International Negotiations on the Environment: Uniform vs. Differentiated Standards*

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Abstract

This paper tries to understand the reasons why countries sign environmental agreements with uniform abatements of their emissions. Currently, international negotiations lead either to agreements on differentiated standards or on uniform standards. At first sight, we can think that differentiated reductions respect the inner and observable characteristics of the countries. Consequently, uniform agreements should concern either similar countries or non-observable characteristics countries.

We show, using a simple Nash bargaining model without any informational asymmetries, that uniform agreements can Pareto-dominate

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differentiated ones for heterogenous countries. One explanation is highlighted to obtain this result. We advocate the existence of monetary transfers, even imperfect. Monetary transfers enable the country with weak incentives for a uniform agreement to achieve it, by compensating for the additional cost implied by a greater abatement effort. We also discuss the reluctance of one country to sign a specific type of agreement, even if it is socially desirable.

Keywords: transboundary pollution, cooperative games, bargaining, standards, transfers.

JEL: Q50, C71.

1 Introduction

This paper deals with the efficiency comparison of internationally negotiated agreements with uniform versus differentiated abatement standards for a transboundary pollution problem, in the presence of imperfect monetary transfers across countries.

It is often admitted in the economic theory that uniform rules are less efficient instruments than "flexible" differentiated rules in the presence of asymmetric players (Harstad (2006), p.2). If the countries have different marginal implementation costs, then uniform rules will increase the total cost of attaining a given environmental objective (Hoel (1992), p.142). We observe, however, a frequent use of these rules in International Environmental Agreements (hereafter IEAs) (Hoel (1991), p.64; Harstad (2006), p.2). Potential signatory countries in these agreements bargain over a uniform emission reduction rate. This means that countries have to reduce their current emissions to reach a percentage of the emissions of a base year. The uniform rule means that this percentage is the same across countries. This type of standard is included in the provisions of the Montreal Protocol on Substances that Deplete the Ozone Layer which specified an emission reduction of CFCs and halons by 20 %, based on 1986 emission levels to be accomplished by 1998. Another example is the Helsinki Protocol which suggested a reduction of sulphur dioxide from 1980 levels by 30 % by 1993 (Finus (2001)).

Our purpose in this paper is to compare the efficiency of negotiated agreements with uniform versus differentiated emission reduction quotas, when there is a possibility of a side payment scheme across countries. In the context of a transboundary pollution problem between two countries, this paper mainly asks the following questions. Why do heterogeneous countries gain by signing agreements with uniform standards? Do side payments help to make uniform standards preferable, even if they are costly to implement? In order to answer these questions, we use a negotiation game and the Nash bargaining solution as equilibrium.

As mentioned above, intuition recommends the use of differentiated abatement standards in IEAs. These differentiated rules would take into account the different characteristics of countries (abatement and damage functions, preferences). We can, however, find in the literature several reasons explaining the use of uniform standards. First, uniform solutions could be more rapidly accepted by the signatory countries because of the fairness argument (Welsch (1992)). Secondly, the negotiation process of differentiated standards specific to each country could be costly because of the informational problems between countries (Larson and Tobey (1994), Harstad (2006)). Moreover, simple rules such as uniform quotas may form a "focal point" during negotiations (Schelling (1960)) simplifying the co-ordination of expectations between countries (Schmidt (2001)). Another argument in favor of the use of uniform standards is the presence of agency problems (Boyer and Laffont (1999)). A constitution which mandates the use of uniform standards rather than differentiated ones might solve agency problems. It could prevent for example the setting of lax environmental standards by politicians according to the political pressure from industrial groups[1]. Recently, Copeland and Taylor (2005) presented a trade theory argument in favor of the use of rigid rules in IEAs such as equiproportinate reductions in pollutants. The argument is that trade in goods can act as a substitute for trade in emission permits. So uniform emission reductions in a world with freely traded goods can be efficient even if trade in permits is banned.

We especially concentrate on a transboundary pollution problem between two countries. This means that there exist negative spillovers of pollution between these countries, namely the emissions of one country negatively affect the other country. For issues such as global warming, ozone layer depletion, acid rain or international water pollution, these negative effects are not taken into account by the polluting countries. In the presence of such pollution problems, the terms of an agreement can include situations where the countries that gain compensate the losers. In this case, *side payments*

[1] See also the papers by Panagariya and Rodrik (1993), and Besharov (2002) who discuss the optimality of uniform solutions which prevent lobbying groups.

will ensure the acceptability of the outcome to all countries. For this reason, side payments are often offered in order to increase participation in IEAs. The examples of IEAs including the possibility of transfers between countries are the Fur Seal Treaty (1911), the Montreal Protocol (1987) and the Stockholm Convention on Persistent Organic Pollutants (2001). Nevertheless, there can be losses in transfers across countries ("imperfect transfers"): the given amount is greater than the amount received. Two arguments among others can be advocated. The first argument is that it is costly to donor countries to collect transfers and deliver them to recipient countries because of some administrative costs. The second argument can be the existence of another type of cost: it can be costly, in political terms, for a government of the donor country to convince electors and national lobbies of the necessity of making transfer payments to another country. So in this paper, we also analyze the consequences of the possibly imperfect transfers on the outcomes of international negotiations on the environment.

The international aspect of the pollution problem leads us to consider a negotiation game between two sovereign nations. The negotiation problem is modeled as a one-stage game in which the governments cooperatively bargain over abatement levels and transfers[2]. Because it is a one-stage game, we do not consider the enforcement problems related to the respect of standards by the countries once the agreement is signed. It could be possible to consider this very important aspect of IEAs in a repeated game framework by the use of punishment strategies by countries. But in this paper, we are interested in investigating the outcome of different negotiations. We assume a cooperative spirit in the agreement, in the sense that countries may wish to improve their payoffs through a bargaining process. So we adopt a theoretic cooperative game concept[3] which is the Nash bargaining solution (Nash (1950)). This solution satisfies some axioms, especially that of *Pareto efficiency*. Defining all bargaining-efficient outcomes and the payoff level at the *threat point* which

[2]For simplicity, we only take into account the national government decisions in the negotiation process and exclude from the analysis national interest group pressures on these decisions.

[3]There are a significant number of papers which study environmental problems in a cooperative bargaining framework, such as the Nash bargaining solution: see among others Amacher and Malik (1996), Eckert (2003), Kampas and White (2003). However, in order to take into account the dynamic process of negotiations, there is an alternative way to model negotiations by non-cooperative bargaining games. Some of the papers dealing with environmental problems are, among others, Rotillon et al. (1996), Compte and Jéhiel (1997), Chen (1997) and Manzini and Mariotti (2003).

is the situation without cooperation, bargaining can be defined axiomatically; the *Nash bargaining solution* is such an axiomatic solution[4]. More generally, the bargaining outcome will depend on the relative bargaining powers of countries (Jéhiel. (1997)).

Concerning the studies on transboundary pollution problems, the most common traditions are either to look at the issues of formation of coalitions for signing an agreement, or the determination of the maximal number of the countries which would voluntarily be part of a self-enforcing IEA. Regarding this latter approach, a self-enforcing IEA will be signed only by a small number of countries, because the gains from cooperation do not improve substantially upon the non-cooperative outcome (Barrett (1994)). Hence, there is a need to consider different incentive instruments in order to induce the countries to participate in these agreements[5]. It is possible to quote three possible instruments in IEAs. The first instrument is the use of side payment schemes[6]. Since most frequently cash payments are paid in IEAs including provisions for transfer schemes, it could be convenient to assume monetary side payments (Barrett (2003)). The second instrument is issue linkage[7] which means a negotiation process on multiple issues, i.e. on the protection of the environment, and trade or technological transfers, etc. The last instrument corresponds to technological transfers for the abatement process across countries[8].

Another branch of the literature studies the efficiency of different international environmental instruments, such as standards or taxes. Finus and Rundshagen (1998) consider a uniform standard and an effluent tax. They show that for global pollutants, where the number of the countries suffering from an externality is large, governments agree on a quota regime rather than an effluent tax. Their result widely depends on a special rule determining the uniform standard which will be imposed on all countries. This rule is the lowest common denominator, meaning that the lowest proposal from one country

[4] An introduction to (n) person simple Nash bargaining games can be found in Harsanyi (1977), chapter 10.

[5] The introduction of these instruments naturally removes the "self-enforcing" character of the agreements.

[6] See among others Carraro and Siniscalco (1993), Petrakis and Xepapadeas (1996), Chen (1997), Chang (1997), Barrett (2001) and Kolstad (2005).

[7] See among others Folmer et al. (1993), Cesar and de Zeeuw (1996), Carraro and Siniscalco (1997), Conconi and Perroni (2002).

[8] See among others Lee (2001), Millock (2002), Buchner et al. (2005).

will be imposed on all countries. As Harstad (2006) admits, the traditional justification for the existence of uniform rules is asymmetric information[9]. In the presence of asymmetric information between firms and a regulator, Heyes and Simons (2003) examine the comparative efficiency of uniform and firm-specific emission standards for a domestic pollution problem. They claim that tying regulation to the population average characteristics can mitigate (in part) the ratchet effect[10]. They show that if the regulator has the possibility to differentiate standards and does not use this possibility, this possibility should be removed as it is always harmful. Even if the regulator chooses to use this possibility, it may be welfare-improving to remove it. This result, however, depends on the assumption of a large number of firms in the economy. Harstad (2006) studies a bargaining model under private information where reluctance, in equilibrium, is signaled by a delay. The model derives the conditions for which it is efficient to consider uniform policies - with and without side payments- and when it is efficient to prohibit side payments in the negotiations between two heterogeneous regions. He shows that while political differentiation and side payments increase efficiency, they create conflicts of interest between regions and thus delay. Hence, uniformity and prohibiting side payments can be welfare-improving, in certain cases, by reducing strategic delay.

The originality of our paper is based on three aspects. First, it offers an alternative argument for explaining why countries sign agreements of uniform standards, without assuming asymmetric information across countries, or without introducing an additional negotiation variable, other than transfers (no international trade, no issue linkage). This alternative argument is the presence of side payments, even imperfect. Another contribution of the paper is to include an analysis of welfare, for each agreement, in terms of both individual and total welfares. In this respect, we study the impact

[9]Since the benefits or costs of abatement activities are imperfectly known in general to the parties to a regional or an international agreement, it could be optimal to agree on an average (or uniform) rule, rather than a differentiated one. It is rather an obvious argument.

[10]An explanation of the ratchet effect can be found in Laffont (2005): "A lack of commitment puts the ratchet effect in motion. Faced with incentives in the first period, firms fear that taking advantage of these incentives today (efficient firms make more money by having low costs) will lead to more demanding incentive schemes in the future. A way to commit credibly to not expropriating rents in the future is to learn nothing today about the firms' efficiency."(p.22).

of the degrees of the imperfection of transfers and of the asymmetry across countries, on the robustness of uniform solutions. Finally, we highlight the situations where a country can be reluctant to sign a uniform agreement, even if it is better-off than with non-cooperation, because it could earn more in a differentiated agreement.

The paper is organized as follows. Section 2 presents the model. This corresponds to the description of the threat point of the negotiations, as well as to the definition of the bargaining-efficient outcomes for the agreement on uniform standards with transfers and the agreement on differentiated standards without transfers. In Section 3, we make total welfare comparisons between the two agreements. Individual welfare comparisons between the two agreements are made in Section 4. In the case of a linear cost function, this corresponds to the construction of Pareto frontiers. In the non-linear case, this is achieved using the first-order conditions of the programs of the two agreements. We offer concluding remarks in Section 5.

