to help developing countries to switch to new and clean substances, pushed others countries to join one of the most successful IEA known in history.

Therefore it would be desirable to do a similar thing with green house gases (GHG) emissions. But for this case some important barriers appear. First, tackling the production and trade of CFCs is an simple task. Where doing the same for CO_2 emissions is quite impossible, since their emissions are embedded in almost every product we trade. Hence, completely banning trade seems out of the question. The 'sticks' used in Montreal are not credible in an IEA concerning CO_2. To avoid this obstacle, we can use a border tax, imposed on goods coming from non-signatories countries, in order to deter free-riding and to induce accession, similarly as Montreal did with trade ban. This will be the case in the present paper, acknowledging that this could bring a trade war. In order to avoid this, I will use conservative values for this tax, in line with the results of Anouliès (2014) [1]. A possible drawback of this upper limit is that the stick looses its deterring force and it is quite possible that this is the reason why such an agreement has not been put in place so far.

A second point to note is the fact that in the CFC case, the estimated losses coming from high UV rays exposition and the costs of changing technology, made the choice an easy one. The gains exceed the costs by a huge margin, making the political decision viable. Returning to the CO_2 problem, although there is a big consensus about damages arising from global warming, there are differences among countries of how these damages will hurt each one and moreover, the damage level is uncertain and eventually comparable to the cost of switching to the required clean technology. This factor is an important one since even though in the Montreal case, a Minimum Participation Clause (MPC) was needed in order to induce the desired equilibrium (and not to suffer from free-riding if there were too few signatories). But there was consensus on the damages coming from not doing so. In the present conundrum, having uncertainty of gains and costs of accessing such an agreement, makes the political decision a much harder one to pursuit, and puts the MPC in a level that might not be politically feasible to reach. Or it has such an uncertainty that it becomes political infeasible. Due to this last point I will assume that in order to reach the grand coalition, no MPC should be needed. This premise might seem to hard, but the idea behind it is that if the grand coalition can be reached with this assumption, then it can be reached with a 'small' MPC, which might be politically acceptable. Since this last point is hard to determine, I choose to rule out the use of a MPC.

With all these previous considerations in mind I build a model which is an expanded version of Barrett (1997) [3]. To keep focus on the main objective of the paper, I use some basic premises. I assume that it is profitable for that grand coalition to form, meaning that the gains coming from cutting emissions are higher than the abatement cost and consumption and production loss coming from mitigating them. I also assume that the parameters of the model are such that there exists an initial (small) coalition of green countries.

2 The Game

There is always a trade-off between simplicity and reality when choosing the model. Therefore I start with a 'simple' model, to which I add some features and at the same time I will introduce some simplifications, in order to keep it tractable. To do so, I build on the model used by Barrett (1997) [3]. This model is a three stage game where countries choose to be part or not of an IEA (one shot), then governments set their abatement levels (which their firms must meet) and then firms move by choosing simultaneously their segmented outputs, all this in a Cournot-Nash set-up. It is a perfect information model in the sense that countries perfectly know their costs and gains and the same of other countries.

The idea of choosing this model is that it has some features that are useful to the task at hand. First, it focusses on abatement technology and not in emissions. This is important since, from a 'political' point of view, it leads to an enforceable IEA since technology being used is easily verifiable, where total emissions could be arguable. A second point, an most important to this work, is that I can add technology transfers (carrots), which changes the recipient country's incentives, and therefore the game itself, which is part of the overall plan. On the other hand, it is easy to add asymmetries to the model. In my case, I add two asymmetries: marginal abatement costs (two levels) and heterogeneity in the marginal damage from emissions (environmental concern). Third, it models trade, and therefore carbon leakage, which is a feature (and challenge) that cannot be left aside. The main obstacle in reaching an meaningful IEA comes from having leakage, because it provides countries strong incentives to free-ride. In fourth place, the original model has sanctions (sticks): it bans trade. In my case I will replace the trade ban with a border tax, which follows the same intuition. It is a tool to hinder leakage and it is a credible one.

With the previous specifications, I define two types of countries: those with cheap (good) abatement technology and high marginal damage from emissions, the *'rich'* countries; and those with expensive (bad) abatement technology and lower environmental concern, the *'outsiders'*. I will be using marginal damage from emissions and environmental concern as synonyms, since as it will be seen in the following equations, the higher the damage coming from emissions, the higher are the incentives to a country to reduce emissions (locally and globally) and to join and IEA. In this line I will be also referring to countries with higher environmental concern as 'greener'.

Finally, I set two moments or stages: the *base case*, which is the case where border tax or technology transfers are allowed, but not both at the same time. In this case, I will assume that the conditions (parameters) are such that we get the classical result that there is a small coalition in place or if the grand coalition is a possible equilibrium of the game, is such that we need a MPC in order to induce this equilibrium. The second stage, *After Tax and Transfers*, is the one where both instruments are in place. In this case I will show that the grand coalition forms[(2)], with no MPC as a requirement.

2.1 The model

There are N countries and there are N firms (one per country) that produce an homogeneous traded good and a transboundary pollution. The inverse demand in each country is given by $p(x^i) = 1 - x^i$, where x^i is the consumption of the good in country i. Firm j's costs are $C(\sigma_j, x_j, q_j) = \sigma_j \, q_j \, x_j$, where x_j is total output by firm j, σ_j is its marginal abatement cost and $q_j \in \{0, 1\}$ is the abatement standard for firm j. Firm j takes q_j as given. Transport costs are zero. Emissions by firm j are $x_j(1 - q_j)$. Therefore if abatement is maximal, emissions are zero. If no abatement is undertaken, emissions are equal to output.

[(2)]I assume that the parameters are such that the big coalition *is* an equilibrium (with or without the need of a MPC), after transferring technology to one or more countries.

Looking at σ_j, the abatement marginal cost for firm j, it could reflect the technology used, to produce electricity for example, in country j. Therefore it could be thought as the (accumulative) efforts undertaken by a country in order to be greener. In this model there are two possible levels of marginal abatement cost: cheap (good) technology σ_L and expensive (bad) technology σ_H.

Secondly we have the stick: the border tax. In this case, instead of banning trade between signatories and non-signatories, I have that countries inside a coalition will tax imports, at a rate t, of goods coming (and produced) from non-signatories countries. In this set-up I assume that only signatory tax goods coming from non-signatories and that the later do not retaliate with another tax on signatories' goods. In order for this assumption to be credible (meaning that it does not trigger a trade war), I will use low tax rate levels (although the model will be solved with a generic rate t), in line with Anouliès (2014) [1] results. The idea here is that the border tax will only reflect the cost that the non-signatory country would have incurred if it had abated. In this sense, the maximum value of t will be the marginal abatement cost of the non-signatory, σ_H.

In third place country's choice is binary: $q_j \in \{0, 1\}$. Either the country chooses to fully abate ($q_j = 1$) and none at all ($q_j = 0$). Hence, joining the coalition and having $q_j = 1$ become synonyms. This change has two main basis: First, I discard by construction the case of having coalitions (esp. the grand coalition) that do not abate or when they do, the operate quite close to BAU, as the literature has shown (as in Barrett (1994) [2] and Eichner & Pethig (2013) [11]). Secondly, it makes the model more tractable with clear cut results.(3) On another side, we can see that if country decisions are binary, it makes the coalition formation a 'harder' process, since becoming member of the IEA implies full abatement for the joining country. Also signatories do not have any form to punish a country leaving the coalition, since I assume a border tax rate constant and given. Hence, if a coalition can form in this stricter set-up, they would form in a laxer one.

