Comparison of Uniform versus Differentiated Standards: a transboundary pollution problem

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Abstract

This paper analyses a transboundary pollution problem between two countries, and studies the efficiency comparison of uniform versus differentiated abatement standards for controlling this problem. To achieve this goal, we use a negotiation game with the use of the Nash bargaining solution as the solution concept. We introduce the possibility of imperfect transfers between countries when solving for the Nash bargaining solution. We compare in terms of efficiency and abatement levels, uniform versus differentiated standards with or without the possibility of transfers. Our findings indicate that the differentiated standard case is always welfare-improving compared to the uniform one, even in the presence of imperfect transfers.

1 Introduction

This paper deals with the efficiency comparison of uniform and differentiated pollution abatement standards in the presence of a transboundary pollution problem.

There is a frequent use of uniform standards in international environmental agreements (IEAs). The arguments in favor of this use can be found in several papers.

"In reality, potential signatories to an international environmental agreement frequently negotiate on a uniform emission reduction quota, which implies that countries have to reduce emissions by the same percentage compared to some

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base year. The list of examples of uniform emission reduction quotas is long and includes the *Montreal Protocol* on Substances that Deplete the Ozone Layer, which specified an emission reduction of CFCs and halons by 20 percent based on 1986 emission levels to be accomplished by 1998. Another example is the *Helsinki Protocol*, which suggested a reduction of sulfur dioxide from 1980 levels by 30 percent by 1993. Moreover, the *Sofia Protocol* Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes signed in 1988 called on countries to uniformly freeze their emissions at 1987 levels by 1995 and the *Geneva Protocol* Concerning the Control of Emissions of Volatile Organic Compounds or Their Fluxes signed in 1991 required parties to reduce 1988 emissions by 30 percent by 1999." (Finus, (2001)).

"If quotas are without any doubt an inefficient instrument, why they are nonetheless an element of so many negotiations on international pollution control in reality? One can think of several reasons for this phenomenon: First, uniform solutions are perceived to be fair by the signatory countries. Moreover, negotiating complex and differentiated solutions is associated with high transactions costs and manifold informational problems. In addition, when several agreements are possible (in the presence of multiple equilibria), simple rules such as uniform quotas may serve as a "focal point" during negotiations in the sense of Schelling (1960)" (Schmidt, (2002)).

We especially concentrate on a *transboundary* pollution problem between two countries. This means that there exist negative spillovers of pollution between these countries. A country's emissions negatively affect the other country. In areas 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. The transboundary pollution problems can be well described by the *prisoners' dilemma* game in game theory. We can look for an example[1] which can well illustrate this situation:

X\Y	Abate	Pollute
Abate	$1, 1$	$-1, 2$
Pollute	$2, -1$	$0, 0$

"There are two countries, labeled X and Y. For this game, the set of feasible actions is binary; the countries can only choose between playing Abate or Pollute. Then, there are four feasible outcomes: (Abate, Pollute), (Abate, Abate), (Pollute, Abate), (Pollute, Pollute). The payoffs associated with these outcomes are in the table above. Though the outcome (Abate, Abate) is strictly preferred by both players to the Nash equilibrium (Pollute, Pollute), the outcomes (Abate, Pollute) and (Pollute, Abate) are also Pareto efficient. So the answer is not obvious. However, we can shrink the set of jointly preferred outcomes by allowing the countries that gain to compensate the losers. Here, the player required to play Abate will have a lower payoff than what he could guarentee for itself by

[1] The example and following explanations are taken from the book of Barrett (2003), chapters 3 and 13.

playing Pollute. In this case, *side payments*[2] would be needed to ensure that the outcome be acceptable to the two countries. Of course, the problem of sustaining this agreement would still remain. Side payments make the recipient countries more inclined to participate, but they lower the payoffs of the donor countries, so make them less inclined to participate. In fact, side payments can help to sustain cooperation only when the game is strongly asymmetric. Such "side payments" need not be monetary (in the Fur Seal case, seal skins were exchanged). Cash payments are often paid, however (even in the fur seal case, money was exchanged), and it will usually be convenient to assume that side payments are paid in money. The intent in offering side payments is often to increase participation. In the Fur Seal Treaty, side payments were needed to induce the pelagic nations to participate."