2 The Model

We consider a transboundary pollution problem across two countries $i = 1, 2$. This means that the emissions of one country negatively affect the welfare[11] of the other (existence of externalities). We are interested in a situation where two countries cooperate, taking into account their total welfare, in order to mitigate this transboundary pollution problem. The cooperation is realized by international negotiations between the two countries. These countries are supposed to be heterogeneous in terms of their benefits from global abatement, or in other words, in terms of their damage from global pollution, and in terms of their abatement costs.

Without any cooperation, the objective of each country is to maximize its utility function with respect to its budget constraint. The program of country $i = 1, 2$ can be written in the following way:

[11] In our model, the individual welfare signifies the level of utility of each country, which can be written either as the sum of benefits from global abatement and the consumption of a private good, or as the sum of benefits from global abatement and exogeneous initial endowments, minus abatement costs.

$$\underset{a_i}{Max} NB_i = \underset{a_i}{Max} \left[B_i(a_1 + a_2) + c_i\right] \tag{1}$$
$$\Omega_i \geq c_i + C_i(a_i)$$

where $B_i(a_1 + a_2)$ represents the benefits from global abatement $A = a_1 + a_2$ of country $i = 1, 2$, and c_i represents the consumption of a private good. Ω_i denotes the exogenous initial endowments of country i used for the consumption of a private good c_i and for the abatement costs $C_i(a_i)$. In each country, there is a firm which produces a good with a "one to one" technology. There is also an abatement technology associated with the cost function $C_i(a_i)$[12].

The total abatement, $A = a_1 + a_2$, is formed by the abatement efforts of countries 1 and 2 respectively, $a_1 = \bar{E}_1 \times \beta_1$ and $a_2 = \bar{E}_2 \times \beta_2$. The variables $\bar{E}_1$ and $\bar{E}_2$ denote the emission levels of countries 1 and 2 in a base year. In general, the choice of the base year in IEAs is subject to discussions across countries. For example, the year 1986 was chosen, after long discussions, as the base year for the reductions of the emissions of CFC in the Montreal Protocol (1987). In this paper, we firstly assume that these levels are given exogenously, because they are usually determined on the basis of scientific evidence in IEAs. We thus do not consider any negotiation across countries on the choice of the base year. Moreover, we assume that these emission levels of the countries at a base year are identical, and are equal to 1, i.e. $\bar{E}_1 = \bar{E}_2 = 1$. This assumption allows us to focus on two types of heterogeneity across the countries, independently of their population size. We can justify this argument in the following manner. Since the source of the pollution problem is the fact that the countries did not undertake abatement activities before the signature of the agreement, their emission levels in the past are only determined by their respective population size, and not by their sensitivity to global pollution or by the level of their abatement costs. We assume that countries 1 and 2 have the same population size, which can mean that they have identical emission levels in a base year.

The variables β_1 and β_2, with $\beta_1 \leq 1$ and $\beta_2 \leq 1$, denote respectively the differentiated rates of reduction of the emissions of countries 1 and 2.

[12] Ω_i can be considered as an initial endowment in labor, which plays the role of the numeraire. The production of the good is then achieved with a "one to one" technology.

For example, in the Kyoto Protocol (1997), the burden sharing agreement in the European Union implies differentiated emission reduction rates. Namely, the following countries must reduce their 1990 emissions by differentiated percentages: Austria (-13%), France (0%), Greece (+25%).

In the benefit function from global abatement $B_i(a_1 + a_2)$ for country $i = 1, 2$, the abatement efforts of one country are beneficial to the other because of the existence of positive spillovers. This function is assumed to be increasing and concave. The abatement costs of country $i = 1, 2$ are represented by the function $C_i(a_i)$, which is assumed to be increasing and convex. The argument of this function only depends on the individual abatement effort of the country under consideration a_i. From this perspective, we exclude any possibility of technological transfers or spillovers across the two countries. We assume that the abatement cost is null when there is no abatement effort, i.e. $C_i(0) = 0$, for $i = 1, 2$.

In order to take into account the heterogeneity across countries in terms of the exposure to global pollution, we write the benefit functions respectively for countries 1 and 2 in the following way: $B(a_1+a_2)$ and $\alpha B(a_1+a_2)$, where α is a positive constant parameter, with $\alpha \leq 1$. Furthermore, we model the heterogeneity across countries in terms of the abatement costs in the following manner: $C(a_1)$ for country 1 and $\delta C(a_2)$ for country 2, where δ represents a positive constant parameter. We do not make assumptions about the value of the parameter δ.

We now define the different programs, corresponding to the agreement on uniform standards with transfers and to the agreement on differentiated standards without transfers, that we shall deal with given their first-order conditions. Before that, we study the threat point (or the disagreement point) of the negotiations, which represents the situation without cooperation.

2.1 Threat point

We assume that the countries use Nash equilibrium strategies when they prefer not to cooperate.

Lemma 1 *The abatement levels of countries* 1 *and* 2 *are respectively defined by system* 2:

$$\begin{cases} B^{'}(A) = C^{'}(a_1) \\ \alpha B^{'}(A) = \delta C^{'}(a_2) \end{cases} \quad (2)$$

These conditions give the equality of the individual marginal benefits from global abatement to the individual marginal abatement costs. In fact, when a country abates, it does not take into account the positive effects of its action on the welfare of the other country.

Proof. The objective of country 1 is to maximize its utility function with respect to its budget constraint, taking as given the level of abatement of country 2, a_2 :

$$\underset{a_1}{Max} \left[B(a_1 + a_2) + \Omega_1 - C(a_1) \right] \quad (3)$$

The first-order condition of this program is the following: $B^{'}(A) = C^{'}(a_1)$ because Ω_1 is exogenous.

Similarly, the first-order condition of the program for country 2 is the following: $\alpha B^{'}(A) = \delta C^{'}(a_2)$. ■

The solution of system 2 gives us respectively the abatement for country 1, for country 2 and the total abatement at the Nash equilibrium, $\hat{a}_1$, $\hat{a}_2$, $\hat{A}$. So one can calculate the welfare levels for each country:

$$N\hat{B}_1 = B(\hat{A}) + \Omega_1 - C(\hat{a}_1) \quad (4)$$

$$N\hat{B}_2 = \alpha B(\hat{A}) + \Omega_2 - \delta C(\hat{a}_2) \quad (5)$$

We now compare the efficiency of two second-best agreements: the agreement on uniform standards with transfers (UT) and the agreement on differentiated standards without transfers (D).

2.2 Cooperation: agreement on uniform standards with transfers and agreement on differentiated standards without transfers

Our objective in this section is to compare, in terms of welfare, two second-best agreements (UT and D)[13]. On the one hand, agreement "UT" integrates

[13]In this paper, our aim is to compare, in terms of welfare, these two second-best agreements which are frequently observed in reality. We do not try to explain why these

the constraint of uniformity of the abatement standards for heterogeneous countries, but includes a side payment scheme. Many agreements motivate this choice, such as the Stockholm Convention on Persistent Organic Pollutants (POPs) signed in 2001, which requires signatory countries to eliminate the production and recent intentional use of POPs[14]. Moreover, a mechanism of financial assistance is included in the provisions of the agreement, in order to induce the less developed countries to participate in the agreement[15]. On the other hand, agreement "D" is able to take into account the heterogeneity of the countries via differentiated reduction rates of the emissions, but does not involve a side payment scheme. For example, the Kyoto Protocol on Climate Change implies differentiated standards for different blocs of countries[16], but does not include an explicit side payment scheme[17]. Nevertheless, as emphasized by Chander et al. (2002, p.113) and Barrett (2003, p. 361), the market for emission permits and the clean development mechanism constitute alternatives to monetary transfers, which allow the obtention of similar results by an appropriate distribution of initial allowances.

The question that can be raised is why we are interested in these two specific agreements. In fact, we exclude from our analysis agreement on differentiated standards with transfers (DT) and agreement on uniform standards without transfers (U). It is clear that the agreements with a larger set of negotiation variables will dominate, in terms of total and individual welfare, all the other agreements, given the assumptions on the concavity of the benefit function and the convexity of the cost function. Hence we always obtain the superiority, in the Pareto sense, of agreement D on the U, agreement DT on the UT, and finally agreement DT on the U. It thus remains for us to compare, in terms of welfare, the two second-best agreements UT and D.

In the following, we first analyze the Nash bargaining solution for the agreement on uniform standards with transfers.

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two arrangements emerge.

[14]The Montreal Protocol (1987) is another important example. This protocol specifies a uniform emission reduction rate for all countries, but includes a side payment scheme from developed countries to less developed ones (namely the Multilateral Fund).

[15]Source: http://www.epa.gov/oppfead1/international/pops.htm.

[16]The Oslo Protocol on Further Reduction of Sulphur Emissions (1994) also implies differentiated standards.

[17]This point is also made in Chander and Tulkens (2006, p.11, footnote 12).

2.2.1 Agreement on uniform standards with transfers

The Nash bargaining solution is written in the following way in this case[18]:

$$\underset{\bar{a},t}{Max}\left[\begin{array}{c}\left[B(2\bar{a})+\Omega_1-C(\bar{a})-(1+\lambda)t-\hat{N}B_1\right]^{\gamma}\\ \times\left[\alpha B(2\bar{a})+\Omega_2-\delta C(\bar{a})+t-\hat{N}B_2\right]^{1-\gamma}\end{array}\right] \tag{6}$$

The uniform standard $\bar{a}$ and transfers t are the negotiation variables in this agreement. The first (*resp.* second) term represents the gains to cooperation for country 1 (*resp.* 2). We allow countries to have different bargaining powers in the negotiation, namely γ for country 1 and $(1-\gamma)$ for country 2, where γ is a positive parameter with $0 < \gamma < 1$. As γ increases, the weight of the utility of country 1 increases, and vice versa. This Nash bargaining solution is unique for every pair of bargaining powers of the two countries.

We assume that transfer payments[19] are imperfect in the sense that country 1 must incur the cost $(1+\lambda)t$ in order to give transfer t to country 2, with $\lambda \geq 0$. So parameter λ measures the imperfection of transfers between the countries. The extreme case $\lambda = 0$ represents the situation with no loss in transfers. The idea of the imperfection of transfers is similar to the concept of the marginal cost of public funds, i.e. the social cost of raising one unit of funds[20]. Parameter λ could be also interpreted as a political cost. We consider the case where transfers are positive,

[18] The budget constraints of countries 1 and 2 are written respectively:

$\Omega_1 = C(\bar{a}) + c_1 + (1+\lambda)t$

$\Omega_2 = \delta C(\bar{a}) + c_2 - t$

The difference of these budget constraints compared to those at the threat point comes from the existence of transfer payments t. In fact, country 1 gives transfers $(1+\lambda)t$ to country 2 and country 2 receives transfers t, where $\lambda \geq 0$ measures the loss in transfer payments.

[19] "To introduce money side payments requires an assumption: each player's utility for money must be linear or equivalently, the marginal utility for money must be constant" (taken from Barrett, (2003)).

[20] As Laffont (2005, p. 1) notes, the marginal cost of public funds includes in particular a deadweight loss because governments raise revenues by means of distortionary taxes.