Focussing now on the solution of the game at hand, I proceed using backward induction. First I solve the firm production, which depends of the abatement undertaken by each country. With this, each country j can evaluate two options, $q_j = 1$ or $q_j = 0$, which also depends of the decisions taken by others. With all this in mind, each country chooses to be part of the coalition of size k, $\mathcal{S}_k$ or not. Firms choose their output for each market simultaneously. Firm j takes its own abatement standard and the segmented outputs of other firms as given and chooses a quantity to produce and ship to market i, x_j^i, so as to maximize,

$$\pi_j = \sum_{i=1}^{N} (1 - x^i - t_j^i - \sigma_j q_j) x_j^i \tag{2.1}$$

(3)Binary choices can also be found in the literature, as for example in Heal (1994) [12].

with $t_j^i = t$ if $i \in \mathcal{S}_k \wedge j \notin \mathcal{S}_k$, and $t_j^i = 0$ otherwise. First order conditions are[(4)]

$$1 - x^i - t_j^i - \sigma_j\, q_j - x_j^i = 0 \qquad \forall i, j \tag{2.2}$$

Taking into account the fact the $q_j \in \{0, 1\}$ and solving the system of equations, we get:

$$x^i = \begin{cases} \frac{N - \sigma_{\mathcal{S}} - (N-k)\cdot t}{N+1} & \text{if } i \in \mathcal{S}_k \\ \frac{N - \sigma_{\mathcal{S}}}{N+1} & \text{if } i \notin \mathcal{S}_k \end{cases} \tag{2.3}$$

where k is the size of the coalition, and $\sigma_{\mathcal{S}} = \sum_{j\in\mathcal{S}} \sigma_j$ (the sum of the coalition's marginal abatement costs). Replacing this result into the FOC, we have:

$$x_j^i = \begin{cases} \frac{1+\sigma_{\mathcal{S}} - (N+1)\sigma_j + (N-k)\cdot t}{N+1} & \frac{1+\sigma_{\mathcal{S}} - (k+1)\cdot t}{N+1} & \text{if } i \in \mathcal{S}_k \\ \frac{1+\sigma_{\mathcal{S}} - (N+1)\sigma_j}{N+1} & \frac{1+\sigma_{\mathcal{S}}}{N+1} & \text{if } i \notin \mathcal{S}_k \\ \uparrow & \uparrow & \\ \text{if } j \in \mathcal{S}_k & \text{if } j \notin \mathcal{S}_k & \end{cases} \tag{2.4}$$

From where we can calculate the firm profit π_j:[(5)]

$$\pi_j = \begin{cases} \frac{N\cdot\aleph_j^2 + k(N-k)t\left(2\aleph_j + (N-k)t\right)}{(N+1)^2} & \text{if } j \in \mathcal{S}_k \\ \frac{N\cdot\aleph_2^2 + k(k+1)t\left((k+1)t - 2\aleph_2\right)}{(N+1)^2} & \text{if } j \notin \mathcal{S}_k \end{cases} \quad \text{with} \quad \begin{array}{l} \aleph_j = 1 + \sigma_{\mathcal{S}} - (N+1)\sigma_j \\ \aleph_2 = 1 + \sigma_{\mathcal{S}} \end{array} \tag{2.5}$$

Countries choices

Country j's net benefits are the sum of firm j's profits, the consumer surplus of its citizens, less the environmental damage suffered, plus border taxes collected, if it is the case. Pollution is assumed to be a pure public bad and aggregate emissions are given by $\sum_{i=1}^N x_i(1 - q_i)$. Marginal environmental damage for each country is ω_j. As stated in the Introduction, there is heterogeneity in ω_j, with the rich countries having ω_H and 'outsiders' having $\omega_j < \omega_H$ (abusing the notation). For the consumer surplus we have that, given demand specifications, it is equal to $(x^j)^2/2$ for country j. For the tax collected, we just add up those of the signatory countries ($q_j = 1$) taxing products coming from the non-signatories ($q_j = 0$). With these, country profit is:

$$\Pi_j = \pi_j + (x^j)^2/2 - \omega_j \left[\sum_{i=1}^N x_i(1 - q_i)\right] + t \cdot q_j \cdot \sum_{i=1}^N x_i^j(1 - q_i) \tag{2.6}$$

(4) I only consider the situations where firms produce positive quantities in equilibrium.
(5) Mathematical development of eqns. (2.2), (2.3) and (2.4) are in Appendix A.

where x^j and x_i^j are those found in equations (2.3) and (2.4) respectively, and x_i is $\sum_{j=1}^{N} x_i^j$, the production of firm i.

2.2 Enlarging the coalition

As stated in the Introduction, the idea is to show that starting from a *Base Case* moment in where there is no grand coalition in place, we can arrive into a situation, called *After Tax and Transfers*, where the grand and meaningful coalition forms. In order to arrive to this point, some r countries have to receive a technological transfer that reduces their marginal abatement cost from σ_H to σ_L. These technological transfers can be thought of an international aid from rich countries to some other countries in order to induce the grand coalition formation. For example, rich countries could be willing to change how electricity is produced, in order to shift from a carbon intensive power sources, into a more eco-friendly ones. This transfer has a cost K per recipient and it is done only once. The idea then is to minimize the amount r of recipient countries and to know to *which* countries confer this new technology. It is also assumed that countries paying these transfers are the rich countries, which will be denoted by (σ_L, ω_H), being them of an amount of d (for *donors*). In the same manner in the *After Tax and Transfers* stage we have r recipients denoted by (σ_L, ω_j) and $(N-d-r)$ non-recipients denoted by (σ_H, ω_j).

In order to picture the game, I start with the *Base Case* where only d rich countries form part of the coalition. This means that no other country is willing to join the coalition. In particular, we can see that to have this situation we only need that the greenest outsider is not willing to join. This is simply due to the fact that all outsiders share the same abatement technology σ_H and they only differ on their environmental concern ω_j. Hence, if the greenest one is not willing to join, from the country profit equation (2.6) is evident that no other will. It is important to note this, since having an heterogeneous set-up means that a broader amount of scenarios should be considered. Now, since countries that might join the coalition only differ on their environmental concern, I can order them from the greenest one to the least green one. I can now verify if this sequence (of all remaining countries) will be willing to join a given coalition. If it is not the case, we therefore know that there is no other sequence that will make the job. It is worth noticing that this is a one-shot set-up, and therefore when I talk about a *'sequence'* of countries, implying therefore an *order*, in reality what I am simulating is the thinking process of each country in order to decide if it will join or not a given coalition. In this sense and having in mind that a MPC is not allowed in this framework, we can understand the 'simultaneous' decision process as following: Having a coalition in place of k countries, the greenest outsider evaluates if it is profitable for it to join or not. Obviously all countries are doing this at the same time, but let us imagine that for this country it is profitable, no matter what the rest do.

So it will be willing to join and other countries know this. Hence, it may be the case that 'now' it is also profitable for the second greenest country, no matter what the rest do (and it correctly assumes that it is so for the greenest). In this way, we could have a 'cascading' process ending up with all countries joining the coalition. Of course, when I talk of a 'cascading' I am not implying a dynamic process, but only this strategic reasoning that countries do, in order to decide their accession. In the same manner, we can clearly see that if this 'ordered' sequence of countries do not produced the full cascading (meaning to reach the grand coalition), therefore no other 'order' will. Since all countries know this, they proceed accordingly.(6)

On the other hand, we can have two cases when referring to being profitable (or not): We can either assume that it is profitable for each one, individually and *without* profit sharing among the coalition, or we can assume countries belonging a coalition share their profits. The first case is straightforward, where in the second case we would have to pay attention to the sharing rule. But I will have no need to rely on this since I will only analyse if a given coalition or an evaluated coalition (when players are analysing different scenarios) is Internally Stable (IS).(7) In other words, I only verify if the sum of profits of a coalition of k countries is greater than the sum of their *outside options*, meaning the profit each country would get if it leaves the coalition and a coalition of the remaining $(k-1)$ countries forms. In the following I will refer to the second case, but it will be clear that proofs and the reasoning underlying them work for the first case too. The IS condition can be represented as

$$\sum_{j\in\mathcal{S}_k} \Pi_j^s > \sum_{j\in\mathcal{S}_k} \Pi_j^{oo} \tag{2.7}$$

where Π_j^s is the country profit of a signatory (belonging to the coalition of size k: $\mathcal{S}_k$) and Π_j^{oo} is the country outside option (for the same group of countries). If inequality (2.7) is divided by k (the coalition size), we can talk of the mean coalition profit and the mean outside option, which will turn out to be more convenient.