As we have already underlined, the uniform standards are most frequently used in IEA's. The efficiency criteria would recommend, however, the use of differentiated emission reduction quotas specified for each country. These differentiated rules would respect the different caracteristics of the countries (abatement and damage functions, preferences). Our purpose is to compare the abatement and welfare levels under a uniform versus differentiated emission reduction quotas when there is possibility of a transfer scheme between countries. Especially, we will study the effect of *imperfect transfers* on our results. Finus and Rundshagen (1998) note that the few IEAs which have a provision for transfers, are mostly very unspecific regarding transfer obligations. They claim that the actual transfers which have been conducted so far are negligible compared to (expected) abatement and damage costs. This could be one of the arguments justifying the existence of imperfect transfers. The second argument could be that it is costly to the donor countries to collect transfers and to deliver them to the recipient countries. If there were a supranational authority with the right to collect transfers, the donor country would be obliged to pay this institution.

To study this transboundary pollution problem, we suppose a negotiation game between two countries. The international negotiation is a one-stage game in which the governments holding regulatory powers *cooperatively* bargain over abatement levels. "Cooperation is motivated by the fact that without cooperation (because of spillovers), the outcome would be inefficient. In such a case, countries may wish to improve their payoffs through a process of bargaining which will lead, in turn, to a cooperative outcome. In particular, the bargaining outcome will be such that no country could be made better off (in terms of its payoff function) without reducing the payoff to the other country. This notion will be referred to as *bargaining efficiency.* We will then first characterize all bargaining-efficient outcomes of the problem. We also have to define the situation without bargaining because this plays the role of a *threat point* for the bargaining parties. [We assume that without bargaining, the countries behave independantly and simultaneously when they determine their level of abatement.

[2]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.

This is the Nash equilibrium of the game.] Knowing the bargaining-efficiency frontier and the threat point, the bargaining can be defined axiomatically; the *Nash* (1950) *bargaining solution* provides an example of such an axiomatic solution. More generally, the bargaining outcome will depend on the relative bargaining powers of countries" (Jéhiel., (1997)).

One of the papers in the litterature studying the comparison of the instruments to solve a global pollution problem is the model of Finus and Rundshagen (1998). They analyze the coalition formation process in a global emission game with asymmetric countries where the number of signatories, the abatement target and the policy instrument are chosen simultaneously. Two instruments, a uniform emission reduction quota and an effluent charge are considered. 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. Heyes and Simons (2003) examine also the comparative efficiency of two instruments uniform emission standards and firm-specific emission standards, in the presence of a domestic pollution problem, in a two-period model in which firms have private information about their access to low-cost abatement techniques. They show that if the power to tailor standards is not going to be used by the agency then those powers should be taken away, as they are always harmful. Even if the agency opts to use those powers, it may be welfare-improwing to remove them.

A number of papers in the litterature study the changes coming from the introduction of side payments in terms of participation constraints in a IEA and the environmental consequences. Barrett (2001) indicates that the existing strong asymmetry between countries changes the rules of the game of global public good provision and side payments become the vehicle for increasing participation in a cooperative agreement with no need to a commitment by signatories. Carraro and Siniscalco (1993) consider the possibility that signatories may commit to paying the non-signatories to cooperate. They show that side payments can help to increase participation unless the signatories can commit to remaining as signatories. Chen (1997) studies the outcome of a international negoatiation on combatting the global warming using a two-country noncooperative (Rubinstein (1982) model) bargaining model. It is shown that while side payments between countries will generally be part of an agreement, some of these payments are made purely as a result of asymmetry in bargaining power. Factors affecting the outcome of negotiation include a country's size of population, the welfare level at the disagreement point, and the order of making offers. Chang (1997) presents a model of signaling game that indicates that the side payments (or "carrots-only" regime) to induce the participation of the nonsignatory countries would encourage greater environmental harm under conditions of asymmetric information.

So, our purpose is to compare the efficiency of uniform versus differentiated abatement standards in the presence of a transboundary pollution problem between two countries. To do this, we use the Nash bargaining solution concept of the cooperative game theory incorporating the possibility of imperfect transfer scheme between countries.

