

Pushing the Tipping in International Environmental Agreements

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Abstract

This paper intends to provide an alternative approach to the formation of International Environmental Agreements (IEA). The existing consensus within the literature is 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 a 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.

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1 Introduction

The present paper focuses on the idea that the creation of an International Environmental Agreement (IEA) that brings together many countries can be 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 to reach an effective agreement concerning climate change are a clear example of this fact. Other solutions that have been analysed in order to arrive at a successful IEA involve the idea of starting with a small sub-set of countries and incorporating others as time goes by. A first possibility explored by Heal and Kunreuther (2011) [13] suggests enlarging a small coalition in a cascading process. A second solution analysed by Carraro & Siniscalco (1993) [7], Hoel & Schneider (1997) [14], and Barrett (2001) [4] is to use transfers in order to induce more countries to join the IEA. Unfortunately, all these papers showed that a commitment problem prevents the formation of the grand coalition – or if it forms, the countries still function as though it were business as usual (BAU). The commitment problem comes from the fact that the IEA set-up resembles a chicken game: Signatories are better off compared to not having an IEA at all, but they would prefer to have others to sign and abstain themselves. 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. 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. These results could be quite important in face of the recent failures in reaching an IEA that effectively tackles climate change. It is possible that the reasonings presented in this paper could light the ongoing negotiations and offer potential solutions.

In order to develop this idea, I build a model that is an expanded version of Barrett (1997) [3]. In his paper, the world is composed of identical countries, each containing one firm that produces an homogeneous and traded good and pollution as a side product. In Barrett's three-stage game, each country decides to join an IEA or not (one shot). In the second stage, the formed coalition is group rational and plays accordingly, with non-signatories playing as singletons. Finally, firms maximize their profits by choosing their segmented outputs à la Cournot and markets clear.

⁽¹⁾Meaningful in the sense that countries are actually making an effort in abating and not simply acting in a way similar to BAU.

Starting from this set-up, I first add asymmetries among countries in terms of damages from emissions and abatement costs. These asymmetries are empirically motivated. Societies exhibit green behaviour, 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 terms of development level and 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 have become (quite) aware of the environmental problem at hand and have started acting accordingly. Hence, 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 could be 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 bad technology (high marginal cost of abatement) or good one (low marginal cost of abatement).

Secondly, I add the possibility of transfers between countries, which creates the potential to enlarge the existing coalition, in a fashion similar to Carraro & Siniscalco (1993) [7]. However, I consider technology transfers (instead of monetary transfers, as Carraro and Siniscalco do), which can change the game itself. The final addition to the baseline model is that I allow the coalition to impose a border tax on non-signatories. As expected, the idea behind this is to deter free-riding (and possibly induce accession), similarly to the intention of the trade ban in Barrett's (1997) [3] paper.

Through 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 this 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]). In this case one country, the United States, was unilaterally willing to cut emissions and consumption of ozone-depleting substances. They were well aware that at first, leakage coming from trade could reduce their effort results, but knew that if other big economies would follow suit, the gains (both nationally and globally) would be much larger. Therefore, they were willing to not only 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 other countries to join what would become one of the most successful IEA in history.

Obviously, it would be appealing to do a similar thing with greenhouse gases (GHG). First, however, while tackling the production and trade of CFCs is a simple task, it is quite impossible for CO_2 emissions since they are embedded in almost every product we

trade. Of course, 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. This will be the case in the present paper, acknowledging that this could bring on 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 loses 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 ray exposure 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 consensus about the damages arising from global warming, there are differences in opinion among countries regarding how these damages will hurt them specifically. 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 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). In the present conundrum, uncertainty about the gains and costs of such an agreement makes the political decision a much harder one to pursue, and puts the MPC on a level that might not be politically feasible to reach. As a consequence, I assume that no MPC should be needed to reach the grand coalition. This premise might seem too 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.

The rest of the paper is structured in the following way: Section 2 presents the model without transfers and solves the firm maximization program. Section 3 adds transfers to the model and explains how the big coalition could be reached. Section 4 focuses on finding the amount of recipients needed to produce this coalition. Section 5 concludes.

2 The model

I develop a two-stage game built on Barrett (1997) [3]. In the first stage, each country chooses whether or not to be part of the coalition of size k , S_k . There are N countries that are asymmetric in two dimensions. First, the technology they have access to can offer a low marginal cost of abatement (σ_L , good technology) or a high one (σ_H , bad technology). Second, countries differ in terms of the marginal damage from emissions they suffer from, noted ω_j , for country j . I will be using marginal damage from emissions and en-

environmental concern as synonyms; in this line, I will also be referring to countries with higher environmental concern as 'greener'. I then define two types of countries. The 'rich' are those with the good abatement technology, σ_L , and a high marginal damage from emissions, ω_H . The outsiders have the bad abatement technology, σ_H , and a lower environmental concern than the rich: $\omega_j < \omega_H$, where ω_j , the marginal damage from emissions of country j , is a continuous variable.⁽²⁾

Departing from Barrett's (1997) model, I assume that if a country enters the coalition, it will fully abate ($q_j = 1$). If not, it will abate nothing ($q_j = 0$). Hence, for country j , joining the coalition and having $q_j = 1$ become synonyms.⁽³⁾ In the non-signatory case, this assumption poses no real restriction, since $q_j = 0$ is optimal for these countries (using some standard assumptions), which is not the case for signatories. This feature has two main bases. First, I discard by construction the case of having coalitions (especially the grand coalition) that do not abate, or who operate quite close to BAU when they do abate, as the literature has shown (as in Barrett (1994) [2] and Eichner & Pethig (2013) [11]). Second, it makes the model more tractable with clear-cut results.⁽⁴⁾ On another side, if countries' decisions are binary, it makes the coalition formation a harder process, since becoming a member of the IEA implies full abatement for the joining country. Finally, signatories can not punish a country for leaving the coalition by increasing emissions. Hence, if a coalition can form in this stricter set-up, it would also form in a more lax one.