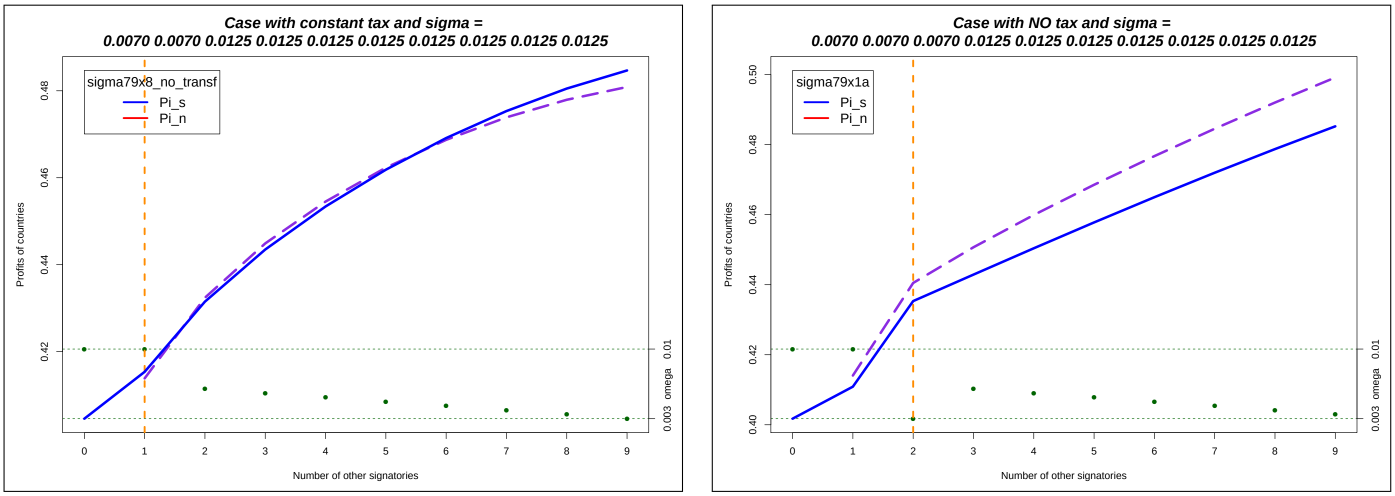
Base case

In order to give the intuition of the game at hand, I start simulating two cases of the **base case**. To visualize the decision making process I will use the same type of graphic representation as in Barrett (1997) [3], Carraro (1999) [6] and Diamantoudi & Sartzetakis (2006) [10]. Fig. 1a illustrates the case in where the border tax is implemented, but no

(6)It could also be considered a dynamic case where countries join sequentially. If this where the case, a discount factor for future gains or losses should be introduced and a timing system, which would add more complexity to the model. Since the idea is to keep to model as simple as possible, I do not consider this option, although the reader can visualise this scenario too.

(7)Internal and External Stability as defined by D'Aspremont et al. 1983 [9] and subsequently used by a substantial literature.

technological transfer has been made. Fig. 1b is the inverse case, meaning in where there is no border tax and a transfer to one country has been made: $r = 1$. Both cases are modelled with $\sigma_L = 0.0070$, $t = \sigma_H = 0.0125$, $\omega_H = 0.100$, $\omega_L = 0.060 \ldots 0.030$, $d = 2$ and $N = 10$.



(a) Border tax, no transfer.

(b) Transfer, no border tax.

Figure 1: Base case.

In both cases, the solid line represents the mean coalition profit and the dashed line the mean outside option. On the horizontal axis we have the amount of countries in the coalition. Since in this set-up the countries are heterogeneous, the accession ordering (which is implicitly represented in the graph) **is** important. Therefore to depict this sequence I introduce round dots, which account for ω_j of each country, represented in the secondary y-axis. As expected, the d rich countries (equal to two in this example) are the first ones in the graph, on the left. We know they are part of any coalition. In Fig. 1a no country receives any transfer and following the reasoning of section 2.2 (page 8), testing the greenest – least-green ordering suffices, which is the one depicted. For the case with transfer(s), the question relays in which are the recipient countries. I plot one option, in where the least-green country is the one receiving the transfer, the third dot in Fig. 1b. After it, the same sequence ordering was used, as in Fig. 1a. Choosing another outsider as recipient does not change this result. Finally, the value of σ_j for each country (following their order) is printed on the top of the graph and the vertical dashed line shows the transition from countries with good technology (the expanded coalition), to those without it (non-recipients).

We observe that in the first case, although implementing a border tax can alleviate the burden carried by the rich countries, by reducing carbon leakage, increasing coalition firms profits and getting and extra revenues (from taxes), it does not trigger the grand coalition formation. On the other side, making only one technology transfer and not implementing a border tax is even worse. The absence of border tax makes the rich countries much worse off and the transfer by itself does not induce the recipient country to join (and stay) in the coalition.

We can also note that in the first case, if MPC were possible (dismissed by assumption), a MPC of 6 countries could trigger the grand coalition formation. It is important to note the goal of the instruments (border tax and transfers) is to reduce the MPC, up to the point in where there is no more need of it, meaning that the extended coalition (rich + recipients) can induce by itself the 'cascading' process explained before.

After Tax and Transfers

Let us now study the case where a border tax has been implemented and transfers to one or more recipients have been made. The first question that arises is: which countries are the recipients? I show that, if a group of r recipients produces the cascading (working jointly with the border tax), then the set of groups that satisfies this condition always includes the group of outsiders that are the **least-green**. This result can appear counter intuitive at the beginning. We have to note two things: first, since countries are of the same size, the cost to switch their abatement technology from σ_H to σ_L is always K, regardless of how green the country is. Secondly, knowing that r countries are recipients, then I have $(N-d-r)$ non-recipients. Therefore the goal is to make these $(N-d-r)$ countries to produce the cascading. Following a similar line of thought of section 2.2, leaving the greenest countries in the non-recipients group is the best thing to do, since *these* are the countries more prone to access any given coalition. Knowing that the expanded coalition countries have cheap technology, the *ones expanding* this coalition into the grand-coalition will be the ones that will bear the higher abatement costs.

To prove this, I will assume that there is a group r of recipients countries that produce the whole cascading. Abusing a little with the notation, r will refer either to the amount of recipient countries and/or the group of such countries. I show then that if a new recipient group r' is formed, changing one country of the original r group with one less-green country from the non-recipients, then $(d+r')$ also produces the cascading. Iterating in the modification of the recipient group, I arrive to $(d+r^*)$, where r^* is the group of the least-green outsiders (of the same size of r), which again generates the cascading.