$t \geq 0$[21], i.e. where country 1 makes transfer payments to country 2[22]. This situation corresponds to the case where country 2 has small initial endowments (Ω_2 small) and/or has less benefits from global abatement ($\alpha << 1$) than country 1.

If we note V the objective function of the Nash bargaining solution, the first-order condition with respect to the uniform standard $\bar{a}$ is written:

$$\frac{\partial V}{\partial \bar{a}} = 0 \Longleftrightarrow \frac{\gamma \left[2B'(\bar{a}) - C'(\bar{a})\right]}{\left[B(2\bar{a}) + \Omega_1 - C(\bar{a}) - (1+\lambda)t - \hat{NB}_1\right]} \tag{7}$$

$$= \frac{(\gamma - 1)\left[2\alpha B'(\bar{a}) - \delta C'(\bar{a})\right]}{\left[\alpha B(2\bar{a}) + \Omega_2 - \delta C(\bar{a}) + t - \hat{NB}_2\right]}$$

The first-order condition with respect to transfers t is:

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow \frac{\gamma \left[-(1+\lambda)\right]}{\left[B(2\bar{a}) + \Omega_1 - C(\bar{a}) - (1+\lambda)t - \hat{NB}_1\right]} \tag{8}$$

$$= \frac{(\gamma - 1)}{\left[\alpha B(2\bar{a}) + \Omega_2 - \delta C(\bar{a}) + t - \hat{NB}_2\right]}$$

These first-order conditions give us the levels of the uniform standard $\bar{a}$ and transfers t in the agreement on uniform standards with transfers. The welfare levels of countries 1 and 2 are then equal to:

$$NB_{1UT} = B(2\bar{a}) + \Omega_1 - C(\bar{a}) - (1+\lambda)t \tag{9}$$

[21] See the appendix A1 for the proof showing the positivity of transfers in the case $\alpha \simeq 0$, $\delta < 1$ and $\gamma = 1/2$, with a linear cost function.

[22] In fact, we only focus on the case of strictly positive transfers from country 1 to country 2. Because when the transfer is null, the Pareto frontier in the uniform case is below the Pareto frontier in the differentiated case without transfer. In that case, the comparison is obvious.

$$NB_{2UT} = \alpha B(2\bar{a}) + \Omega_2 - \delta C(2\bar{a}) + t \quad (10)$$

We now turn to the analysis of the Nash bargaining solution in the agreement on differentiated standards without transfers.

2.2.2 Agreement on differentiated standards without transfers

The Nash bargaining solution can be denoted in the following way in this case[23]:

$$\underset{a_1,a_2}{Max} \left[\begin{array}{c} \left[B(a_1+a_2) + \Omega_1 - C(a_1) - \hat{N}B_1 \right]^{\gamma} \\ \times \left[\alpha B(a_1+a_2) + \Omega_2 - \delta C(a_2) - \hat{N}B_2 \right]^{1-\gamma} \end{array} \right] \quad (11)$$

The differentiated standards of the two countries a_1 and a_2 constitute the negotiation variables in this agreement.

If we note V the objective function of the Nash bargaining solution, the first-order condition with respect to the differentiated standard of country 1, a_1 is written:

$$\frac{\partial V}{\partial a_1} = 0 \Longleftrightarrow \frac{\gamma \left[B^{'}(a_1+a_2) - C^{'}(a_1) \right]}{\left[B(a_1+a_2) + \Omega_1 - C(a_1) - \hat{N}B_1 \right]} \quad (12)$$

$$= \frac{(\gamma - 1) \left[\alpha B^{'}(a_1+a_2) \right]}{\left[\alpha B(a_1+a_2) + \Omega_2 - \delta C(a_2) - \hat{N}B_2 \right]}$$

Similarly, the first-order condition with respect to the differentiated standard of country 2, a_2 is:

[23] The budget constraints of countries 1 and 2 are:
$\Omega_1 = C(a_1) + c_1$
$\Omega_2 = \delta C(a_2) + c_2$

$$\frac{\partial V}{\partial a_2} = 0 \Longleftrightarrow \frac{\gamma\left[B'(a_1+a_2)\right]}{\left[B(a_1+a_2)+\Omega_1 - C(a_1) - \hat{N}B_1\right]} \tag{13}$$
$$= \frac{(\gamma-1)\left[\alpha B'(a_1+a_2) - \delta C'(a_2)\right]}{\left[\alpha B(a_1+a_2)+\Omega_2 - \delta C(a_2) - \hat{N}B_2\right]}$$

These first-order conditions give us the levels of differentiated standards a_1 and a_2 in the agreement on differentiated standards without transfers. The welfare levels of countries 1 and 2 are given by:

$$NB_{1D} = B(a_1+a_2) + \Omega_1 - C(a_1) \tag{14}$$

$$NB_{2D} = \alpha B(a_1+a_2) + \Omega_2 - \delta C(a_2) \tag{15}$$

In the following section, we compare the social welfare function[24] (or the function of the Nash bargaining solution) of the agreement on uniform standards with transfers and the agreement on differentiated standards without transfers. This allows us to determine the total welfare of the countries after the adoption of a certain type of agreement. This comparison will be useful for the next section when we compare the individual welfare of the countries.

3 Comparison of the Total Welfare Levels

In this section, we first provide the conditions under which the agreement on differentiated standards without transfers dominates, in terms of total welfare, the agreement on uniform standards with transfers. To do this, we start by selecting specific values of the variables a_1 and a_2, for which the value of the social welfare function (or the function of the Nash bargaining solution) $V(a_1, a_2, t = 0)$ is superior to the maximum value attainable by the social welfare function in the uniform agreement $\bar{V}^*(\bar{a}^*, t^*)$. Then, we can conclude that, under these conditions, the maximum value attainable by the

[24]See Mas-Colell et al. (1995, p.825-846) for a justification of V as a social welfare function.

social welfare function in the agreement on differentiated standards without transfers is greater than that attained in the agreement on uniform standards with transfers.

We now present the selection of the particular values of the variables a_1 and a_2.

Definition 1 *Let t^* and $\bar{a}^*$ be the optimal levels of the transfer and the uniform standard in the agreement on uniform standards with transfers. We define a_1 and a_2 such that :*

1) $a_1 + a_2 = 2\bar{a}^*$

2) $C(a_1) = C(\bar{a}^*) + (1+\lambda)t^*$ with $t^* > 0$.

We assume that $a_1 \leq 1$, $a_2 \geq 0$ and $t^* > 0$ (**Condition C1**). Such conditions imply constraints on $\bar{a}^*$ and t^*. It is, however, possible to make assumptions on the fundamental parameters of the model, and which are consistent with the other results of the paper. We provide such an example in Appendices A1 and A2[25]. For the sake of expositional clarity, we prefer this more general presentation.

One can claim that the optimal transfer t^* is equal to zero when the countries are symmetric, i.e. $\alpha = \delta = 1$. In this case, it is natural to obtain the equality of the optimal standards in the agreement on differentiated standards without transfers and the agreement on uniform standards with transfers $\bar{a}^* = a_1^* = a_2^*$, which leads to the equivalence of the total welfare levels under these two agreements.

The first condition of Definition 1 implies that the optimal uniform standard is the average of the two particular differentiated standards. The second condition gives us $a_1 > \bar{a}^*$ by the monotonicity of the convex cost function.

We introduce the following principal condition:

$$\textbf{Condition C2: } \delta(1+\lambda)\left[C(\bar{a}^*) - C(a_2)\right] > \left[C(a_1) - C(\bar{a}^*)\right]$$

Proposition 1 provides the sufficient conditions for the superiority, in terms of total welfare, of the agreement on differentiated standards without transfers over the agreement on uniform standards with transfers.

[25] We did numerical simulations with a quadratic model and checked that Condition C1 is not empty.

Proposition 1 *If Conditions C1 and C2 hold, then the agreement on differentiated standards without transfers outperforms, in terms of total welfare, the agreement on uniform standards with transfers.*

The central condition of this proposition, the Condition **C2**, signifies that the cost of transfers, measured by λ, must be sufficiently low. Intuitively, countries collectively prefer an agreement on differentiated standards without transfers, rather than the agreement on uniform standards with transfers, when the cost of transfers is sufficiently high compared to the extra cost for country 1 to adopt a differentiated standard $(C(a_1) - C(\bar{a}^*))$. This extra cost must be compared with the cost reduction of country 2 associated with the adoption of a differentiated standard $\delta \left[C(\bar{a}^*) - C(a_2) \right]$.

We now provide the conditions under which the agreement on uniform standards with transfers dominates, in terms of total welfare, the agreement on differentiated standards without transfers. For doing this, we select specific values of the variables $\bar{a}$ and t, for which the value of the social welfare function $\bar{V}(\bar{a}, t)$ is superior to the maximum value attainable by the social welfare function in the agreement on differentiated standards without transfers $V^*(a_1^*, a_2^*)$. Then, we can conclude that, under these conditions, the maximum value attainable by the social welfare function in the agreement on uniform standards with transfers is greater than that attained in the agreement on differentiated standards without transfers. These conditions are symmetric to those presented in the preceding paragraph.

We select particular values of the variables $\bar{a}$ and t.

Definition 2 *Let a_1^* and a_2^* be the optimal levels of differentiated standards in the agreement on differentiated standards without transfers. We define $\bar{a}$ and t such that :*

1) $\bar{a} = \frac{a_1^* + a_2^*}{2}$

2) $C(\bar{a}) + (1 + \lambda)t = C(a_1^*)$

We assume that $a_1^* > a_2^*$ (**Condition C3**). Such a condition is verified for an example presented in Appendix A4[26]. Again for the sake of expositional clarity, we prefer this more general presentation.

[26] We did numerical simulations with a quadratic model and checked that Condition C3 is not empty.

We introduce the following principal condition:

$$\textbf{Condition C4}: \delta(1+\lambda)\left[C(\bar{a}) - C(a_2^*)\right] < \left[C(a_1^*) - C(\bar{a})\right]$$

Proposition 2 provides the sufficient conditions for the superiority, in terms of total welfare, of the agreement on uniform standards with transfers over the agreement on differentiated standards without transfers.

Proposition 2 *If Conditions C3 and C4 hold, then the agreement on uniform standards with transfers outperforms, in terms of total welfare, the agreement on differentiated standards without transfers.*

The central condition of this proposition, Condition **C4**, signifies that the cost of transfers, measured by λ, must be sufficiently low compared to the relative abatement costs of the countries in the agreement on differentiated standards without transfers, measured relatively to abatement costs of the countries in the agreement on uniform standards with transfers. This proposition, which is the reverse of Proposition 1, indicates that countries collectively prefer an agreement on uniform standards with transfers, rather than the agreement on differentiated standards without transfers, when the cost of transfers is sufficiently low.

We now focus on the case of a *linear abatement cost function* in order to simplify the interpretation of Conditions **C2 and C4** on the superiority of the social welfare functions between the two agreements. Concerning **Condition C2**, the linearity of the cost function allows the equality of the terms $\left[C(\bar{a}^*) - C(a_2)\right]$ and $\left[C(a_1) - C(\bar{a}^*)\right]$, because $\bar{a}^*$ is, by construction, the average of a_1 and a_2. Similarly, for **Condition C4**, we obtain the equality of the terms $\left[C(\bar{a}) - C(a_2^*)\right]$ and $\left[C(a_1^*) - C(\bar{a})\right]$, because $\bar{a}$ the average of a_1^* and a_2^*. We obtain consequently the following result.