Focusing on abatement technology rather than on emissions is important: From a political point of view, it can more easily lead to an enforceable IEA since the technology being used is more easily verifiable than total emissions. Furthermore, it allows us to consider technology transfers, which change the recipient country's incentives to join the coalition, and therefore the game itself, which is part of the overall plan.

Countries inside the coalition tax imports, at a rate t , of goods produced in non-signatory countries. The main obstacle to reaching a meaningful IEA comes from having carbon leakage, because it provides countries strong incentives to free-ride. The border tax is, then, a credible tool for hindering leakage. In this set-up I assume that only signatories tax goods coming from non-signatories and that the latter 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 the results of Anouliès (2014) [1]. The idea

⁽²⁾Adding heterogeneity to the Barrett's model (1997) should move the model closer to reality, but unfortunately it also adds complexity. Because of this, I have a continuous parameter measuring marginal damage, but I set abatement cost to be among two values, in order to keep the model tractable.

⁽³⁾Conversely, for country j , not joining the coalition and having $q_j = 0$ are also synonyms.

⁽⁴⁾Binary choices can also be found in the literature; one example is in Heal (1994) [12].

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.

In the second stage, firms move by choosing simultaneously their segmented outputs, all within a Cournot-Nash set-up. It is a perfect information model in the sense that countries perfectly know their costs and gains, as well as those of other countries. Focusing now on the solution of the game at hand, I proceed using backward induction. For the moment I leave technology transfers, which can 'change the game' in a permanent way, aside; I will return to these transfers in Section 3.

2.1 Firms' choices

There are N countries and N firms (one per country) that produce an homogeneous traded good and a transboundary pollution. The inverse demand in each country j is given by $p(x^j) = 1 - x^j$, where x^j is consumption in country j . Costs of the firm in country j are $C(\sigma_j, x_j, q_j) = \sigma_j q_j x_j$, where x_j is the total output of the firm, $\sigma_j \in \{\sigma_L, \sigma_H\}$ is its marginal abatement cost, and $q_j \in \{0, 1\}$ is the abatement standard chosen by the government of country j , taken as given for the firm in this country. Emissions by firm j are $x_j(1 - q_j)$: if abatement is maximal, emissions are zero, and if no abatement is undertaken, emissions are equal to output. The marginal abatement cost of firm j 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 to be greener.

Firms choose their output for each market simultaneously. Transport costs are zero, and each firm takes its own abatement standard and the segmented outputs of other firms as given. Firm j chooses a quantity to produce and ship to market i , x_j^i , so as to maximize its profit π_j :

$$\max_{x_j^i \geq 0} \pi_j = \sum_{i=1}^N (1 - x^i - t_j^i - \sigma_j q_j) x_j^i \quad (2.1)$$

with $t_j^i = t$ if $i \in \mathcal{S}_k \wedge j \notin \mathcal{S}_k$, and $t_j^i = 0$ otherwise. There are N first order conditions for firm j :⁽⁵⁾

$$1 - x^i - t_j^i - \sigma_j q_j - x_j^i = 0 \quad \forall i, j \quad (2.2)$$

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

⁽⁵⁾I only consider those situations where firms produce positive quantities in equilibrium.

formed by the N first order conditions for the N firms, we get:

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

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

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

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

From where we can calculate the firm profit π_j :⁽⁶⁾

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

2.2 Countries' choices

Country j 's net benefits are the sum of firm j 's profits, plus the surplus of country j 's consumers, less the environmental damage suffered, plus border taxes collected, if that is the case. Given demand specifications, the consumer surplus is equal to $(x^j)^2/2$. Pollution is assumed to be a pure public bad, and aggregate emissions are given by $\sum_{i=1}^N x_i(1 - q_i)$, where x_i is the total output of firm i . The constant marginal environmental damage is equal to ω_H for the rich countries, and to $\omega_j < \omega_H$ (abusing the notation) for a country j belonging to the group of *outsiders*. If country j is a signatory country (meaning that $q_j = 1$), the border taxes collected are equal to the tax rate t , times the emissions embedded in the imports from non-signatories (all countries i such that $q_i = 0$). With these, country j 's profit is:

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

where π_j , x^j , x_i and x_i^j are expressed in terms of k and model parameters (given by equations (2.3) and (2.4)). Countries choose whether or not to join the coalition, and therefore

⁽⁶⁾Mathematical development of equations (2.2), (2.3) and (2.4) are in Appendix A.

whether to fully abate or not at all, by maximizing this profit.