Let us call *Cascading 1* the case where it is supposed that the expanded coalition $(d+r)$ produces the cascading. This means that for each i non-recipient that enters the coalition (in a greenest – less-green 'order' as stated before), we have that the IS condition in

(2.7) holds. In the same manner, let us denote *Cascading 2* the case where we have substituted one country of the r group with one country from the non-recipients, which is less-green than the replaced one, naming this new recipient group as r'. I show that the new expanded coalition $(d + r')$ also produces the cascading, hence:

Proposition 2.1 *Within the game set-up described above and with d being the amount of initial rich countries in the coalition, r a recipient group (of r countries) that produces the whole cascading (Cascading 1) for all i between 1 and N−d−r, then the whole cascading is also produced starting from the coalition* $(d + r')$*, where* r' *is a less-green recipient group of r countries (Cascading 2):*

$$\underbrace{\Pi_s^{d+r+i} > \Pi_n^{d+r+i-1}}_{\text{Cascading 1}} \quad \Rightarrow \quad \underbrace{{}'\Pi_s^{d+r+i} > {}'\Pi_n^{d+r+i-1}}_{\text{Cascading 2}} \qquad \forall i \in \{1, \ldots, N-d-r\} \quad (2.8)$$

where Π_s^{d+r+i} is the non-recipient profit in a coalition of members $(d+r+i)$ (d donors, r recipients and i non-recipients). The prime in $'\Pi$ indicates that we are in Cascading 2, meaning that the recipient group is r' and that the sequence i of non-recipients coming into the coalition has been replaced accordingly. The following diagram shows the i sequence for Cascadings 1 and 2:

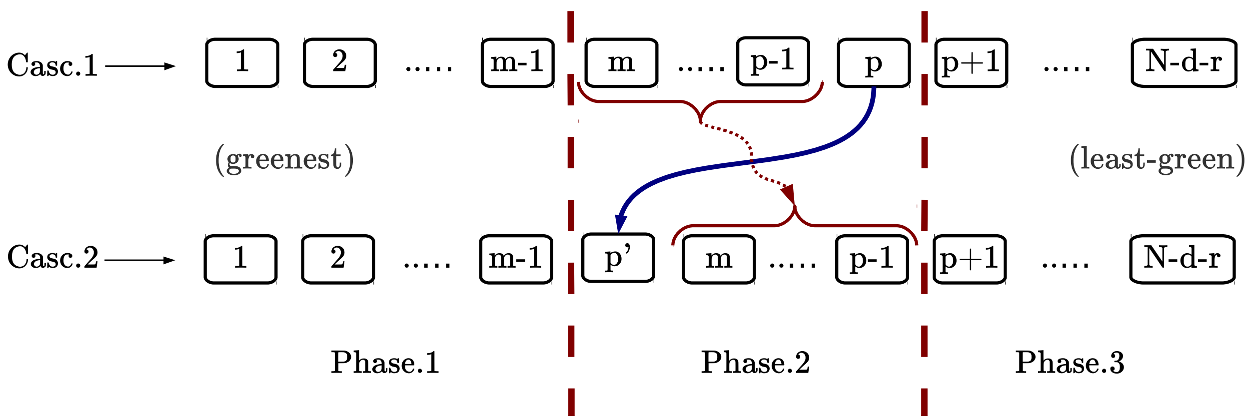


Figure 2: Non-recipients sequence for Cascadings 1 and 2.

As it can be noted in Fig. 2, the non-recipient sequence has been divided in 3 *phases*. This comes from the fact that as we have replaced one country in r, namely [p], which has entered into r', replacing the country $[p']$ which now is in the non-recipient sequence. Due to this, the sequence has been modified, where phases 1 and 3 are unchanged and the modification only applies to the countries in phase 2. By construction $[p']$ is greener than $[p]$ and therefore enters before in the cascading process, as shown in the previous figure.

The proof consist on showing that for each phase, the following two inequalities (Inequality 1 and 2) hold and therefore proving 2.8:

$$\underbrace{\underbrace{{}'\Pi_s^{d+r+i} \geq \overbrace{\Pi_s^{d+r+i}}_{\text{Inequality 1}} > \Pi_n^{d+r+i-1}}^{\text{Cascading 1}} \geq {}'\Pi_n^{d+r+i-1}}_{\text{Inequality 2}}}_{\text{Cascading 2}} \tag{2.9}$$

A detailed proof can be found in Appendix B. This result states that the set of recipient groups that can produce the cascading always contains the group of the r least green countries of outsiders. This is because in some cases, depending on the parameters chosen, this set can contain only one group, r^*, or more than one, but always including r^*. Therefore, if the rich countries want to make a technology transfer in order to induce the grand coalition, they know where to start. The question now is to find out how many are these r^* countries.

Before answering the previous question, let us observe an example of a transfer that produces a cascading in the following figure. I have used the same parameters as of the previous examples and the cascading has been triggered with only one recipient: $r^* = 1$. The intuition is as follows: the technology transfer 'buys in' the least-green country, putting it inside the expanded coalition and changing its incentive for abating, since now it is cheaper for it. By doing so, we have 'artificially' enlarged the initial coalition where now the border tax helps to sustain it. This was the same occurring in the example depicted in Fig. 1a. The difference now is that the cascading has started with $(d+r)$ countries (instead of only d). Therefore when the 'revenue' effect, coming from the border tax diminishes, as countries join the coalition, the IS conditions keep holding. After some more countries have joint the coalition, the border tax has a 'punitive' effect, in the sense that now, non-signatories exports are facing a 'disadvantage' with respect to the rest of the world. Now, after the revenue effect has diminished and before the punitive effect has come into place, there is critical period where the IS condition might not hold, as it happened before. It is like this cascading process mimics a mountain crossing[(8)] (in this case peaking around $k = 3$ or 4), where the outside option is the mountain to be crossed and the mean coalition profit is the maximum altitude we reach reach at each step. With only the border tax, the domino effect stops at some point: the mountain could not be crossed. But combining the border tax **and** a transfer (when leaving out the greenest countries) allows us to make it through. Both instruments reinforce themselves and it is not simply the sum of them.

[(8)]As in the Mountain Crossing theorem.