Principal Proposition 1 *If the abatement cost function is linear, the agreement on differentiated standards without transfers outperforms, in terms of total welfare, the agreement on uniform standards with transfers if*

$$\delta(1+\lambda) > 1$$

whereas the agreement on uniform standards with transfers outperforms, in terms of total welfare, the agreement on differentiated standards without *transfers if*

$$\delta(1+\lambda) < 1$$

First of all, we notice that the welfare comparison in terms of total welfare, for the linear cost function case does not depend on the bargaining powers of the countries γ, because the countries lay out the same bargaining powers in both negotiations. It should be recalled that the parameter α must be inferior 1 to ensure the positivity of transfer payments (see footnote 18). The dependence of the result on the parameter α and on the benefit function B is taken into account in **Conditions C1** and **C3**.

The first condition of the proposition, $\delta(1+\lambda) > 1$, implies that,

- if the countries have the same abatement costs ($\delta = 1$) and transfers are imperfect ($\lambda \neq 0$), then agreement D dominates, in terms of total welfare, agreement UT. This is related to the imperfection of transfers in the uniform agreement.

- if country 2 has higher abatement costs than country 1 ($\delta > 1$) and transfers are perfect ($\lambda = 0$), then agreement D dominates, in terms of total welfare, agreement UT. This result means that even perfect transfers are not able to compensate in terms of welfare for the differential of the abatement costs between the two countries.

- if country 2 has higher abatement costs than country 1 ($\delta > 1$) and transfers are imperfect ($\lambda \neq 0$), then agreement D dominates, in terms of total welfare, agreement UT. The imperfection of the transfers in this case reinforces the preceding result.

Our findings show that the total welfare comparison between the agreement on uniform standards with transfers and the agreement on differentiated standards without transfers reduces, in the case of a linear cost function, to the following mechanism. It consists of the comparison between the loss associated with the monetary transfer (administrative cost and/or political cost) and the relative marginal abatement costs of both countries in the differentiated agreement. If the cost of the transfer from country 1 to country 2, evaluated in terms of the marginal abatement cost (constant, here) of country 2, is inferior to the marginal abatement cost of country 1, then it is in the interest of the two countries to sign an agreement on uniform standards including a side payment scheme, and which reduces the overall costs.

We now turn to the analysis of individual welfare levels of the countries associated with the agreements on uniform standards with transfers and differentiated standards without transfers. In order to conduct this analysis, we first use the concept of the Pareto frontier under the assumption of a linear cost function. We then use the first-order conditions of the two programs under the assumption of a non-linear cost function.

4 Pareto Ranking of the Individual Welfare Levels

When the countries sign an agreement, they implicitly agree on the social welfare function which takes the form of the Nash bargaining function. This program leads to better outcomes than those of the Nash equilibrium obtained in a non-cooperative game. Nevertheless, for a country, the benefit obtained in a special agreement could be greater than that in the other agreement. We are interested in the situations where both countries are better-off signing an agreement: what are the conditions under which both countries win? Conversely, we conclude this section by focusing on the situations where there are conflicts of interest across the countries on the form of the agreement: what are the conditions under which one country benefits more by signing one agreement rather than the other agreement. This could explain why some countries have some reluctance to sign a particular agreement, even though both countries are better-off than in the non-cooperative equilibrium.

More specifically, we are interested in checking the conditions under which both countries can improve their gains when the uniform agreement with transfers is signed. When the cost function is linear, we show that the already highlighted condition $(1+\lambda)\delta < 1$ plays an important role. The interpretation is direct in the case of positive transfers from country 1 to country 2. If it is less expensive, in terms of cost of transfers, to give incentives to country 2 to abate at a lower cost (δ is strictly less than 1), then the two countries have an interest in signing the agreement on uniform standards with transfers. This is true when country 2 has relatively low benefits from global abatement (α small enough) and has a weak initial endowment (for example its total labor force Ω_2 is small). We shall adapt this condition in a more general setup when the cost function is non-linear. The economic interpretation is similar to that in the linear case.

We proceed in three steps. At **stage 1**, we determine the analytical form of the Pareto frontiers in both agreements, UT and D, when the cost function is linear. We show that both frontiers are linear and identical, when $(1+\lambda)\delta = 1$. At **stage 2**, we study the Pareto ranking of these two agreements in the neighborhood of $(1+\lambda)\delta = 1$, when $(1+\lambda)\delta \lesseqgtr 1$. **Stage 3** consists of a generalization of the result when the cost function is non-linear. The last step is achieved using the first order conditions of the programs of maximization, and not using the Pareto frontier concept.

As we have already mentioned (footnote 19), we consider the case of strictly positive transfers from country 1 to country 2. As we shall see, this assumption restricts the parameters α and Ω_2 to be small enough.

We now compare the efficiency, in terms of individual welfare, of agreements UT and D in the case of a linear cost function, when the benefit function is concave and the cost function is linear (Stages 1 and 2).

Stage 1: Quasi-linear Case

Our objective is to construct the Pareto frontiers in the agreements UT and D, and to compare them afterwards (see Appendix B1). The linear function used for the cost function is the following:

$$C(\bar{a}) = c\bar{a}$$

$$\delta C(\bar{a}) = \delta c\bar{a}$$

where $c > 0$ and $\delta > 0$.

Using these functional forms, the Pareto frontiers respectively in the agreement on uniform standard with transfers and the agreement on differentiated standards without transfers take the following forms respectively:

$$\bar{NB_1}^* = -(1+\lambda)\bar{NB_2} + [1+(1+\lambda)\alpha]\, B\left\{B'^{-1}\left[\frac{[1+(1+\lambda)\delta]\, c}{2\,[1+(1+\lambda)\alpha]}\right]\right\} + \Omega_1 \tag{16}$$

$$+ (1+\lambda)\Omega_2 - [1+(1+\lambda)\delta]\,\frac{c}{2}B'^{-1}\left[\frac{[1+(1+\lambda)\delta]\, c}{2\,[1+(1+\lambda)\alpha]}\right]$$

$$NB_1^* = -\frac{1}{\delta}N\bar{B}_2 + \left[1 + \frac{\alpha}{\delta}\right] B \left\{B'^{-1}(\frac{\delta c}{\delta + \alpha})\right\} + \Omega_1 + \frac{1}{\delta}\Omega_2 - cB'^{-1}(\frac{\delta c}{\delta + \alpha}) \quad (17)$$

These Pareto frontiers define the utility of country 1, NB_1, as a linear function of the utility of country 2, NB_2. This is due to the quasi-linear assumption. Concerning the UT agreement, we notice that the Pareto frontier is linear with a slope $-(1+\lambda)$. Since the utility function is transferable, this result is intuitive. In fact, the transfer allows to "transfer" one unit of utility to country 2 by sacrificing $(1+\lambda)$ units of utility of country 1. Less intuitively, the Pareto frontier in the D agreement is linear as well. That comes from the linearity of the cost function which confers a property of transferability on the function of indirect utility (which takes into account the resource constraint). This means that it is possible to "transfer" one unit of utility to country 2 by sacrificing $\frac{1}{\delta}$ units of utility of country 1, via abatement costs. In fact, since abatement costs are linear, the ratio $\frac{dNB_1}{dNB_2}$ is constant along the Pareto frontier. This property is in fact general (see Mas-Colell et al. (1995), chapter 22, section 22-B, pages 818-819).

Proposition 3 *If $(1+\lambda)\delta = 1$, then the Pareto frontiers in the agreement on uniform standards with transfers and the agreement on differentiated standards without transfers are identical.*

In particular, we obtain the equivalence of the Pareto frontiers in the two agreements UT and D, when the countries have the same abatement costs ($\delta = 1$) and the transfers are perfect ($\lambda = 0$), even if the abatement benefits from global abatement are different ($\alpha < 1$). That does not mean that this last condition does not have any importance. This condition allows positive transfers, so then the Pareto frontier in the agreement on uniform standards with transfers is linear. This last property makes possible the comparison of the two Pareto frontiers.

Stage 2

This stage is organized in the following way. Firstly, we provide the sufficient conditions for the superiority of the utility levels obtained in agreement UT over those in agreement D. These conditions simply imply that the Pareto frontier in the first case is above the one in the second case (Proposition 4 and Corollary 4). This is why we must compare the slope and the Y-ordinate of the Pareto frontiers. This explains Definition 3. Secondly, we provide simple conditions for which it is possible to compare the two Pareto frontiers. In fact we know, thanks to Proposition 3, that the two Pareto frontiers coincide when $(1+\lambda) = \delta$. At the neighborhood of this equality, when $(1+\lambda)$ is inferior to δ, the Pareto frontier in agreement UT is "higher" than that in agreement D. This is for two reasons. On the one hand, the Y-ordinate of the Pareto frontier in agreement UT is a decreasing function of $(1+\lambda)$ (Lemma 2). On the other hand, the absolute value of the slope of this frontier $(1+\lambda)$ decreases (Definition 3). This result is not surprising. The two curves of the Pareto frontiers coincide for $(1+\lambda)$ =δ. If the cost of transfers λ reduces below this equality, the set of possible utilities in agreement UT increases. Principal proposition 2 collects the obtained results and allows us to conclude.

We now write the levels of utility of the two countries NB_1 and NB_2 in the agreements: UT and D. To achieve this, we first define new variables.

Definition 3 *We denote by (p) the absolute value of the (negative) slope and by Y the Y-ordinate of the Pareto frontier in the plan (NB_2, NB_1).*

If one refers to the construction of the Pareto frontier in the agreement on uniform standards with transfers, we have:

$$p^U = (1+\lambda)$$

$$\begin{aligned} Y^U = {} & B\left\{B'^{-1}\left[\frac{[1+(1+\lambda)\delta]\,c}{2\,[1+(1+\lambda)\alpha]}\right]\right\}(1+(1+\lambda)\alpha)+\Omega_1+(1+\lambda)\Omega_2 \\ & -(1+(1+\lambda)\delta)\frac{c}{2}B'^{-1}\left[\frac{[1+(1+\lambda)\delta]\,c}{2\,[1+(1+\lambda)\alpha]}\right] \end{aligned}$$

Similarly, in the agreement on differentiated standards without transfers, we have:

$$p^D = \frac{1}{\delta}$$

$$Y^D = B\left\{B'^{-1}(\frac{\delta c}{\delta+\alpha})\right\}(1+\frac{\alpha}{\delta})+\Omega_1+\frac{1}{\delta}\Omega_2 - cB'^{-1}(\frac{\delta c}{\delta+\alpha})$$

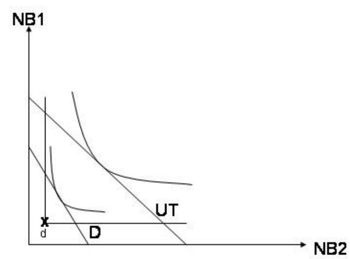

Figure 1: Pareto frontier of the agreement on uniform standards with transfers (UT) and the agreement on differentiated standards without transfers (D)

We represent the Nash bargaining solutions corresponding to the agreement on uniform standards with transfers (UT) and the agreement on differentiated standards without transfers (D) in Figure 1[27]. The x-axis represents the utility of country 2, NB_2, and the y-axis the utility of country 1, NB_1. The point d illustrates the threat point of the negotiations, which is identical for the two types of cooperation (UT and D). The Nash solution corresponds to the maximization of the social welfare function (Nash criteria) with respect to the Pareto frontier, given the bargaining powers of countries 1 and 2.