The paper is organized as follows. Section 2 presents a simple framework with symmetric countries. We realize comparisons of abatement and welfare levels under the Nash equilibrium (threat point), the uniform abatement standard and differentiated abatement standard cases derived from the Nash bargaining solution. In Section 3, we do the same analysis for the asymmetric countries, which differ by their abatement benefit and cost fuctions. To do so, we describe the Nash bargaining solution for the uniform versus differentiated abatement standard cases either with the possibility of tranfers between the countries or without this possibility. We offer concluding remarks in section 4.

We will start our comparative study with the case of symmetric countries.

2 Symmetric Countries

We assume that there exists one polluting firm in each country. The total benefit function is $B(e_1 + e_2)$ or $B(E)$, where e_1 and e_2 are respectively, the level of abatement undertaken by the countries 1 and 2. So, the benefit from abatement for the country 1 depends also on the abatement level of the country 2 (positive spillovers). B is an increasing and concave function of the variable E, i.e. the total level of abatement. So, we have $B^{'}(E) \geq 0$ and $B^{''}(E) \leq 0$. The countries have the same benefit function since they are symmetric.

The abatement cost function is individual for each country. It is equal to $C_1 = co + C(e_1)$ for the country 1 and, $C_2 = co + C(e_2)$ for the country 2. So the total cost function is formed by a fixed cost co and a variable cost $C(e)$. For instance, in the case of a water pollution, a polluting firm in a country must install a special plant for the cleaning of its discharge. The installation of a such plant could represent a fixed cost for the firm. We assume that the cost is zero when there is no effort of abatement, i.e. $C = 0$ when $e = 0$. The varible cost function depends on the level of individual abatement and is assumed to be increasing and convex, i.e. $C'(e) \geq 0$ and $C''(e) \geq 0$.

So, the net benefit function can be expressed as $NB_1 = B(E) - C_1$ for the country 1 and $NB_2 = B(E) - C_2$ for the country 2.

Before passing to the resolution of the Nash Bargaining Solution, we will look briefly at the characteristics of this solution concept [3]. This approach is due to John Nash (1950).[4] This method illustrates the way of finding a solution to a problem when the characteristics of the solution are defined precisely. These characteristics are:

1) *Symmetry*: we can expect that the solution will not depend on the way the players are labeled.

2) *Pareto efficiency:* the solution ought to be in the negotiation set.

[3] The detailed explanations of the axiomatic approach can be found in Osborne and Rubinstein (1994).

[4] The following explanations are taken from the book of Rapoport (1999), chapter 8.

3) *Invariance to equivalent utility representations*: we can expect that the solution is not affected by a linear transformation of the payoffs.

4) *Independence from irrelevant alternatives*: suppose the payoff polygon is enlarged so that now additional payoff pairs become available, while the status quo point remains unchanged. Then these additional pairs should either contain the solution of the game or else they must not affect the solution of the old game.

The problem now is to find a point in the negotiation set which satisfies these four criteria. The only point which satisfies the above criteria is the point obtained by finding the maximum of the function $[X - x_0] \times [Y - y_0]$ where X, Y are respectively the payoffs of the players in the negotiation and x_0, y_0 are the payoffs of the players at the threat point.

In the next section, we will look at the the threat point for the bargaining parties , namely the Nash equilibrium of the game.

2.1 Threat Point: Nash Equilibrium

The country 1's program is to maximize the following function:

$$Max_{e_1} \left[B(E) - C(e_1) \right]$$

Similarly, the country 2's program is to maximize the following function:

$$Max_{e_2} \; \left[B(E) - C(e_2) \right]$$

Since the two countries are symmetric, we obtain the following first-order condition:

$$B^{'}(E) = C^{'}(\frac{E}{2})$$

where $e_1 = e_2 = \frac{E}{2}$.

The resolution of this equation will give us the value of the total abatement at the Nash equilibrium, i.e. $\hat{E}$. So we can calculate the welfare level for each of the countries:

$$\hat{N}B = B(\hat{E}) - co - C(\hat{E}/2)$$

In the next section, we will look at the case where both of the countries undertake the abatement effort. Since the countries are symmetric, they have the same negociation power. So, we can only concentrate on the simple Nash Bargaining solution (NBS) (without introducing the negociation powers of the countries).