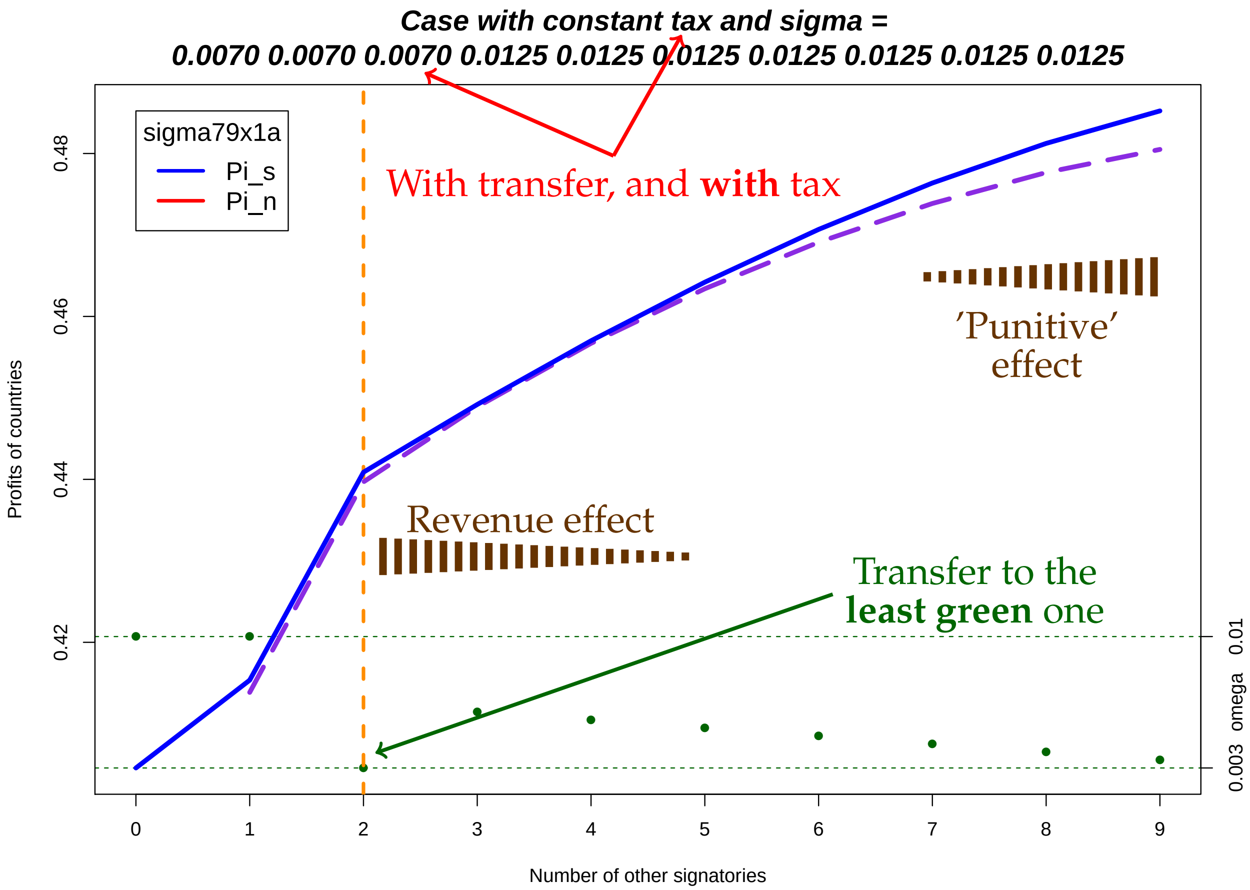


Figure 3: After Tax and Transfers.

2.3 Finding the amount of recipients r^*

Let us resume with the question of how many r^* recipients we need in order to produce the full cascading. Unfortunately, equations get extremely complex in order to get a readable solution for this question, as they develop from the IS condition (inequality (2.7)). Therefore, when we plug in the country profits, which are composed of firm profits, consumer surpluses, environmental damages and tax revenues, the algebra just gets out of hand. In any case, these equations are provided in Appendix B. As a second approach, I relied on simulations in order to show how r^* would go. To do so, I define a $\Delta\Pi^s_{oo}(d,r,i)$ function, which is just inequality (2.7) with all terms put on the left side. Therefore, if for a given value of r, $\Delta\Pi^s_{oo}(d,r,i) > 0$ for all possible i's (d is given), then we get the full cascading. It is worth noting that I can build this function since I know which countries I have to 'buy in' at each r level. In Fig. 4 we can observe a continuous version of this function[9] for the same parameters used in the previous examples.

[9]This is coming directly from the country profit function. The only 'trick' used was that I had to create a continuous version of $\sum \omega_j$ to be used in the damage part of this function. The domain of $\Delta\Pi^s_{oo}$ is restricted to octant I (+++) and with $(d+r+i) \leq N$, which is the area of interest.

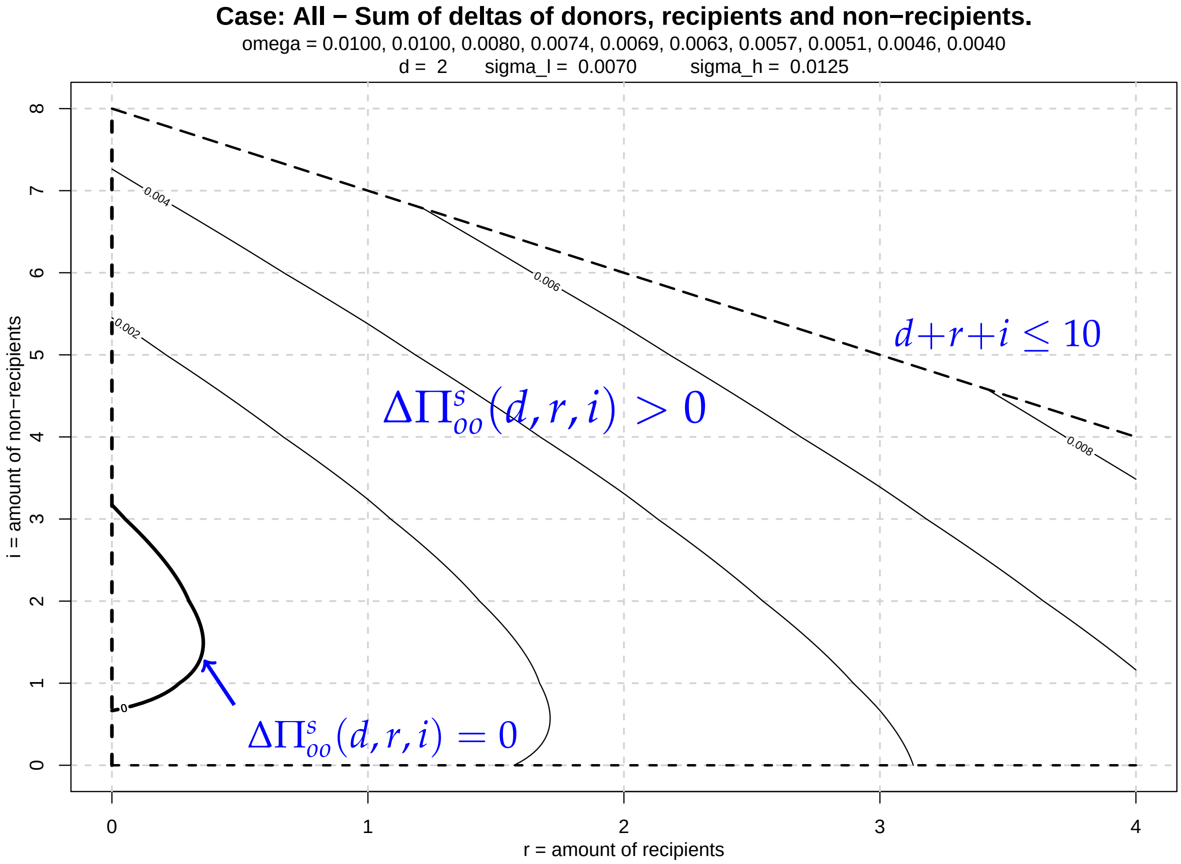
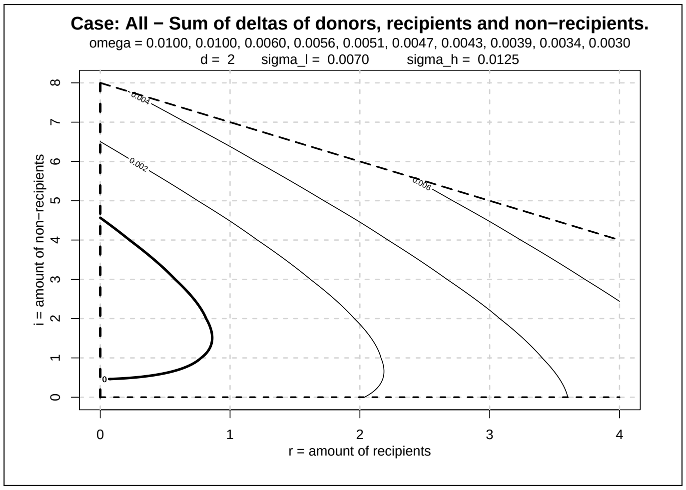


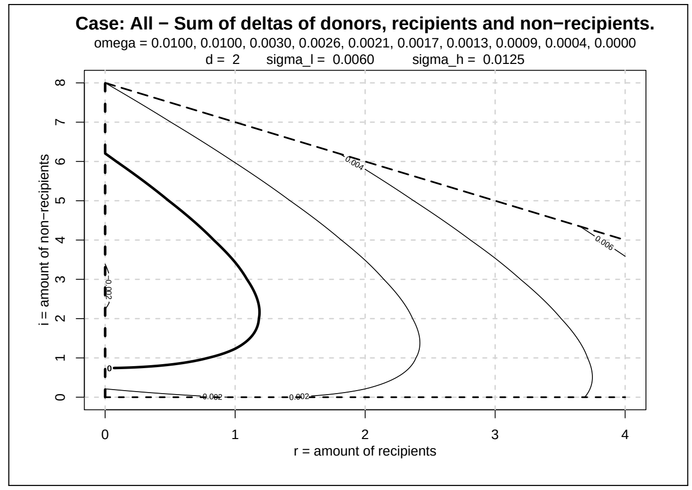
Figure 4: Contour of function $\Delta\Pi^s_{oo}(d,r,i)$, with $d = 2$.