Proposition 4 *The difference between the levels of utility for each country resulting from agreement UT, denoted NB^U, and agreement D, denoted NB^D, is respectively for country 1 and country 2:*

$$NB_1^U - NB_1^D = \gamma(Y^U - Y^D) - \gamma \overset{\wedge}{NB}_2(p^U - p^D)$$

$$NB_2^U - NB_2^D = (1-\gamma)[\tfrac{1}{p^U}(Y^U - \overset{\wedge}{NB}_1) - \tfrac{1}{p^D}(Y^D - \overset{\wedge}{NB}_1)]$$

where $\overset{\wedge}{NB}_1$ and $\overset{\wedge}{NB}_2$ are the levels of utility of each country at the Nash

[27] The position of the curves applies to the case $(1+\lambda) < \frac{1}{\delta}$.

equilibrium.

One then can easily deduce the following corollary:

Corollary 1 *If Y^U is greater than Y^D (resp. Y^U is less than Y^D) and p^U is lower than p^D (resp. p^U is greater than p^D), then the agreement on uniform standards with transfers dominates, in the Pareto sense, the agreement on differentiated standards without transfers: $NB_1^U - NB_1^D > 0$ and $NB_2^U - NB_2^D > 0$ (resp. the agreement on differentiated standards without transfers dominates, in the Pareto sense, the agreement on uniform standards with transfers).*

We now search for the conditions under which the two countries are better-off in the uniform agreement rather than in the differentiated one. In order to achieve this, we need to exhibit the conditions under which Y^U is greater than Y^D. This will make possible the comparison of the utility levels between the two agreements for a given country.

We show in the following Lemma 2 that, if the parameters are such that the transfers in the uniform agreement are strictly positive, Y^U is a decreasing function of $(1 + \lambda)$ in the neighborhood of $(1 + \lambda) = \frac{1}{\delta}$ (Corollary 2 in Appendix B4). This implies that the uniform agreement Pareto-dominates the differentiated one, if the cost of transfers $1 + \lambda$ is less than the inverse of the marginal cost of country 2, $\frac{1}{\delta}$ because in that case $Y^U > Y^D$ and $p^U = (1 + \lambda) < \frac{1}{\delta} = p^D$. Conversely, this also implies that the differentiated agreement Pareto-dominates the uniform one, if $1 + \lambda$ is greater than $\frac{1}{\delta}$. Before exhibiting the conditions under which the function Y^U is decreasing in $(1 + \lambda)$, we need to find the conditions allowing the positivity of transfers in the UT agreement. We shall see further that these last conditions on the values of the parameters are sufficient to obtain the negative partial derivative of Y^U with respect to $1 + \lambda$[28].

Lemma 2 *If the transfer is strictly positive, then the function Y^U is decreasing in $(1 + \lambda)$ in the neighborhood of $(1 + \lambda) = \frac{1}{\delta}$.*

Proof. By construction of the Pareto frontier in the agreement UT (see Appendix B1), $\overline{a}$ is a value for which $(1 + (1 + \lambda)\alpha)B(2\overline{a}) + \Omega_1 + (1 + \lambda)\Omega_2 -$

[28] See Appendix B4 for the conditions related to the positivity of transfers in the UT agreement.

$(1+(1+\lambda)\delta)c\overline{a}$ is maximum. This expression is simply Y^U. Using the envelop theorem, the derivative of Y^U with respect to $(1+\lambda)$, in the neighborhood of $1+\lambda = \frac{1}{\delta}$, is equal to $\alpha B(2\overline{a}) + \Omega_2 - \delta c\overline{a}$ which is negative if the transfer is positive (Proposition 5 and Corollary 2 in Appendix B4). ■

We now state the principal proposition associated with the analysis of the individual welfare of the countries. This proposition sums up the results obtained so far and allows us to conclude on the superiority, in the Pareto sense, in certain cases, of the agreement UT over the agreement D.

Principal Proposition 2 *Given a linear cost function and sufficiently small values of* Ω_2 *and* α*, in the neighborhood of* $(1+\lambda)\delta = 1$*, the agreement on uniform standards with transfers Pareto-dominates the agreement on differentiated standards without transfers, if and only if:*

$$(1+\lambda) < \frac{1}{\delta}$$

Proof. Corollary 2 and Lemma 2 together imply that for a linear cost function and for sufficiently small values of Ω_2 and α, Y^U is a decreasing function of $(1+\lambda)$ in the neighborhood of $(1+\lambda) = \frac{1}{\delta}$. So if $(1+\lambda) < \frac{1}{\delta}$, Y^U is greater than Y^D and $p^U = 1+\lambda$ is less than $p^D = \frac{1}{\delta}$. Corollary 1 gives the result: if Y^U is greater than Y^D and p^U is less than p^D, i.e. $(1+\lambda)\delta < 1$, then the agreement on uniform standards with transfers Pareto-dominates the agreement on differentiated standards without transfers. ■

Hence, using a linear cost function, it can be shown that both countries prefer the agreement on uniform standards with transfers to the agreement on differentiated standards without transfers when the condition within the Principal proposition 2 is verified ($(1+\lambda) < \frac{1}{\delta}$). This condition can only be satisfied if the asymmetry parameter on the abatement costs δ is lower than 1, no matter whether the transfers are perfect ($\lambda = 0$) or imperfect ($\lambda \neq 0$). It is clear that for a given value of the parameter $\delta < 1$, this condition can be more easily satisfied if the degree of the imperfection of transfers is low. This is an expected result and it is related to the imperfection of transfers in the uniform agreement. Correspondingly, for a given level of the imperfection of transfers $\lambda \geq 0$, this condition can be more easily verified if the abatement costs of the countries are very asymmetric ($\delta << 1$). Since the parameter α

is assumed to be low (for the positivity of transfers), this last property leads to the presence of asymmetric countries.

This set of assumptions and properties leads to a situation where country 2 has low benefits from global abatement, but has lower abatement costs than country 1. The intuition for the result is the following. Country 2 has no incentives to abate, given its low benefits from global abatement (α is small). But even with a loss of transfers, it is better for both countries that country 1 gives a transfer to country 2 to compensate for its low abatement costs ($\delta < 1$). Country 1 takes advantage of the low abatement cost of country 2, to abate less. Country 2 takes advantage of the receipt of the transfers even if it must abate more.

Moreover, for a given value of the asymmetry parameter on abatement costs δ ($\delta >< 1$), the preferred agreement by both countries would be the differentiated agreement without transfers, if the loss in side payments λ is high. Finally, we notice that the welfare comparison, in the Pareto sense, for the quasi-linear case does not depend on the bargaining powers of countries γ and $(1-\gamma)$. In the case $(1+\lambda) < \frac{1}{\delta}$, for instance, the Pareto frontier of the agreement on uniform standards with transfers is located on the right-hand side of the Pareto frontier for the agreement on differentiated standards without transfers. This results in higher levels of utility for each country in the UT agreement compared to the D agreement, whatever the respective bargaining powers of the countries.

We now skip to the third stage of our analysis which corresponds to the generalization of the result to the non-linear case.

Stage 3: General Case

We consider here a more general case in which we authorize the cost function to be non-linear. It is important to note that we only give a sufficient condition for the efficiency comparison, in the Pareto sense, which is directly linked to that of the quasi-linear case. Unfortunately we could not use the concept of Pareto frontier, which is now non-linear and thus difficult to handle analytically. We establish a result using **Conditions** (**C3**) and (**C4**) and thus assuming the existence of the optimal levels of differentiated standards a_1^* and a_2^*, and of the optimal levels of the uniform standard $\bar{a}^*$ and the transfer t^*.

The most important point which will be highlighted is that the condition of the quasi-linear case $(1+\lambda)\delta < 1$ is now replaced by the condition $(1+\lambda)\delta\dfrac{C'(a_2^*)}{C'(a_1^*)} < 1$, where $C'(a_1^*)$ and $C'(a_2^*)$ are respectively the marginal abatement costs of countries 1 and 2 associated with the optimal levels of differentiated standards. The interpretation is exactly the same as that of the quasi-linear case. If it is less expensive, in terms of cost of transfers, to give incentives to country 2 to abate at a lower cost (δ is strictly less than 1), then the two countries have an interest in signing the agreement on uniform standards with transfers.

Thanks to Proposition 2**,** in the section related to the analysis of total welfare, one knows that the social welfare at the optimum in the agreement on uniform standards with transfers $\overline{V}^*$ is greater than that in the agreement on differentiated standards without transfers V^*, if the condition $\delta(1+\lambda)\left[C(\bar{a}) - C(a_2^*)\right] < \left[C(a_1^*) - C(\bar{a})\right]$ (**Condition C4**) is verified, and if a_1^* is superior to a_2^* (**Condition C3**). This condition implies the relation $(1+\lambda)\delta\dfrac{C'(a_2)}{C'(a_1)} < 1$ if a_1^* is superior to a_2^*, because increasing marginal abatement costs lead to $\frac{\left[C(a_1^*)-C(\bar{a})\right]}{a_1^*-\bar{a}} < C'(a_1^*)$ and $\frac{\left[C(\bar{a})-C(a_2^*)\right]}{\bar{a}-a_2^*} > C'(a_2^*)$.

We now give the proposition in the general case[29].

Proposition 6 *If conditions (C3) and (C4) are verified, then* NB_2^U *is greater than* NB_2^D*. Furthermore, if* $\frac{NB_2^D - \hat{NB}_2}{NB_2^U - \hat{NB}_2}$ *is less than* $(1+\lambda)\delta\dfrac{C'(a_2^*)}{C'(a_1^*)}$*, then* NB_1^U *is greater than* NB_1^D*. Consequently, the agreement on uniform standards with transfers Pareto-dominates the agreement on differentiated standards without transfers.*

This proposition implies that country 2 prefers the agreement on uniform standards with transfers to the agreement on differentiated standards without transfers under specific conditions. In addition, the difference between the two agreements, in terms of the utility levels for this country, must be sufficiently high. This condition is needed to allow a Pareto improvement for country 1 from the D agreement rather than the UT agreement. This means that, from the change of the agreement on differentiated standards without

[29]See Appendix B5 for the proof of Proposition 6.

transfers to the agreement on uniform standards with transfers, the size of the cake (or the total welfare) must increase significantly such that country 1 also obtains gains from cooperation.

We make two observations about this result:

- the first observation is related to the reluctance of a country to sign a specific agreement, even if it is better-off than by not cooperating at all. In fact, one knows that country 2 has systematic gains from cooperation by the signature of the UT agreement when **Condition C4**, $\delta(1+\lambda)\left[C(\bar{a})-C(a_2^*)\right]<\left[C(a_1^*)-C(\bar{a})\right]$, is satisfied. Country 1, however, cannot gain from this cooperation, which could induce it not to sign the UT agreement. In the case of a linear cost function, one knows that country 1 is always gaining, but nothing guarantees that it is gaining for every type of cost function.