3 Enlarging the coalition

As stated in the Introduction, the idea is to show that it is possible, starting from a *Base Case* moment where there is no grand coalition in place, to get to an *After Tax and Transfers* moment where the grand and meaningful coalition forms. I use some basic premises. I assume that it is profitable for the grand coalition to form, meaning that the gains coming from cutting emissions are higher than the abatement costs and the consumption and production losses 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. In order to arrive at 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 as international aid from rich countries to some other countries – for example, to change how electricity is produced – in order to shift from carbon-intensive power sources toward more eco-friendly ones. This one-time transfer costs K per recipient. The objective, then, is to minimize the number r of recipient countries and to know to *which* countries confer this new technology.

In order to picture the game, I start with the *Base Case* where only the rich countries form part of the coalition. This means that no other country is willing to join the coalition, which is the case when 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 only differ on their environmental concern ω_j : They then can be ordered from the greenest one to the least-green one. Hence, if the greenest one is not willing to join, it is evident from the country profit equation (2.6) that no other country is. 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 as it decides whether or not it will join a given coalition. In this sense, and having in mind that an MPC is not allowed in this framework, we can understand the simultaneous decision process as following: Given a coalition of k countries, the greenest outsider evaluates whether or not it is profitable to join, whatever the other countries do. Obviously, all other countries also think about accessing the coalition at the same time, and know that it is profitable for the greenest outsider to join. In that case, it may be profitable for the second greenest country to join the coalition, no matter what the rest do. In this way, we could have a cascading process ending with all countries joining the coalition. Of course, when I use the word ‘cascading’, I am not implying a dynamic process, only the strategic reasoning presented. In the same manner, we can clearly see that if this ordered sequence of countries does not produce the full cascading (leading to the grand coalition), no other order will. Since all

countries know this, they proceed accordingly.⁽⁷⁾

Being profitable can have two meanings. We can either assume that it is profitable for each country, individually and *without* profit sharing among the coalition, or we can assume that the countries belonging a coalition share their profits, according to some sharing rule. Here I only analyse whether a coalition is Internally Stable (IS).⁽⁸⁾ In other words, I only verify that the sum of profits of coalition members is greater than the sum of their *outside options*, meaning the profit each country would make if it were to leave the coalition of k countries and a coalition of the remaining $(k-1)$ countries formed. The IS condition can be represented as

$$\sum_{j \in \mathcal{S}_k} \Pi_j^s > \sum_{j \in \mathcal{S}_k} \Pi_j^{oo} \quad (3.1)$$

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 (3.1) 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.

3.1 Base case

In order to illustrate the game at hand, I start by simulating two cases of the *base case* with 10 countries, in which the initial coalition is composed of the two rich countries. To visualize the decision-making process I 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 where the border tax is implemented without technological transfers. The border tax rate is assumed to be equal to the marginal cost of abatement outsiders would have incurred if they had abated (σ_H). Fig. 1b presents the reverse case, where one country benefits from the technological transfer ($r = 1$) paid by the two rich countries ($d = 2$, with d for donors) and there is no border tax. Both cases are modelled using the following parameters: $\sigma_L = 0.0070$, $t = \sigma_H = 0.0125$, $\omega_H = 0.100$, $\omega_L = 0.060 \dots 0.030$.⁽⁹⁾

In both cases, the solid line represents the mean coalition profit and the dashed line the mean outside option. The horizontal axis presents the number of countries in the coali-

⁽⁷⁾It could also be considered a dynamic case where countries join sequentially. If this were the case, a discount factor for future gains or losses should be introduced alongside 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.

⁽⁸⁾Internal and External Stability as defined by D'Aspremont et al. 1983 [9] and subsequently used by a substantial literature.

⁽⁹⁾These values were chosen in order to: a) resemble the examples shown in Barrett (1997) [3], b) have all countries producing a positive amount of good and, c) have a small coalition in the base case.

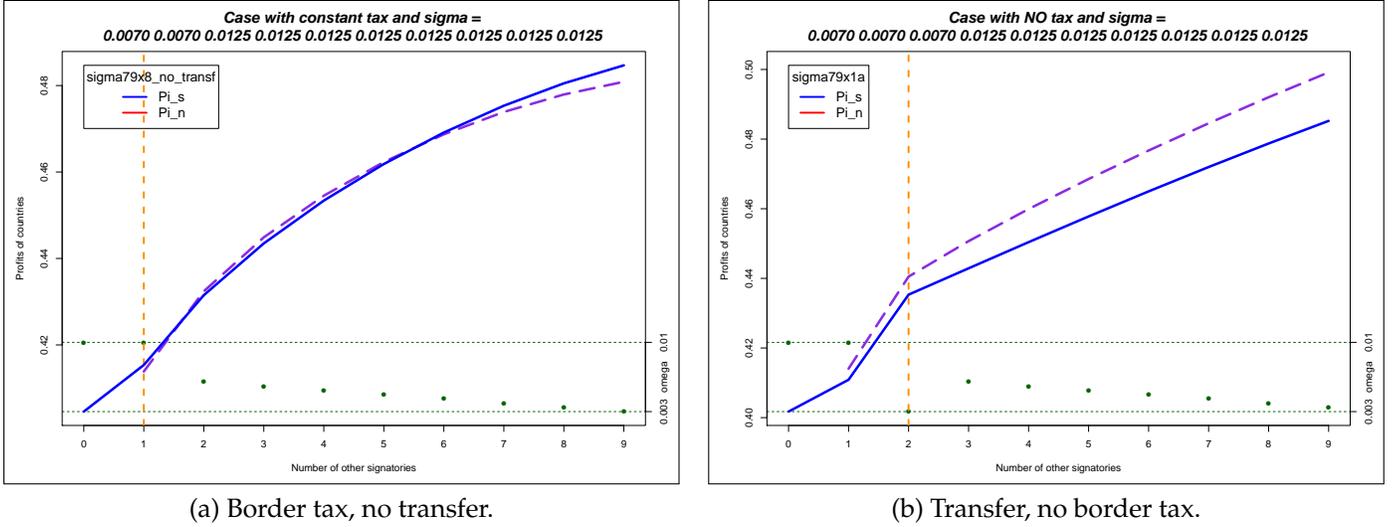


Figure 1: Base case.