The figure shows the solution area where $\Delta\Pi^s_{oo}(d,r,i) > 0$, and more importantly, its limit $\Delta\Pi^s_{oo}(d,r,i) = 0$. Therefore it is easy to see that the solution for this case is $r^* = 1$. With $r = 0$ we have the Base Case where there is no transfer and border tax is implemented. Following the vertical dashed line at $r = 0$, we can observe that we have the same result as before. For values of i between 0 and 0.8 and then from 3.2 until the end, the value of $\Delta\Pi^s_{oo} > 0$. In the range left in between, it is negative, meaning that for this case we are in need of a MPC, if we want to reach the grand coalition (we are not able to cross the mountain). In the case with $r = 1$, we can clearly see that $\Delta\Pi^s_{oo} > 0$ for all the range of i, meaning that full cascading occurs. Following this reasoning, r^* can be found by checking when $\partial r/\partial i = 0$ in the implicit function between r and i, given by $\Delta\Pi^s_{oo} = 0$. Hence we find a maximum (of r with respect to i in this implicit function) and r^* is just the integer greater or equal to this maximum. This development can also be found in Appendix B (*Work in Progress*).

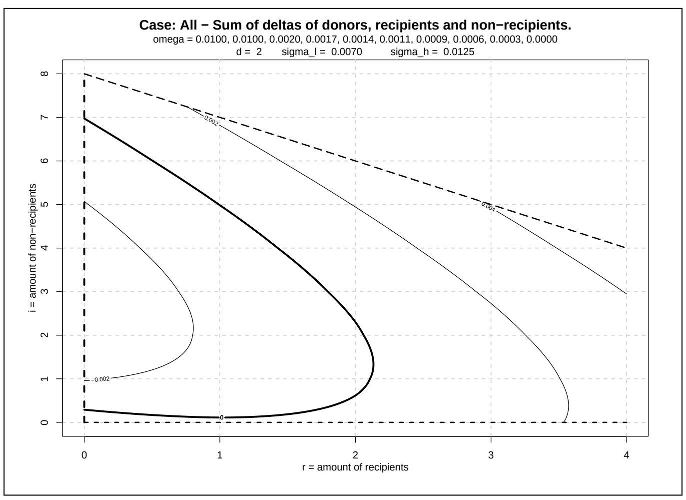
A handy feature of this graphical representation is that it allows us to analyse what happens if we change some parameters, as for example the environmental concern ω_j of outsiders, or the technological levels σ_L and σ_H. Some examples of this are depicted in Figs. 5a–d, where some expected features can be observed.



(a) Lower outsiders environmental concern.



(b) Same as (a), but even lower, with better good tech.



(c) Same as (b), but even lower environmental concern.

(d) More even σ_j with cheaper bad tech.

Figure 5: Some examples changing ω_j, σ_L and σ_H.

The lower the environmental concern is for outsiders (lower values of ω_j), the harder is to cross the mountain, meaning that the locus in where $\Delta\Pi^s_{oo} = 0$, switches to the right and therefore $r*$ might increase. A similar effect occurs when making abatement technology (good and bad one) more expensive.

Paying transfers

One question that has been left aside is if these r transfers are worth while. The assumption is that rich countries pay for these transfers and therefore the logical question is if they are actually willing to do so. They will if their gains coming from switching from a small equilibrium of d countries into the grand coalition of N countries are bigger than the transfers cost ($K \cdot r$) divided among themselves, d. Noting that when all countries abate there are no damages coming from emissions and neither taxes are being levied, the comparison simplifies a bit into de gain/loss in firm profits and consumer surplus, plus the forgone damages and less the taxes, which have disappeared. Denoting a subscript d for rich countries and superscripts N and d for the grand coalition and initial coalition respectively, it is profitable if the following inequality holds:

$$\underbrace{(\pi_d^N - \pi_d^d)}_{>0} + \underbrace{(CS_d^N - CS_d^d)}_{<0} \underbrace{-Dam_d^d}_{>0} \underbrace{-Taxes_d^d}_{<0} \geq \frac{K \cdot r}{d} \tag{2.10}$$

Again the algebra gets nasty and detailed results can be found in Appendix C. Two extreme cases can be easily analysed though: if $K = 0$ rich countries can always produce the cascading. Actually, they can just buy-in all outsiders (which induce the grand coalition by assumption). Moreover, the LHS of inequality (2.10) is positive too, since if it were not the case, it would not be any (serious) environmental issue even to start with. On the other side, if K is just too big, then it is obvious that transfers might never be profitable. On the other hand, the LHS of this inequality imposes a ceiling to r, meaning that for a given value of K, even if there exists a r^* that produces the cascading, it might be too high in order for the rich countries to finance these transfers. Moreover, the LHS contains r,[10] which makes the algebraic solution not attractive.

[10] This is due to the fact that firm profits and CS for donors are influenced by the total abatement technology used in the world, at the grand coalition case. Hence the term $r \cdot (\sigma_H - \sigma_L)$ appears having a negative impact in firm profits and a positive one in CS.

3 Conclusions

The present work explores a different approach for reaching an International Environmental Agreement (IEA). Following Heal and Kunreuther's (2011) [13] idea, that a set of countries could tip the rest from a dirty equilibrium to a clean one, I have developed a simple model that shows that this is possible. Starting from a well-known model (Barrett (1997) [3]) and adding some heterogeneity in countries and simplifying in other features, I have shown that a small group of countries (for example, 2 out of 10) can actually induce this cascading process. The first stage of this process 'buys-in' some countries to the initial coalition. But after having these countries on board, they could impose costs to non-joiners, costs such as border taxes, in order to finalize the cascading process, something similar to what happened with the Montreal Protocol and its subsequent amendments. In this later case, trade bans were possible due to the nature of the pollutant (specificity of CFCs), where in the present conundrum (CO_2 emissions and climate change) this instrument is not a credible threat.

An interesting result is that in order to minimize transfers and to improve the chances of reaching the grand coalition, the recipient countries are those with least environmental marginal damage, also referred as the least-green ones. Although it might be a coincidence, it looks like this is what is happening with the bilateral agreement between the U.S. and China, reached this last November. Of course in this case, other considerations are at hand, as size and emissions of the two specific countries. Another point to note is the reinforcement effect between the border tax and a technological transfer. The border tax by itself is not sufficient to induce the grand coalition, since it need some critical mass to work. On the other hand, the transfer by itself does not work alone either, since it does not deal with the free-rider incentives. But both used, and in a proper way, have a leverage effect among them, making the grand coalition a feasible outcome.

Finally and in order to expand this work, two options can be thought of. The first one is the direct application of these two tools, the border tax and the transfers, in a more realistic set-up and using real data. For example, a model with 6 or 12 regions could be used in order to test the feasibility of the solution proposed here. A second vein could be to analyse the strategic interplay in being a recipient or not. This comes from the fact that non-recipients do not receive any incentive (since they will accede due to the trade pressure). Therefore, this might induce them to join the agreement in an earlier stage, and hence getting the transfer. This strategic interplay can again be anticipated by the promoters of the IEA and by the rest of the players, enlarging the game set-up and eventually changing or reasserting the previous result.