- the second observation is related to the share of the total surplus by the two countries. In fact, according to the first-order conditions of the two programs, given by the equations 48 and 49, we have:

$$(\mathrm{D}) : \gamma U_2 \frac{C'(a_1)}{\delta C'(a_2)} = (1-\gamma) U_1$$

$$(\mathrm{UT}) : \gamma \bar{U}_2 (1+\lambda) = \bar{U}_1 (1-\gamma)$$

where $U_1 = NB_1^D - \overset{\wedge}{NB}_1$ and $U_2 = NB_2^D - \overset{\wedge}{NB}_2$ represent the gains from cooperation by countries 1 and 2 in the agreement "D", and $\bar{U}_1 = NB_1^{UT} - \overset{\wedge}{NB}_1$ and $\bar{U}_2 = NB_2^{UT} - \overset{\wedge}{NB}_2$ those in the agreement "UT".

This signifies that if $(1+\lambda) < \dfrac{C'(a_1)}{\delta C'(a_2)}$, the share of the gains from cooperation of country 1 diminishes in the transition from a negotiation on agreement "D" to agreement "UT" (which is the case in the linear framework), even if the gain from cooperation of country 1 in agreement "UT" is greater than that in agreement "D".

The objective of this paper was to present a new argument for explaining the frequent use of IEAs with uniform standards. This argument is the existence of compensatory transfer payments across countries, which are used, in reality, in a certain number of IEAs. It is important to emphasize that our result, on the optimality of the uniformization of standards, rather than their differentiation, is not based on an assumption of asymmetric information, as in the case of the models of Heyes (2003), or Harstad (2006) with the delay in negotiations. Harstad (2006) shows that the uniformization of standards, in the absence of side payments, is preferred to their differentiation when the degree of heterogeneity across the countries is low[30]. Our result, on the optimality of uniform standards with transfers, holds for asymmetric countries. This result is not based on the existence of an additional variable of negotiation, other than monetary transfers, which is likely to slacken the constraint of uniformity of standards. For instance, Copeland and Taylor (2005) show that the uniformity of standards can be optimal in the presence of international trade.

5 Conclusion

This paper deals with the efficiency comparison of the agreements on uniform versus differentiated standards to control a transboundary pollution problem between two countries. One of the most recommended rules in IEAs in the presence of such a pollution problem is the imposition of a uniform emission reduction rate for all countries. At first sight, intuition would recommend, however, the use of differentiated emission reduction rates specified for each country. These differentiated rules would respect the different characteristics of the countries. Only identical countries should then sign agreements with uniform standards. We construct a model which contradicts this intuition. To understand the frequent use of uniform rules in IEAs, we use a negotiation game and the Nash bargaining solution as the equilibrium concept, with the assumption of imperfect monetary transfers between countries.

Our findings show, in a quasi-linear framework, that an agreement on uniform standards with transfers can be better, in terms of total and individual welfare, than an agreement on differentiated standards without transfers under a certain condition. The condition is that the cost of transfers, evaluated in terms of the marginal abatement cost of the "*less environmen-*

[30] Harstad's result (2006) also relies on other conditions: an important effect of externalities and a low value of the agreement.

tally conscious country"[31], is less than the marginal abatement cost of the "*environmentally conscious country*". A similar result is obtained, in terms of individual welfare, in the case of a non-linear cost function. This result requires, however, an additional assumption on the gains from cooperation by the countries. The explanation of these overall results comes from the existence of, possibly imperfect, monetary transfers across the countries. Weakly imperfect transfers contribute to compensate for the additional abatement cost of the "*less environmentally conscious country*", because its level of abatement is higher in the agreement on uniform standards with transfers. These findings are obtained for heterogeneous countries. This shows that the uniform standard is not limited to identical countries. This paper thus shows the possible efficiency of the agreements on uniform standards, in the absence of any informational problems across countries and in the absence of any additional variables of negotiation, other than transfers.

The analysis has been limited in scope. First, we have compared two particular quota agreements, namely the agreements on uniform versus differentiated standards. We have not considered the efficiency of agreements on uniform or differentiated taxes, or agreements on trade sanctions. We have assumed that the negotiation process between the countries is efficient. Several inefficiencies, such as a delay in the negotiation process because of a stochastic character on the size of the cake to share, could qualify our results. Another inefficiency could come from the existence of asymmetric information across the countries on their abatement costs or their willingness to pay for a better global environmental quality. Complete information is an essential prerequisite in order to determine the Nash bargaining solution. So informational problems across the countries should be analyzed in a different context.

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APPENDIX

A- Total Welfare (NOT TO BE PUBLISHED)

The goal of Appendix A is to exhibit simple examples which fulfill Conditions C1 and C3.

A1- Positivity of transfers in the agreement UT: quasi-linear case with $\alpha \simeq 0$, $\delta < 1$, $\gamma = 1/2$ (**Condition C1**)

When the benefits from global abatement of country 2 are low ($\alpha \simeq 0$) and the abatement costs of country 2 are lower than that of country $1's$ ($\delta < 1$), the transfers from country 1 to country 2 are positive.

For the agreement on uniform standards with transfers from country 1 to country 2, the Nash bargaining problem with equal bargaining powers ($\gamma = 1/2$) can be expressed as follows:

$$Max_{\bar{a},t} \left[B(2\bar{a}) + \Omega_1 - c\bar{a} - (1+\lambda)t - N\hat{B}_1 \right] \times \left[\alpha B(2\bar{a}) + \Omega_2 - \delta c\bar{a} + t - N\hat{B}_2 \right]$$

The first-order condition with respect to transfer (t) is:

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow -(1+\lambda) \left[\alpha B(2\bar{a}) + \Omega_2 - \delta c\bar{a} + t - N\hat{B}_2 \right] +$$
$$\left[B(2\bar{a}) + \Omega_1 - c\bar{a} - (1+\lambda)t - N\hat{B}_1 \right] = 0$$

$$\Longleftrightarrow 2(1+\lambda)t = B(2\bar{a})(1 - (1+\lambda)\alpha) - (1+\lambda)\Omega_2 + \Omega_1 + c\bar{a}((1+\lambda)\delta - 1)$$
$$+ ((1+\lambda)N\hat{B}_2 - N\hat{B}_1)$$

Concerning the term $((1+\lambda)N\hat{B}_2 - N\hat{B}_1)$, we use the expressions defined in the equation 47:

$$N\hat{B}_1 = B(B'^{-1}(c)) + \Omega_1 - cB'^{-1}(c)$$
$$N\hat{B}_2 = \alpha B(B'^{-1}(c)) + \Omega_2$$

That gives us:

$$
\begin{aligned}
((1+\lambda)N\hat{B}_2 - N\hat{B}_1) = {} & (1+\lambda)(\alpha B(B'^{-1}(c)) + \Omega_2) \\
& - B(B'^{-1}(c)) - \Omega_1 + cB'^{-1}(c) \\
& \Longleftrightarrow (1+\lambda)\Omega_2 - \Omega_1 + (1+\lambda)\alpha B(B'^{-1}(c) \\
& - B(B'^{-1}(c)) + cB'^{-1}(c)
\end{aligned}
$$

We make the following simplifying assumption:

$$\alpha \simeq 0$$

Then, the level of transfers becomes:

$$2(1+\lambda)t \simeq B(2\bar{a}) - c\bar{a}(1-(1+\lambda)\delta) - B(B'^{-1}(c)) + cB'^{-1}(c)$$

The expression $\left[B(2\bar{a}) - c\bar{a}(1-(1+\lambda)\delta)\right]$ is superior or equal to $(NB_1 - \Omega_1)$ because $B(2\bar{a}) - c\bar{a}(1-(1+\lambda)\delta) \geq B(2\bar{a}) - c\bar{a} - (1+\lambda)t$. Furthermore, the expression $[-B(B'^{-1}(c)) + cB'^{-1}(c)]$ is equal to $(-N\hat{B}_1 + \Omega_1)$. We thus have,

$$
\begin{aligned}
2(1+\lambda)t & \simeq B(2\bar{a}) - c\bar{a}(1-(1+\lambda)\delta) - B(B'^{-1}(c)) + cB'^{-1}(c) \\
& \geq NB_1 - N\hat{B}_1
\end{aligned}
$$

When country 1 signs an agreement on uniform standards with transfers, its utility is greater than that at the threat point, hence the transfers from country 1 to country 2 are positive.

A2- The conditions $a_1 \leq 1$ and $a_2 \geq 0$ (**Condition C1**)

In order to have $a_1 \leq 1$ and $a_2 \geq 0$, it is sufficient, for instance, that in the quasi-linear case, $\alpha \simeq 0$, $(1+\lambda)\delta \simeq 1$ ($(1+\lambda)\delta$ could be less or greater than 1, in the neighborhood of 1), c be sufficiently large and the function $B'^{-1}(.)$ be sufficiently small.

In the quasi-linear case, the second condition of Definition 1 gives us:

$$C(a_1) = C(\bar{a}^*) + (1+\lambda)t^* \Longleftrightarrow ca_1 = c\bar{a}^* + (1+\lambda)t^*$$
$$\Longleftrightarrow a_1 = \bar{a}^* + \frac{(1+\lambda)t^*}{c}$$

We search for a differentiated standard a_1 which is inferior or equal to 1. Similarly, in the quasi-linear case, the first condition of Definition 1 gives:

$$a_2 = 2\bar{a}^* - a_1 \Longleftrightarrow a_2 = 2\bar{a}^* - \bar{a}^* - \frac{(1+\lambda)t^*}{c}$$
$$\Longleftrightarrow a_2 = \bar{a}^* - \frac{(1+\lambda)t^*}{c}$$

We search for a differentiated standard a_2 which is superior or equal to 0.

One knows, from proof A1, that the first-order conditions related to the Nash bargaining solution with equal bargaining powers ($\gamma = 1/2$) in the agreement on uniform standards with transfers imply:

$$(2B^{'}(2\bar{a}) - c)\left[\alpha B(2\bar{a}) + \Omega_2 - \delta c\bar{a} + t - N\hat{B}_2\right] +$$
$$(2\alpha B^{'}(2\bar{a}) - \delta c)(1+\lambda)\left[\alpha B(2\bar{a}) + \Omega_2 - \delta c\bar{a} + t - N\hat{B}_2\right]$$
$$= 0$$

$$\Longleftrightarrow (2B^{'}(2\bar{a}) - c) + (2\alpha B^{'}(2\bar{a}) - \delta c)(1+\lambda) = 0$$

$$\Longleftrightarrow B^{'}(2\bar{a}) = \frac{c(1+\delta(1+\lambda))}{2(1+\alpha(1+\lambda))}$$

We make the following assumptions: $\delta(1+\lambda) \simeq 1$ and $\alpha \simeq 0$. Under these assumptions, the expression of the marginal benefit becomes $B^{'}(2\bar{a}) \simeq c$. This implies the optimal level of the uniform standard $\bar{a} \simeq \frac{1}{2}B^{'^{-1}}(c)$, which is positive.