tion. Since the countries are heterogeneous, the accession ordering 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. The d rich countries (equal to two in this example) are the first ones in the graph, on the left. By assumption they are part of any coalition. In Fig. 1a no country receives any transfer, and following the reasoning of section 3 (page 8), I only need to test if the greenest – least-green ordering suffices, which is the one depicted. When a transfer is considered, the question relays in the identity of the recipient(s). I plot one option in which the least-green country is the one receiving the transfer, signified by the third dot in Fig. 1b. The rest of the sequence is identical to the one used in Fig. 1a. Choosing another recipient does not change the 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, implementing a border tax can alleviate the burden carried by the rich countries by reducing carbon leakage, increasing coalition firms' profits, and getting extra revenues (from taxes), but it does not trigger the grand coalition formation. The result in the second case is even worse, since the absence of the border tax makes the rich countries much worse off and the unique technology transfer does not induce the recipient country to join (and stay) in the coalition.

We can also note that in the first case, an MPC of six countries could trigger the grand coalition formation. It is important to note that the goal of the border tax and the transfers is to reduce the MPC up to the point where it is no longer needed, meaning that the

extended coalition (rich + recipients) can induce by itself the cascading process explained before.

3.2 After Tax and Transfers

Let us now study the case where both a border tax is implemented and transfers to one or more recipients are possible. The first question that arises is: which countries are the recipients? I show that in the presence of a border tax, if a group of r recipients produces the cascading, 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, but it should be noted: first, that 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. Second, knowing that r countries are recipients and d countries are donors, then $(N - d - r)$ countries are non-recipients, and the goal is to make them produce the cascading. Leaving the greenest countries in the non-recipients group is the best thing to do, since they are more prone to access any given coalition. That means that the countries joining the expanded coalition (donors plus recipients) to form the grand-coalition, are the ones that bear the higher abatement costs.

To prove this, I assume that there is a group of r recipients that produce the whole cascading. Abusing the notation a bit, r will refer both to the amount of recipient countries and to 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 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 non-recipient i that enters the coalition (in a greenest – less-green 'order' as stated before), the IS condition in (3.1) holds. In the same manner, let us denote *Cascading 2* the case where we have substituted one country from the r group with one country from the non-recipients (this new country being, of course, less green than the replaced one), naming this new recipient group r' . I show that the new expanded coalition $(d + r')$ also produces the cascading, hence:

Proposition 1 *Within the game set-up described above, and with d being the amount of initial rich countries in the coalition, and r being 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):*

$$\underbrace{\Pi_s^{d+r+i} > \Pi_n^{d+r+i-1}}_{\text{Cascading 1}} \Rightarrow \underbrace{'\Pi_s^{d+r+i} > '\Pi_n^{d+r+i-1}}_{\text{Cascading 2}} \quad \forall i \in \{1, \dots, N-d-r\} \quad (3.2)$$

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), and $\Pi_n^{d+r+i-1}$ is the non-signatory profit of a coalition with one member less (the outside option for the non-recipient i). 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:

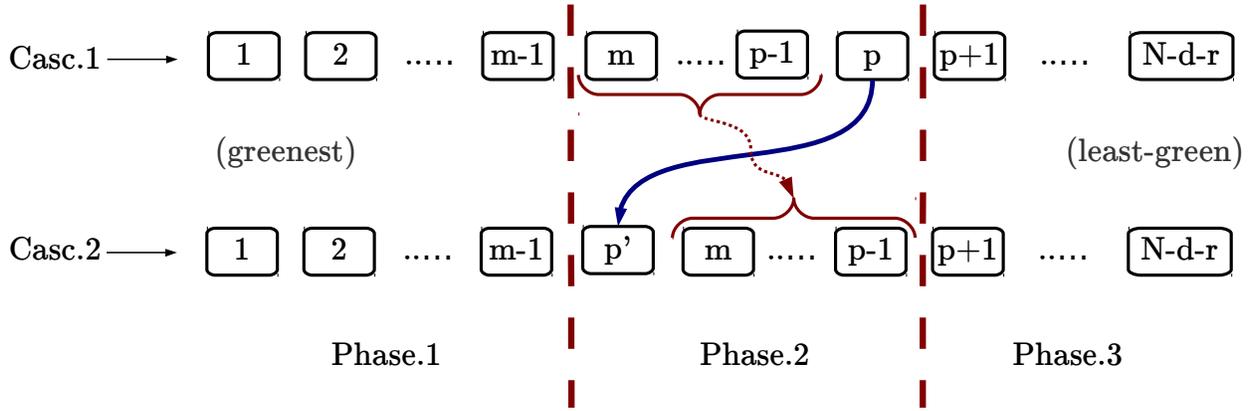


Figure 2: Non-recipients sequence for Cascadings 1 and 2.