References

[1] Lisa Anouliés. The strategic and effective dimensions of the border tax adjustment. *Journal of Public Economic Theory*, pages n/a–n/a, 2014.

[2] Scott Barrett. Self-enforcing international environmental agreements. *Oxford Economic Papers*, 46:pp. 878–894, 1994.

[3] Scott Barrett. The strategy of trade sanctions in international environmental agreements. *Resource and Energy Economics*, 19(4):345–361, November 1997.

[4] Scott Barrett. International cooperation for sale. *European Economic Review*, 45(10):1835–1850, December 2001.

[5] Scott Barrett. *Environment and Statecraft: The Strategy of Environmental Treaty-Making: The Strategy of Environmental Treaty-Making*. Oxford University Press, 2003.

[6] Carlo Carraro. The structure of international environmental agreements. In Carlo Carraro, editor, *International Environmental Agreements on Climate Change*, volume 13 of *Fondazione Eni Enrico Mattei (Feem) Series on Economics, Energy and Environment*, pages 9–25. Springer Netherlands, 1999.

[7] Carlo Carraro and Domenico Siniscalco. Strategies for the international protection of the environment. *Journal of Public Economics*, 52(3):309–328, October 1993.

[8] Lorenzo Cerda Planas. Moving to greener societies: Moral motivation and green behaviour. Working paper, Paris School of Economics - Université Paris 1 Panthéon - Sorbonne, August 2014.

[9] Claude D'Aspremont, Alexis Jacquemin, Jean Jaskold Gabszewicz, and John A. Weymark. On the stability of collusive price leadership. *The Canadian Journal of Economics / Revue canadienne d'Economique*, 16(1):pp. 17–25, 1983.

[10] Effrosyni Diamantoudi and Eftichios S Sartzetakis. Stable international environmental agreements: An analytical approach. *Journal of public economic theory*, 8(2):247–263, 2006.

[11] Thomas Eichner and Rüdiger Pethig. Self-enforcing environmental agreements and international trade. *Journal of Public Economics*, 102(0):37 – 50, 2013.

[12] Geoffrey Heal. Formation of international environmental agreements. In Carlo Carraro, editor, *Trade, Innovation, Environment*, volume 2 of *Fondazione Eni Enrico Mattei (FEEM) Series on Economics, Energy and Environment*, pages 301–322. Springer Netherlands, 1994.

[13] Geoffrey Heal and Howard Kunreuther. Tipping climate negotiations. Technical report, National Bureau of Economic Research, 2011.

[14] Michael Hoel and Kerstin Schneider. Incentives to participate in an international environmental agreement. *Environmental and Resource Economics*, 9(2):153–170, 1997.

[15] SJ Rubio and A Ulph. Self-enforcing agreements and international trade in greenhouse emission rights. *Oxford Economic Papers*, 58:233–263, 2006.

A Firm maximization problem

The firm's profit function to be maximized is the following:

$$\pi_j = \sum_{i=1}^{N} (1 - x^i - t_j^i - \sigma_j\, q_j) x_j^i \tag{A.1}$$

with $t_j^i = t$ if $i \in \mathcal{S}_k \wedge j \notin \mathcal{S}_k$, and $t_j^i = 0$ otherwise. I only consider situations where firms produce positive quantities in equilibrium. We can get the first order conditions, which are:

$$1 - x^i - t_j^i - \sigma_j\, q_j - x_j^i = 0 \qquad \forall i, j \tag{A.2}$$

Summing over i, conditions in equations A.2 can be rewritten as:

$$N(1 - \sigma_j\, q_j) - 2x_j - x_{-j} - t_j = 0 \qquad \forall j \tag{A.3}$$

where $t_j = \sum_{i=1}^{N} t_j^i$ is the sum of the tax rates 'paid' by product produced by country j, $x_j = \sum_{i=1}^{N} x_j^i$ is the total output of firm j, and $x_{-j} = \sum_{k \neq j} x_k^i$ is the rest-of-the-world output. This can be re-written in a matrix form, getting:

$$\underbrace{\begin{bmatrix} 2 & 1 & \cdots & 1 \\ 1 & 2 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 2 \end{bmatrix}}_{C} \cdot \underbrace{\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix}}_{\overrightarrow{x_j}} = \underbrace{\begin{bmatrix} N - N\sigma_1\, q_1 \\ N - N\sigma_2\, q_2 \\ \vdots \\ N - N\sigma_N\, q_N \end{bmatrix} - \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_N \end{bmatrix}}_{D} \tag{A.4}$$

Using the Sherman-Morrison formula, we can get $\overrightarrow{x_j} = C^{-1} \cdot D$, being

$$C^{-1} = I - \frac{B}{N+1}$$

where I is the identity matrix and B (of dimension N by N) is a matrix of ones. This gives the general solution of:

$$\overrightarrow{x_j} = \frac{1}{N+1} \begin{bmatrix} N & -1 & \cdots & -1 \\ -1 & N & \cdots & -1 \\ \vdots & \vdots & \ddots & \vdots \\ -1 & -1 & \cdots & N \end{bmatrix} \begin{bmatrix} N - N\sigma_1\, q_1 - t_1 \\ N - N\sigma_2\, q_2 - t_2 \\ \vdots \\ N - N\sigma_N\, q_N - t_N \end{bmatrix}$$

Or equivalently:

$$x_j = \frac{1}{N+1} \left[N\Big(1 - N\sigma_j q_j - t_j + \sum_{i \neq j} \sigma_i q_i\Big) + \sum_{i \neq j} t_i \right] \tag{A.5}$$

Finally, for the country consumption levels x^i, we can use the FOC (eqn. A.2) and we get:

$$x^i = \frac{N - \sum_{j=1}^{N} \sigma_j \, q_j - t^i}{N+1} \tag{A.6}$$

with $t^i = \sum_{j=1}^{N} t_j^i$ being the sum of tax rates *imposed* by country i. Given that only signatories tax non-signatories products, we have that:

$$t^i = \begin{cases} (N-k) \cdot t & \text{if } i \in \mathcal{S}_k \\ 0 & \text{if } i \notin \mathcal{S}_k \end{cases}$$

which yields to

$$x^i = \begin{cases} \frac{N - \sigma_{\mathcal{S}} - (N-k) \cdot t}{N+1} & \text{if } i \in \mathcal{S}_k \\ \frac{N - \sigma_{\mathcal{S}}}{N+1} & \text{if } i \notin \mathcal{S}_k \end{cases} \tag{A.7}$$

where $\sigma_{\mathcal{S}} = \sum_{j \in \mathcal{S}} \sigma_j$ (the sum of the coalition's marginal abatement costs). Replacing this result into the FOC (Eqn. (A.2)), we finally have the segmented production of firm j shipped to country i:

$$x_j^i = \begin{cases} \frac{1+\sigma_{\mathcal{S}} - (N+1)\sigma_j + (N-k) \cdot t}{N+1} & \frac{1+\sigma_{\mathcal{S}} - (k+1) \cdot t}{N+1} & \text{if } i \in \mathcal{S}_k \\ \frac{1+\sigma_{\mathcal{S}} - (N+1)\sigma_j}{N+1} & \frac{1+\sigma_{\mathcal{S}}}{N+1} & \text{if } i \notin \mathcal{S}_k \end{cases} \tag{A.8}$$

$$\begin{matrix} \uparrow & \uparrow \\ \text{if } j \in \mathcal{S}_k & \text{if } j \notin \mathcal{S}_k \end{matrix}$$