The preceding proof also provides the expression of the transfers when $\alpha \simeq 0$:

$$2(1+\lambda)t \simeq B(2\bar{a}) - c\bar{a}(1-(1+\lambda)\delta) - B(B'^{-1}(c)) + cB'^{-1}(c)$$

If we use the assumption $\delta(1+\lambda) \simeq 1$ and introduce the expression of the optimal uniform standard, we obtain:

$$(1+\lambda)t \simeq \frac{1}{2}cB'^{-1}(c)$$

Let us now come back to the study of the levels of differentiated standards a_1 and a_2.

$$a_1 = \bar{a}^* + \frac{(1+\lambda)t^*}{c} \Longleftrightarrow a_1 = \frac{1}{2}B'^{-1}(c) + \frac{1}{2}B'^{-1}(c)$$
$$\Longleftrightarrow a_1 = B'^{-1}(c)$$

$$a_2 = \bar{a}^* - \frac{(1+\lambda)t^*}{c} \Longleftrightarrow a_2 = \frac{1}{2}B'^{-1}(c) - \frac{1}{2}B'^{-1}(c)$$
$$\Longleftrightarrow a_2 = 0$$

A3- Total welfare analysis: proof of Proposition 1

Proof. The maximum value attainable by the social welfare function in the agreement on uniform standards with transfers is:

$$\bar{V}^* = \left[B(2\bar{a}^*) - C(\bar{a}^*) - (1+\lambda)t^* - N\hat{B}_1\right]^\gamma \times \left[\alpha B(2\bar{a}^*) - \delta C(\bar{a}^*) + t^* - N\hat{B}_2\right]^{1-\gamma} \quad (18)$$

This function, if α is strictly positive, can be written in the following way:

$$\frac{\bar{V}^*}{\alpha^{1-\gamma}} = \left[B(2\bar{a}^*) - C(\bar{a}^*) - (1+\lambda)t^* - N\hat{B}_1\right]^\gamma \times \left[B(2\bar{a}^*) - \frac{\delta}{\alpha}C(\bar{a}^*) + \frac{t^*}{\alpha} - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma} \quad (19)$$

Now, we write the social welfare function with particular values of the differentiated standards:

$$\frac{V(a_1, a_2)}{\alpha^{1-\gamma}} = \left[B(a_1 + a_2) - C(a_1) - N\hat{B}_1\right]^{\gamma} \times \left[B(a_1 + a_2) - \frac{\delta}{\alpha}C(a_2) - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma} \tag{20}$$

We notice that the first terms in brackets in equations 19 and 20 are the same because of Definition 1. Hence, the condition of superiority of the differentiated social welfare function over the uniform one becomes:

$$\left[B(a_1 + a_2) - \frac{\delta}{\alpha}C(a_2) - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma} > \left[B(2\bar{a}^*) - \frac{\delta}{\alpha}C(\bar{a}^*) + \frac{t^*}{\alpha} - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma} \tag{21}$$

$$\iff [-\delta C(a_2)] > \left[-\delta C(\bar{a}^*) + t^*\right] \tag{22}$$

because $B(a_1 + a_2) = B(2\bar{a}^*)$ by Definition 1, α and $(1 - \gamma)$ are positive. From Definition 1, we have $t^* = \frac{C(a_1)-C(\bar{a}^*)}{1+\lambda}$. Introducing this expression of transfers into equation 22, we obtain:

$$[-\delta C(a_2)] > \left[-\delta C(\bar{a}^*) + \frac{C(a_1) - C(\bar{a}^*)}{1 + \lambda}\right] \tag{23}$$

$$\iff \delta(1 + \lambda)\left[C(\bar{a}^*) - C(a_2)\right] > \left[C(a_1) - C(\bar{a}^*)\right] \tag{24}$$

From **Condition C1** and the first condition of Definition 1, we have $a_2 < \bar{a}^* < a_1$. This implies the positivity of the terms in brackets in **Condition 2**, say $\left[C(\bar{a}^*) - C(a_2)\right] > 0$ and $\left[C(a_1) - C(\bar{a}^*)\right] > 0$. ■

A4- Superiority of a_1^* over a_2^* (**Condition C3**)

Our objective here is to show that $a_1^* > a_2^*$, when the countries have the same bargaining powers $\gamma = 1/2$, and a linear cost function $C(a) = ca$, where c is a positive parameter.

The first-order conditions in the agreement on differentiated standards without transfers, when $\gamma = 1/2$, are the following:

$$\frac{\partial V}{\partial a_1} = 0 \Longleftrightarrow \frac{\left[B'(a_1 + a_2) - c\right]}{\left[B(a_1 + a_2) + \Omega_1 - ca_1 - \hat{N}B_1\right]} + \frac{\left[\alpha B'(a_1 + a_2)\right]}{\left[\alpha B(a_1 + a_2) + \Omega_2 - \delta ca_2 - \hat{N}B_2\right]} = 0$$

$$\frac{\partial V}{\partial a_2} = 0 \Longleftrightarrow \frac{\left[B'(a_1 + a_2)\right]}{\left[B(a_1 + a_2) + \Omega_1 - ca_1 - \hat{N}B_1\right]} = \frac{\left[\alpha B'(a_1 + a_2) - \delta c\right]}{\left[\alpha B(a_1 + a_2) + \Omega_2 - \delta ca_2 - \hat{N}B_2\right]} = 0$$

The ratio of these first-order conditions gives us (assuming that one does not divide by 0):

$$\frac{B'(a_1 + a_2) - c}{B'(a_1 + a_2)} = \frac{\alpha B'(a_1 + a_2)}{\alpha B'(a_1 + a_2) - \delta c} \qquad (25)$$

$$\Longleftrightarrow B'(a_1 + a_2) = \frac{\delta c}{\delta + \alpha} \Longleftrightarrow a_1 + a_2 = B'^{-1}(\frac{\delta c}{\delta + \alpha})$$

If we replace $B'(a_1 + a_2) = \frac{\delta c}{\delta + \alpha}$ in equation 25, we obtain the following relation:

$$U_2 = \delta U_1$$

where $U_1 = \left[B(a_1 + a_2) + \Omega_1 - ca_1 - \hat{N}B_1\right]$ and $U_2 = \left[\alpha B(a_1 + a_2) + \Omega_2 - \delta ca_2 - \hat{N}B_2\right]$.

We thus have:

$$\begin{aligned} U_2 &= \delta U_1 \Longleftrightarrow \left[\alpha B(a_1 + a_2) + \Omega_2 - \delta ca_2 - \hat{N}B_2\right] = \\ & \delta\left[B(a_1 + a_2) + \Omega_1 - ca_1 - \hat{N}B_1\right] \end{aligned}$$

$$(\delta - \alpha)B(a_1 + a_2) + \hat{N}B_2 - \delta\hat{N}B_1 = \delta c(a_1 - a_2)$$

We wonder whether the term $(\delta-\alpha)B(a_1+a_2)+\hat{N}B_2-\delta\hat{N}B_1$ is positive. We replace the expressions of the utility levels at the threat point $\hat{N}B_1$ and $\hat{N}B_2$ that have been calculated above, and we obtain:

$$(\delta - \alpha)\left[B(B^{'-1}(\frac{\delta c}{\delta + \alpha})) - B(B'^{-1}(c))\right] + \delta cB'^{-1}(c) = \delta c(a_1 - a_2)$$

We have $B^{'-1}(\frac{\delta c}{\delta+\alpha}) > B'^{-1}(c)$ because $\frac{\delta c}{\delta+\alpha} < c$ and $B^{'-1}(.)$ is a decreasing function.

We can then conclude that $a_1^* > a_2^*$ if $\delta > \alpha$.

A5- Total welfare analysis: proof of Proposition 2

Proof. The condition of superiority of the social welfare function in the agreement on uniform standards with transfers over the one in the agreement on differentiated standards without transfers $V^*(a_1^*, a_2^*)$ is:

$$\frac{\bar{V}(\bar{a}, t)}{\alpha^{1-\gamma}} = \left[B(2\bar{a}) - C(\bar{a}) - (1+\lambda)t - N\hat{B}_1\right]^{\gamma} \times \tag{26}$$

$$\left[B(2\bar{a}) - \frac{\delta}{\alpha}C(\bar{a}) + \frac{t}{\alpha} - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma} >$$

$$\frac{V^*(a_1^*, a_2^*)}{\alpha^{1-\gamma}} = \left[B(a_1^* + a_2^*) - C(a_1^*) - N\hat{B}_1\right]^{\gamma} \times$$

$$\left[B(a_1^* + a_2^*) - \frac{\delta}{\alpha}C(a_2^*) - \frac{N\hat{B}_2}{\alpha}\right]^{1-\gamma}$$

We notice that the first terms in brackets of equation 26 are the same because of Definition 2. Hence, the condition of superiority of the uniform social welfare function over the differentiated one becomes:

$$\left[-\delta C(\bar{a}) + t\right] > \left[-\delta C(a_2^*)\right] \tag{27}$$

Given Definition 2, we have $t = \frac{C(a_1^*) - C(\bar{a})}{(1+\lambda)}$. By introducing this expression of the transfer in equation 27, we obtain the result. **Condition C3** and the first condition of Definition 2 imply the positivity of the terms in brackets in **Condition C4**, i.e. $\left[C(\bar{a}) - C(a_2^*)\right] > 0$ and $\left[C(a_1^*) - C(\bar{a})\right] > 0$. ■

B- Individual Welfare

B1- Construction of the Pareto frontiers

The Pareto frontier in agreement UT

The Pareto optimality results from the following program:

$$\max_{\bar{a}} \ NB_1 = \max_{\bar{a}} \left[B(2\bar{a}) + c_1\right] \tag{28}$$

$$\begin{cases} \Omega = c_1 + (1+\lambda)c_2 + C(\bar{a}) + (1+\lambda)\delta C(\bar{a}) \\ NB_2 = \alpha B(2\bar{a}) + c_2 \geq N\bar{B}_2 \end{cases}$$

where the first constraint is constructed from the two resource constraints, $\Omega_1 = c_1 + (1+\lambda)t + C(\bar{a})$ and $\Omega_2 = c_2 - t + \delta C(\bar{a})$, $\Omega = \Omega_1 + (1+\lambda)\Omega_2$.

If we introduce the two constraints into the utility function of country 1, we get:

$$\max_{\bar{a}} \; NB_1 = \max_{\bar{a}} \left[B(2\bar{a}) + \Omega - (1+\lambda)(\bar{NB}_2 - \alpha B(2\bar{a})) - C(\bar{a}) - (1+\lambda)\delta C(\bar{a}) \right] \tag{29}$$

that can be rewritten as follows:

$$\Longleftrightarrow \max_{\bar{a}} \; NB_1 = \max_{\bar{a}} \left[B(2\bar{a}) \left[1 + (1+\lambda)\alpha\right] + \Omega - (1+\lambda)\bar{NB}_2 - C(\bar{a}) - (1+\lambda)\delta C(\bar{a}) \right] \tag{30}$$

The first-order condition with respect to $\bar{a}$ gives us:

$$2\left[1 + (1+\lambda)\alpha\right] B^{'}(2\bar{a}) = \left[1 + (1+\lambda)\delta\right] C^{'}(\bar{a}) \tag{31}$$

This equation defines the optimal level of the uniform standard $\bar{a}^*$, which, in turn, will determine the Pareto frontier:

$$NB_1 = -(1+\lambda)\bar{NB}_2 + B(2\bar{a}^*) \left[1 + (1+\lambda)\alpha\right] + \Omega_1 + (1+\lambda)\Omega_2 - \left[1 + (1+\lambda)\delta\right] C(\bar{a}^*) \tag{32}$$

In order to determine the optimal level of the uniform standard $\bar{a}^*$, we use a linear abatement cost function of the form:

$$C(\bar{a}) = c\bar{a}$$
$$\delta C(\bar{a}) = \delta c\bar{a}$$

where $c > 0$ and $\delta > 0$.