As noted in Fig. 2, the non-recipient sequence has been divided into 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 $[p']$ that is now 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 first in the cascading process, as shown in the previous figure.

The proof of the statement in (3.2) consists on showing that for each phase, the following Inequality 1 and 2 hold:

$$\underbrace{\underbrace{'\Pi_s^{d+r+i} \geq \Pi_s^{d+r+i}}_{\text{Inequality 1}} > \underbrace{\Pi_n^{d+r+i-1} \geq '\Pi_n^{d+r+i-1}}_{\text{Inequality 2}}}_{\text{Cascading 2}} \quad (3.3)$$

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 within the outsiders.⁽¹⁰⁾

Let us observe an example of a transfer that produces a cascading in the following figure. I have used the same parameters as in Fig. 1a and Fig. 1b, and the cascading has been

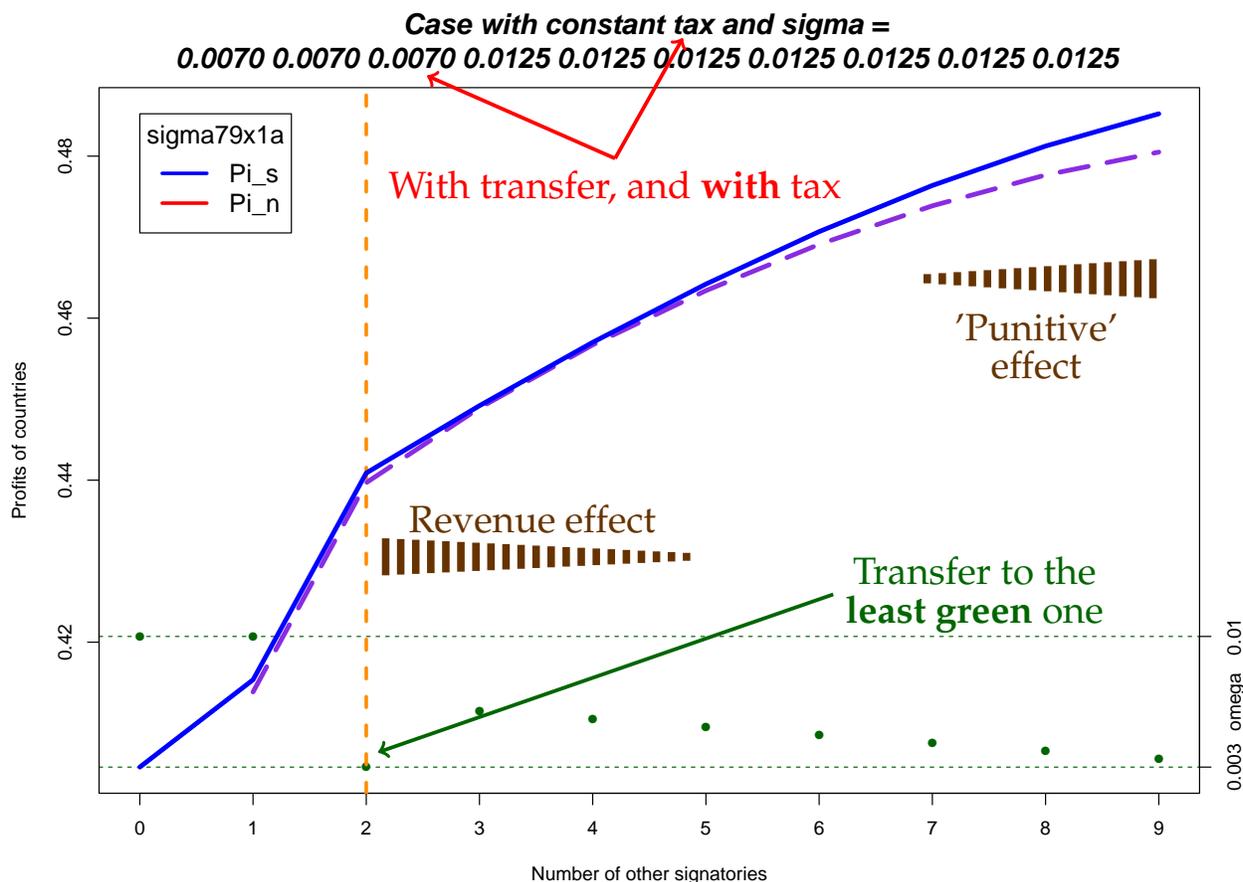


Figure 3: After Tax and Transfers.

triggered with only one recipient, the least-green outsider. 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. The initial coalition is enlarged, and the border tax helps to sustain it. The cascading then occurs, starting with $(d+r)$ countries. Compared to what happened in Fig. 1a without any transfer, here the IS condition continues to hold even if the revenue effect coming from the border tax diminishes, as countries join the coalition. When more countries join the coalition, the border tax has a punitive effect, in the sense that non-signatories' exports are facing a disadvantage with respect to

⁽¹⁰⁾ Depending on the parameters chosen, this set can contain only one group, r^* , or more than one, but it always includes r^* .

the rest of the world. Nevertheless, after the reduction of the revenue effect and before the apparition of the punitive effect of the border tax, there is a critical period where the IS condition might not hold. This cascading process mimics a mountain crossing⁽¹¹⁾ (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 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; it is not simply the sum of the two.