Finally, having x_j, x^i and x_j^i and recalling the equations for the firm profit (π_j), consumer surplus (CS_j), environmental damage (DAM_j) and taxes collected (TAX_j), we get:

$$\pi_j = \begin{cases} \frac{N \cdot \aleph_j^2 + k(N-k)t\left(2\aleph_j + (N-k)t\right)}{(N+1)^2} & \text{if } j \in \mathcal{S}_k \\ \frac{N \cdot \aleph_2^2 + k(k+1)t\left((k+1)t - 2\aleph_2\right)}{(N+1)^2} & \text{if } j \notin \mathcal{S}_k \end{cases} \quad \text{with} \quad \begin{matrix} \aleph_j = 1 + \sigma_{\mathcal{S}} - (N+1)\sigma_j \\ \aleph_2 = 1 + \sigma_{\mathcal{S}} \end{matrix} \tag{A.9}$$

$$CS_j = \begin{cases} \frac{\left(N - \sigma_{\mathcal{S}} - (N-k)t\right)}{2(N+1)^2} & \text{if } j \in \mathcal{S}_k \\ \frac{\left(N - \sigma_{\mathcal{S}}\right)}{2(N+1)^2} & \text{if } j \notin \mathcal{S}_k \end{cases} \tag{A.10}$$

$$DAM_j = -\omega_j \cdot \frac{(N-k)}{N+1} \cdot \Big((1+\sigma_{\mathcal{S}})N - k(k+1)t\Big) \tag{A.11}$$

$$TAX_j = t \cdot (N-k) \cdot \frac{\Big(1 + \sigma_{\mathcal{S}} - (k+1)t\Big)}{N+1} \tag{A.12}$$

B Proof of r^* being the least-green recipient group

As stated in subsection 2.2, the proof consists in showing that if conditions for *Cascading 1* hold, then conditions for *Cascading 2* hold too. In order to do so, I will use to following inequalities:

$$\underbrace{\underbrace{{}'\Pi_s^{d+r+i} \geq \Pi_s^{d+r+i}}_{\text{Inequality 1}} \overbrace{>}^{\text{Cascading 1}} \underbrace{\Pi_n^{d+r+i-1} \geq {}'\Pi_n^{d+r+i-1}}_{\text{Inequality 2}}}_{\text{Cascading 2}} \tag{B.1}$$

Hence, the proof resumes to showing that *Inequality 1* and *Inequality 2* hold. The first one says that the profit of an i^{th} country coming into the coalition ${}'\Pi_s^{d+r+i}$ (Cascading 2) is greater or equal than the same profit in the case of *Cascading 1*, where r' has been replaced by the original r and the i^{th} country entering the coalition might or might not be the same of *Cascading 2*, according to the following diagram:

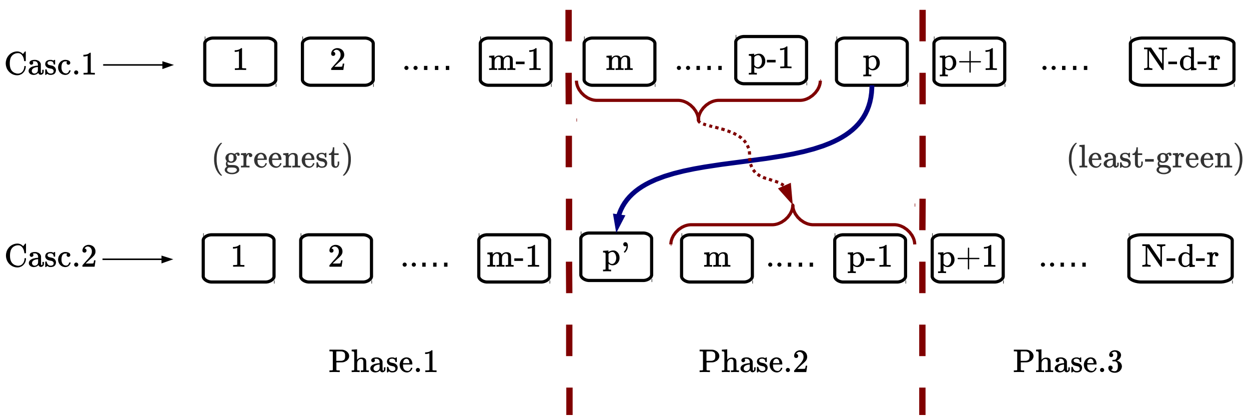


Figure 6: Non-recipients sequence for cascadings 1 and 2.

The same has to be done for *Inequality 2*, where now we have to show that the outside option of an i^{th} country coming into the coalition $\Pi_n^{d+r+i-1}$ (Cascading 1) is greater or equal than its counterpart in Cascading 2. To do so, I will analyse the possible changes in firm profits, consumer surplus, damages and taxes collected. As shown in the previous picture I will divide the analysis in three phases: 1, 2 and 3.

First, let us note that the amount $\sigma_{\mathcal{S}} = \sum_{j \in \mathcal{S}} \sigma_j$ (the sum of the coalition's marginal abatement costs) does not change between Cascading 1 and 2. In this due to the simple fact that the group of countries with good technology is always of size $(d+r)$. In the same way, $\aleph_j$ and $\aleph_2$ stay constant between those two cases. Therefore the only difference that may arise comes from the replacement of ω_j, either of countries accessing the coalition (the i's) or those in the recipient group (r or r').

Inspecting the firm profit equation (A.9) it is clear that its value does not change between Cascading 1 and 2. The same holds for the consumer surplus and for the taxes collected. Hence we only have to focus on the damages coming from emissions. Studying this equation shows as that emissions are also invariant between these two cases, since they only depend on σ_S and k. Hence the only changes comes directly from the term $-\omega_j$ (in Eqn. (A.11)).

Define $\Delta D_1 =' \text{DAM}_j^{d+r+i} - \text{DAM}_j^{d+r+i}$, which is the difference in damages of country j between Cascading 2 and 1 cases, in the presence of a coalition of size $(d+r+i)$. In the same manner, define $\Delta D_2 =' \text{DAM}_j^{d+r+i-1} - \text{DAM}_j^{d+r+i-1}$, which is just the same, with a coalition of size $(d+r+i-1)$. Finally, denote ω_p the corresponding marginal damage for the country p in r being replaced by a less-green country q in r'. And let ω_q be the marginal damage of the replacing country q.

Let us start with the signatories (Inequality 1). In phase 1, $\Delta D_1 = (\omega_p - \omega_q) \cdot emissions$, which is positive. In phase 2 we will have a similar case, where the pair of ω's at stake will be: ω_p v/s ω_m, ω_m v/s ω_{m+1} $\ldots$ ω_{m+j-1} v/s ω_{m+j} (recall Fig. 6) and therefore resulting again in $\Delta D_1 > 0$. For phase 3, since the coming countries i's and the group already in the coalition $(d+r+i-1)$ have the same ω's, $\Delta D_1 = 0$. Therefore, for phases 1, 2 and 3 together we have that: $\Delta D_1 \geq 0$ which proves Inequality 1.

For the case of non-signatories (Inequality 2) we have that for phases 1 and 3, $\Delta D_2 = 0$, since here we are only concerned on the entering country. For these two phases, the entering country is the same for both Cascadings. Following the same reasoning of phase 2 in the previous paragraph, we get that $\Delta D_2 < 0$ for this phase. Putting the three phases together leads to $\Delta D_2 \leq 0$, which again proves Inequality 2 (note that Inequality 2 has the Cascading 1 and 2 inverted with respect to Inequality 1).

This last point proves that Cascading 1 implies Cascading 2. We iterate on the swapping process in r', until the recipient group becomes r^* the least-green outsider, which finishes the proof.

C Profitability of transfers for rich countries

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