Given this functional form of the abatement cost function, condition 31 becomes:

$$2\left[1+(1+\lambda)\alpha\right]B^{'}(2\bar{a}) = \left[1+(1+\lambda)\delta\right]c \tag{33}$$
$$\Longleftrightarrow B^{'}(2\bar{a}) = \frac{\left[1+(1+\lambda)\delta\right]c}{2\left[1+(1+\lambda)\alpha\right]}$$
$$\Longleftrightarrow \bar{a}^{*} = \frac{1}{2}B^{'-1}\left[\frac{\left[1+(1+\lambda)\delta\right]c}{2\left[1+(1+\lambda)\alpha\right]}\right]$$

The Pareto frontier can be rewritten using this optimal value of the uniform standard:

$$\bar{NB_1}^{*} = -(1+\lambda)\bar{NB_2} + \left[1+(1+\lambda)\alpha\right]B\left\{B^{'-1}\left[\frac{\left[1+(1+\lambda)\delta\right]c}{2\left[1+(1+\lambda)\alpha\right]}\right]\right\} + \Omega_1 \tag{34}$$
$$+(1+\lambda)\Omega_2 - \left[1+(1+\lambda)\delta\right]\frac{c}{2}B^{'-1}\left[\frac{\left[1+(1+\lambda)\delta\right]c}{2\left[1+(1+\lambda)\alpha\right]}\right]$$

The Pareto frontier in agreement D
The Pareto optimality results from the following program:

$$\max_{a_1,a_2} NB_1 = B(a_1+a_2) + c_1 \tag{35}$$
$$w.r.\ \begin{cases} \Omega_1 = c_1 + C(a_1) \\ \Omega_2 = c_2 + \delta C(a_2) \\ NB_2 = \alpha B(a_1+a_2) + c_2 \geq \bar{NB_2} \end{cases}$$

If we introduce the constraints, we get:

$$\max_{a_1,a_2} NB_1 = B(a_1+a_2) + \Omega_1 - C(a_1) \tag{36}$$
$$\alpha B(a_1+a_2) + \Omega_2 - \delta C(a_2) \geq \bar{NB_2}$$

One can write the Lagrangian of this program of maximization using the linear cost function:

$$L = [B(a_1 + a_2) + \Omega_1 - ca_1] + \rho \left[\alpha B(a_1 + a_2) + \Omega_2 - \delta c a_2 - N\bar{B}_2 \right] \quad (37)$$

where ρ represents the Lagrangian multiplier associated with the constraint. The first-order conditions are:

$$\frac{\partial L}{\partial a_1} = 0 \Longleftrightarrow B^{'}(a_1 + a_2) - c + \rho\alpha B^{'}(a_1 + a_2) = 0 \quad (38)$$
$$\frac{\partial L}{\partial a_2} = 0 \Longleftrightarrow B^{'}(a_1 + a_2) + \rho \left[\alpha B^{'}(a_1 + a_2) - \delta c \right] = 0$$

The ratio of these first-order conditions gives us (assuming that one does not divide by 0):

$$B^{'}(a_1 + a_2) = \frac{\delta c}{\delta + \alpha} \quad (39)$$
$$\Longleftrightarrow (a_1 + a_2) = B^{'-1}(\frac{\delta c}{\delta + \alpha})$$

The use of the two last constraints of the initial program of maximization leads to:

$$\alpha B \left\{ B^{'-1}(\frac{\delta c}{\delta + \alpha}) \right\} + \Omega_2 - \delta c a_2 = N\bar{B}_2 \quad (40)$$

which implies, with equation 39, the levels of differentiated standards:

$$\Longleftrightarrow a_2 = \frac{1}{\delta c} \left[\alpha B \left\{ B^{'-1}(\frac{\delta c}{\delta + \alpha}) \right\} + \Omega_2 - N\bar{B}_2 \right] \quad (41)$$
$$a_1 = B^{'-1}(\frac{\delta c}{\delta + \alpha}) - \frac{1}{\delta c} \left[\alpha B \left\{ B^{'-1}(\frac{\delta c}{\delta + \alpha}) \right\} + \Omega_2 - N\bar{B}_2 \right]$$

The Pareto frontier in the agreement on differentiated standards without transfers then becomes:

$$NB_1^* = -\frac{1}{\delta} N\bar{B}_2 + \left[1 + \frac{\alpha}{\delta} \right] B \left\{ B^{'-1}(\frac{\delta c}{\delta + \alpha}) \right\} + \Omega_1 + \frac{1}{\delta}\Omega_2 - cB^{'-1}(\frac{\delta c}{\delta + \alpha}) \quad (42)$$

B2- Utility levels of the countries: proof of Proposition 4

Proof. The Nash bargaining solution, when countries 1 and 2 have respectively the bargaining powers γ and $(1-\gamma)$, corresponds to the solution of the following program:

$$\underset{NB_1,NB_2}{\text{Max}}\left[\gamma\ln(NB_1-\overset{\wedge}{NB_1})+(1-\gamma)\ln(NB_2-\overset{\wedge}{NB_2})\right] \quad (43)$$
$$NB_1=-pNB_2+Y$$

If we take into account the constraint (the Pareto frontier) in the social welfare function, equation 43 becomes:

$$\underset{NB_1}{\text{Max}}\left[\gamma\ln(NB_1-\overset{\wedge}{NB_1})+(1-\gamma)\ln(\frac{Y-NB_1}{p}-\overset{\wedge}{NB_2})\right] \quad (44)$$

The first-order condition of this program with respect to NB_1 is:

$$\frac{\gamma}{NB_1-\overset{\wedge}{NB_1}}=\frac{(1-\gamma)}{p}\frac{1}{NB_2-\overset{\wedge}{NB_2}} \quad (45)$$

The constraint of the program and equation 45 help to define the levels of utility of the two countries:

$$NB_1=\gamma Y+(1-\gamma)\overset{\wedge}{NB_1}-\gamma p\overset{\wedge}{NB_2} \quad (46)$$
$$NB_2=\gamma\overset{\wedge}{NB_2}+\frac{(1-\gamma)}{p}(Y-\overset{\wedge}{NB_1})$$

By substituting p by p^U and p^D, and Y by Y^U and Y^D of Definition 3, we obtain the welfare levels of the countries in agreements UT and D.

Below, we provide the calculus of the welfare levels of the countries at the threat point in the quasi-linear case:

$$\overset{\wedge}{NB_1}=B(B'^{-1}(c))+\Omega_1-cB'^{-1}(c) \quad (47)$$
$$\overset{\wedge}{NB_2}=\alpha B(B'^{-1}(c))+\Omega_2$$

■

B3- Threat point: quasi-linear case

The utility functions of the countries, associated with a linear cost function, are written in the following way:

$$NB_1 = B(a_1 + a_2) + \Omega_1 - ca_1$$
$$NB_2 = \alpha B(a_1 + a_2) + \Omega_2 - \delta ca_2$$

The first-order conditions are:

$$B'(a_1 + a_2) = c$$
$$B'(a_1 + a_2) = \frac{\delta c}{\alpha}$$

If ($\frac{\delta}{\alpha} > 1$), then the marginal benefit of country 2, $B'(a_1 + a_2)$ is higher than that of country 1. This, in turn implies, by the concavity of the benefit function, that the optimal level of the total abatement $(a_1 + a_2)$ for country 2 is lower than that of country 1. We then conclude that the Nash equilibrium abatement level of country 2 is zero $\hat{a}_2 = 0$, and the one for country 1 is defined by $\hat{a}_1 = B'^{-1}(c)$. These abatement levels lead to the payoffs at the threat point for countries 1 and 2 respectively:

$$N\hat{B}_1 = B(B'^{-1}(c)) + \Omega_1 - cB'^{-1}(c)$$
$$N\hat{B}_2 = \alpha B(B'^{-1}(c)) + \Omega_2$$

B4- Positivity of the transfers

Proposition 5 *Let $\overline{a}$ be the value of the uniform standard for which $Y^U = (1 + (1 + \lambda)\alpha)B(2\overline{a}) + \Omega_1 + (1 + \lambda)\Omega_2 - (1 + (1 + \lambda)\delta)c\overline{a}$ is maximal*

if $\alpha B(2\overline{a}) + \Omega_2 - \delta c\overline{a} < 0$, then the possible transfers are strictly positive all along the points of the Pareto frontier.

Proof. This maximization corresponds to the construction of the Pareto frontier in the agreement on uniform standards with transfers. It means that all along this frontier $\overline{a}$ is constant. Moreover, from the budget constraint of country 1 we have $(1+\lambda)t = \Omega_1 - c_1 - c\overline{a} = \Omega_1 + B(2\overline{a}) - NB_1 - c\overline{a}$. To have $t > 0$, we need $NB_1 < \Omega_1 + B(2\overline{a}) - c\overline{a}$. So if $Y^U < \Omega_1 + B(2\overline{a}) - c\overline{a}$, the transfers are positive all along the frontier because Y^U is the maximum of utility NB_1 attainable by country 1 ($NB_1 = Y^U$ when $NB_2 = 0$). The last inequality is equivalent to $\alpha B(2\overline{a}) + \Omega_2 - \delta c\overline{a} < 0$. ■

Corollary 2 *As* $\overline{a} = \frac{1}{2}B'^{-1}(\frac{(1+(1+\lambda)\delta)c}{2(1+(1+\lambda)\alpha)})$ *and* $B(2\overline{a})$ *are upper bounded, sufficiently small values of* Ω_2 *and* α *are sufficient to have a strictly positive transfer.*

This result (coming from the construction of the Pareto frontier in the agreement UT) simply says that a relatively poor country with a weak incentive to abate, will receive a positive transfer from country 1, if they decide to negotiate an agreement on uniform standards with transfer.

B5- Proof of Proposition 6

Proof. We use the first-order conditions of the programs associated with the agreements UT and D. This consists of the use of equation 8 in the program of agreement UT and equations 12 and 13 in the program of agreement D. We obtain:

$$\text{(UT) } \gamma(1+\lambda)(NB_2^U - \hat{NB}_2) = (1-\gamma)(NB_1^U - \hat{NB}_1) \quad (48)$$

$$\text{(D) } \gamma C'(a_1^*)(NB_2^D - \hat{NB}_2) = (1-\gamma)\delta C'(a_2^*)(NB_1^D - \hat{NB}_1) \quad (49)$$

Proposition 2 implies that $\overline{V}^*$ is greater than V^* under **Conditions C3** and **C4**. So we have $\overline{V}^* = (\frac{\gamma(1+\lambda)}{(1-\gamma)})^\gamma(NB_2^U - \hat{NB}_2) > (\frac{\gamma C'(a_1^*)}{(1-\gamma)\delta C'(a_2^*)})^\gamma(NB_2^D - \hat{NB}_2) = V^*$. As $(1+\lambda)\delta\dfrac{C'(a_2^*)}{C'(a_1^*)} < 1$, NB_2^U is greater than NB_2^D. Moreover $(NB_1^U - \hat{NB}_1) > (NB_1^D - \hat{NB}_1)$ if and only if $\dfrac{\gamma(1+\lambda)}{(1-\gamma)}(NB_2^U - \hat{NB}_2) > \dfrac{\gamma C'(a_1^*)}{(1-\gamma)\delta C'(a_2^*)}(NB_2^D - \hat{NB}_2)$. ■