4 Finding the amount of recipients r^*

Having determined that, if the rich countries want to make a technology transfer in order to induce the grand coalition, they have to start with the least-green countries, let us now address the question of how many r^* recipients we need in order to produce the full cascading. Unfortunately, equations developed from the IS condition get much too complex to help create a readable analytical solution for this question. I therefore rely on numerical simulations. I define a $\Delta\Pi_{oo}^s(d, r, i)$ function, which is just inequality (3.1) with all terms put on the left side. Therefore, the IS condition holds if the function is positive. Hence, we have:

$$\Delta\Pi_{oo}^s(d, r, i) = \sum_{j \in \mathcal{S}_k} \Pi_j^s - \sum_{j \in \mathcal{S}_k} \Pi_j^{oo} \quad (4.1)$$

Therefore, if for a given value of r , $\Delta\Pi_{oo}^s(d, r, i)$ is strictly positive, for all possible i 's (d is given), then we get the full cascading. Defining this function makes use of the fact that outsider countries that should be targeted to receive a technology transfer are perfectly known from proposition 1, for each level of r . In Fig. 4 we can observe a continuous version of this function⁽¹²⁾ using the same parameters as in the previous examples.

The figure shows the solution area where $\Delta\Pi_{oo}^s(d, r, i) > 0$, and more importantly, its limit $\Delta\Pi_{oo}^s(d, r, i) = 0$. 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 the 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 $\Delta\Pi_{oo}^s > 0$. In the range left in between, it is negative, meaning that for this case we are in need of an MPC if we want to reach the grand coalition (we are not able to cross the

⁽¹¹⁾As in the Mountain Crossing theorem.

⁽¹²⁾This is coming directly from the country profit function. The only 'trick' 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 $\Delta\Pi_{oo}^s$ is restricted to octant I (+++) and with $(d+r+i) \leq N$, which is the area of interest.

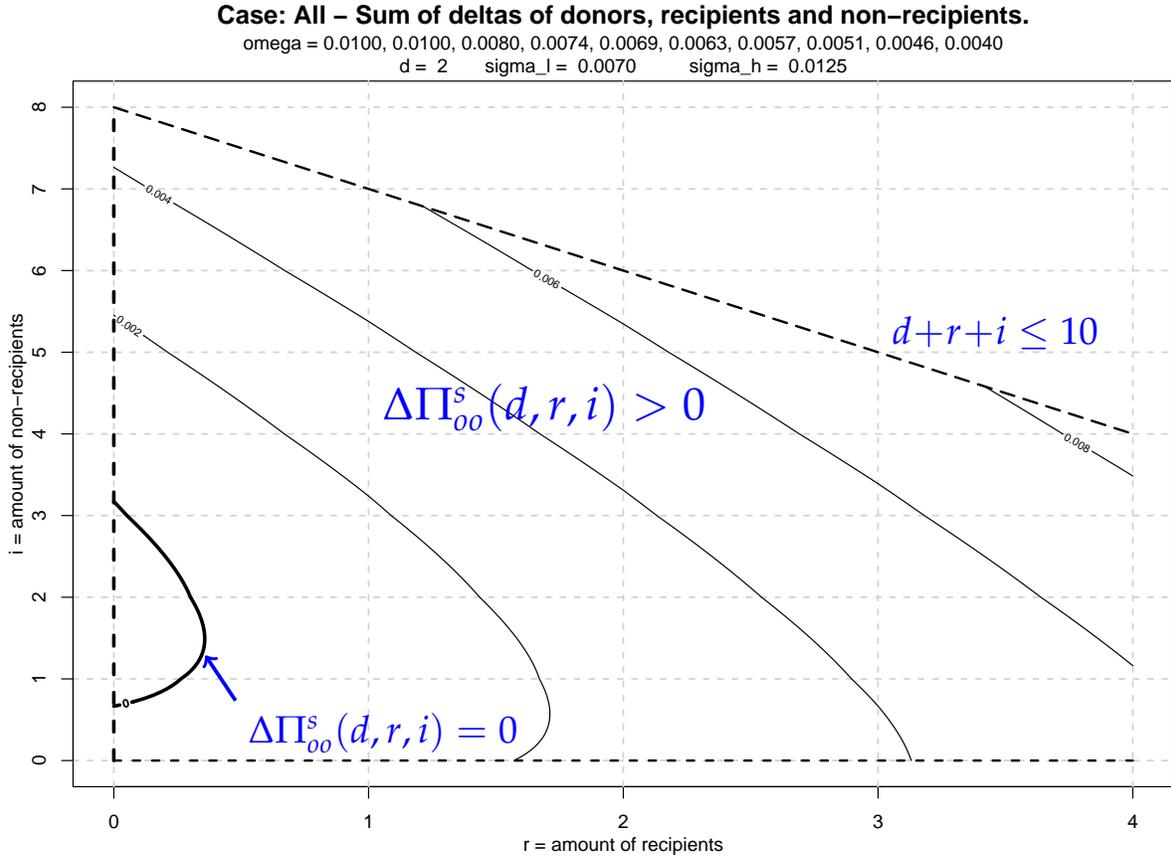
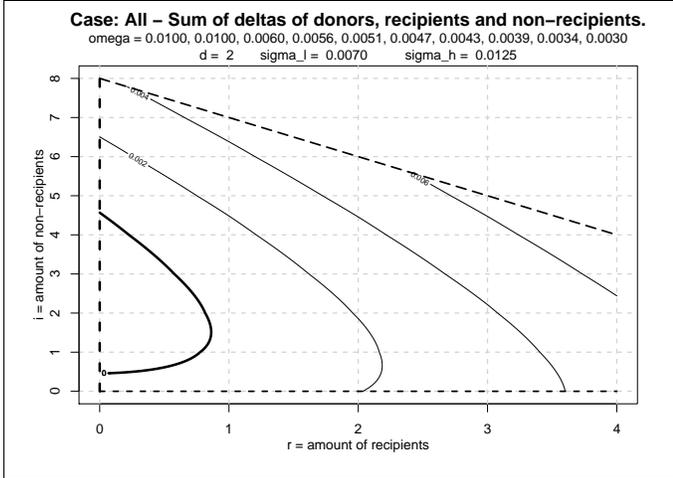


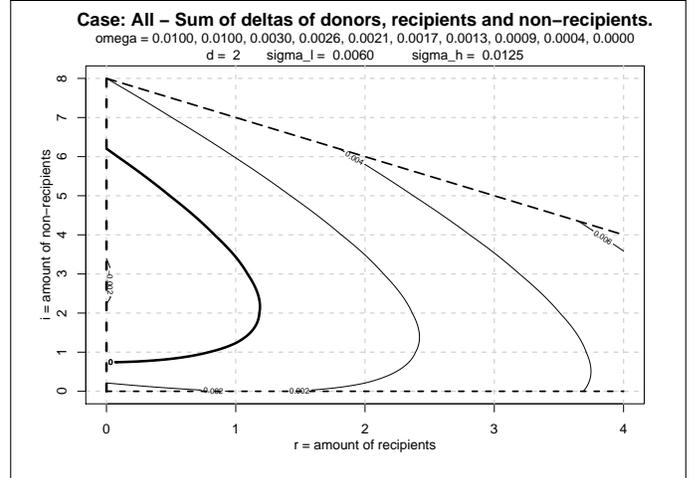
Figure 4: Contour of function $\Delta\Pi_{00}^s(d, r, i)$, with $d = 2$.

mountain). In the case of $r = 1$, we can clearly see that $\Delta\Pi_{00}^s > 0$ for the full 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 $\Delta\Pi_{00}^s = 0$. Hence we find a maximum \hat{r} (of r with respect to i in this implicit function), and r^* is just the integer solution for $r^* > \hat{r}$. Actually, \hat{r} can cross some integer, say r_1 , and r^* can still be equal to $r_1 - 1$. This is due to the fact that we only have to check that, for a given integer level r , $\Delta\Pi_{00}^s(d, r, i) > 0$ for all possible cases of i integers; this means we only have to check for the points on the grid formed of integer coordinates. Nevertheless, having an analytical solution for \hat{r} would be helpful in order to perform sensibility analysis on r^* , which could be done in future research.

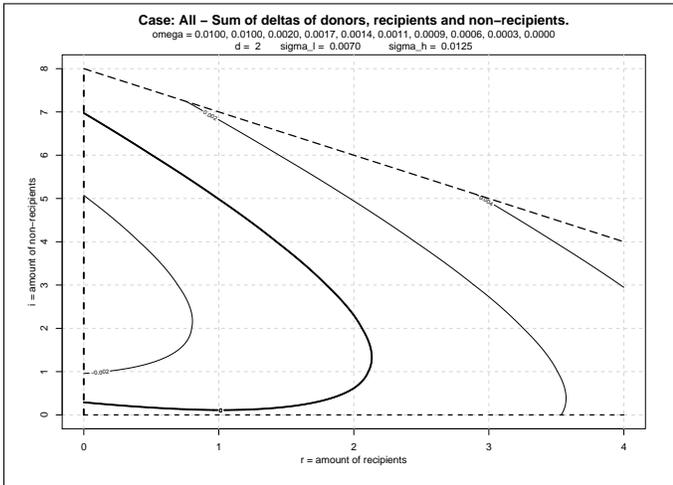
A convenient feature of this graphical representation is that it allows us to analyse what happens if we change some parameters – for example, the environmental concern ω_j of outsiders or the technological levels σ_L and σ_H . Some examples of this are depicted in Figs. 5a–d, where some expected features 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 of outsiders (lower values of ω_j), the harder it is to cross the mountain, meaning that the locus at which $\Delta\Pi_{00}^S = 0$ switches to the right, and therefore r^* might increase. A similar effect occurs when making abatement technologies more expensive.

4.1 Paying transfers

One final question is: Are these r transfers worthwhile? The assumption is that rich countries pay for these transfers, but they are actually willing to do so only if their gains coming from switching from a small coalition of d countries into the grand coalition of N countries are greater than the transfer costs divided amongst themselves. Noting that when all countries abate there are no damages coming from emissions and no border

taxes are being levied, and using the subscript d for rich countries and superscripts N and d for the grand coalition and initial coalition respectively, it is profitable for rich countries to pay r transfers if the following inequality holds:

$$\underbrace{(\pi_d^N - \pi_d^d)}_{>0} + \underbrace{(CS_d^N - CS_d^d)}_{<0} - \underbrace{Dam_d^d}_{>0} - \underbrace{Taxes_d^d}_{<0} \geq \frac{K \cdot r}{d} \quad (4.2)$$

Unfortunately, the algebra gets nasty again here, so I will bring to light some examples and simple considerations. First, two extreme cases can be easily analysed: if $K = 0$, rich countries can always produce the cascading. Actually, they can just buy in all outsiders (which induces the grand coalition by assumption). Moreover, the LHS of inequality (4.2) is positive too, since if that were not the case, there would not have been any (serious) environmental issue to start with. Conversely, 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 an r^* that produces the cascading, it might be too high for the rich countries to finance these transfers.

5 Conclusions

The present work explores a new approach for reaching an International Environmental Agreement (IEA) following a cascading process. The first step of this process 'buys in' some countries to the initial coalition through technology transfers, following Heal and Kunreuther's (2011) [13] idea that a set of countries could tip the rest to get to a clean equilibrium. The second step makes sure that these countries could impose costs to non-joiners, such as border taxes, in order to finalize the cascading process, in a way similar to what happened with the Montreal Protocol and its subsequent amendments. There 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 needs some critical mass to work. On the other hand, the transfer does not work alone either, since it does not deal with the free-rider incentives. However, if both are used in a proper way, they cause a leverage effect and reinforce one another, making the grand coalition a feasible outcome.

Another interesting result is that in order to minimize transfers and improve the chances of reaching the grand coalition, the recipient countries are those with the least environmental marginal damage, also referred as to the least-green ones. Although it might be a coincidence, it looks like this is what is currently happening with the bilateral agreement between the United States and China reached last November. Of course in this case, other considerations are at hand, such as the size and emissions of these two specific countries.

Finally, two options can be suggested to expand this work. The first is the direct application of these two tools, the border tax and the transfers, in a more realistic set-up using real data. For example, a model with 6 or 12 regions could be used to test the feasibility of the solution proposed here. A second vein could be to analyse the strategic implications of 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 get 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.

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A Firm maximization problem

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

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

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:

$$1 - x^i - t_j^i - \sigma_j q_j - x_j^i = 0 \quad \forall i, j \quad (\text{A.2})$$

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

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

where $t_j = \sum_{i=1}^N t_j^i$ is the sum of the tax rates 'paid' by a 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:

$$\begin{array}{ccc} \begin{bmatrix} 2 & 1 & \cdots & 1 \\ 1 & 2 & \cdots & 1 \\ \vdots & \vdots & \ddots & \vdots \\ 1 & 1 & \cdots & 2 \end{bmatrix} & \cdot \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} & = \underbrace{\begin{bmatrix} N - N\sigma_1 q_1 \\ N - N\sigma_2 q_2 \\ \vdots \\ N - N\sigma_N q_N \end{bmatrix}}_D - \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_N \end{bmatrix} \end{array} \quad (\text{A.4})$$

Using the Sherman-Morrison formula, we can get $\vec{x}_j = C^{-1} \cdot D$, 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:

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

Or equivalently:

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

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

As stated in section 3, the proof consists of showing that if conditions for *Cascading 1* hold, then conditions for *Cascading 2* hold too. In order to do so, I will use the following inequalities:

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

Hence, the proof shows that *Inequality 1* and *Inequality 2* hold. The first one says that the profit of an i^{th} country coming into the coalition Π_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 as *Cascading 2*, according to the following diagram:

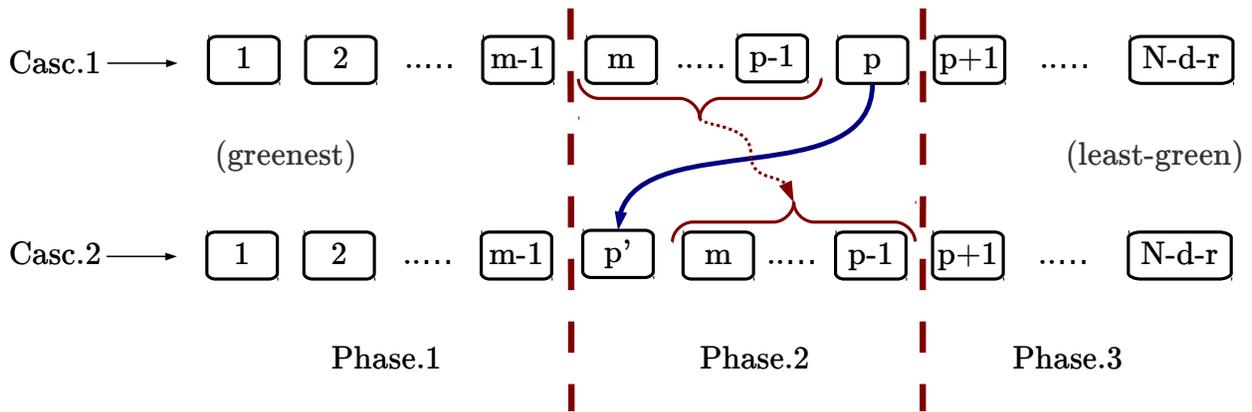


Figure 6: Non-recipients sequence for cascading 1 and 2.

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 into three phases: 1, 2 and 3.

First, let us note that the amount $\sigma_S = \sum_{j \in S} \sigma_j$ (the sum of the coalition's marginal abatement costs) does not change between *Cascading 1* and 2. This is 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 us 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 $\Delta D_1 = 'DAM_j^{d+r+i} - DAM_j^{d+r+i}$, 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 $\Delta D_2 = 'DAM_j^{d+r+i-1} - DAM_j^{d+r+i-1}$, 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} ... 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.