2.2 A Case with Uniform Standards

The NBS is written in the following way when both of the countries realize abatement effort:

$$Max_{e_1,e_2}\left[(B(e_1+e_2)-co-C(e_1)-\overset{\wedge}{NB})\times(B(e_1+e_2)-co-C(e_2)-\overset{\wedge}{NB})\right]$$

If we note as V the above value function, the first-order condition with respect to e_1 is:

$$\begin{aligned}\frac{\partial V}{\partial e_1} &= 0 \Longleftrightarrow \left[B^{'}(e_1+e_2)-C'(e_1)\right]\times\left[B(e_1+e_2)-co-C(e_2)-\overset{\wedge}{NB}\right]= \\ &-\left[B(e_1+e_2)-co-C(e_1)-\overset{\wedge}{NB}\right]\times\left[B^{'}(e_1+e_2)\right]\end{aligned}$$

Similarly, the first-order condition with respect to e_2 is:

$$\begin{aligned}\frac{\partial V}{\partial e_2} &= 0 \Longleftrightarrow \left[B^{'}(e_1+e_2)\right]\times\left[B(e_1+e_2)-co-C(e_2)-\overset{\wedge}{NB}\right]= \\ &-\left[B(e_1+e_2)-co-C(e_1)-\overset{\wedge}{NB}\right]\times\left[B^{'}(e_1+e_2)-C'(e_2)\right]\end{aligned}$$

The symmetry assumption allows that both of the countries realize the same abatement level, i.e. $e_1=e_2=e$. This is why we call this situation the *uniform standard* case. Then, the first condition becomes:

$$\begin{aligned}&\left[B^{'}(2e)-C'(e)\right]\times\left[B(2e)-co-C(e)-\overset{\wedge}{NB}\right]= \\ &-\left[B(2e)-co-C(e)-\overset{\wedge}{NB}\right]\times\left[B^{'}(2e)\right]\end{aligned}$$

$$\Longleftrightarrow \left[B(2e)-co-C(e)-\overset{\wedge}{NB}\right]\times\left[B^{'}(2e)-C'(e)+B^{'}(2e)\right]=0$$

$$\Longleftrightarrow B'(E)=\frac{1}{2}\times C^{'}(\frac{E}{2})$$

where $E=2e$.

The resolution of this equation will give us the value of the total abatement under the uniform standard case, i.e. E_{NU}. Then we can calculate the welfare level for each of the countries:

$$NB_{NU}=B(E_{NU})-co-C(E_{NU}/2)$$

Now, we can look at the case where only one of the countries undertakes the abatement effort. The reason behind this behaviour could be very rational. The fact that only one of the countries undertakes abatement and pays for the fixed cost *co* prevents the other country to pay again for the fixed cost. So, the country 1 can do the abatement effort for both and the country 2 can pay a transfer to compensate the country 1.

2.3 A Case with Differentiated Standards

Here, we assume that only the country 1 abates and the country 2 pays for a *transfer* t to compensate the country 1 ($e_1 > 0, e_2 = 0$). This is why we call this situation the *differentiated standard* case. Furthermore, we assume that these transfers are *imperfect* in the sense that the country 2 pays more than t, i.e. $(1+\lambda)t$, and the country 1 receives only t. As we have already mentioned, the reason behind this assumption could be that it can be costly to the country 2 to collect transfers and to deliver them to the country 1.

The NBS is written in the following way:

$$Max_{e_1,t}\left[(B(e_1) - co - C(e_1) - \hat{N}B + t)^{\gamma} \times (B(e_1) - (1+\lambda)t - \hat{N}B)^{1-\gamma}\right]$$

where the parameters γ, $(1-\gamma)$ represent respectively, the negociation powers of the country 1 and the country 2. Since the countries are symmetric, this parameter will be equal to 0.5. We remark that now we have two choice variables, namely the abatement level e_1 and the transfer level t.

If we note as V the above value function, the first-order condition with respect to e_1 is:

$$\frac{\partial V}{\partial e_1} = 0 \Longleftrightarrow \frac{\gamma\,[B'(e_1) - C'(e_1)]}{(B(e_1) - co - C(e_1) - \hat{N}B + t)} = \frac{(\gamma - 1)\,[B'(e_1)]}{(B(e_1) - (1+\lambda)t - \hat{N}B)}$$

Similarly, the first-order condition with respect to t is:

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow \frac{\gamma}{(B(e_1) - co - C(e_1) - \hat{N}B + t)} = \frac{(\gamma - 1)\,[-(1+\lambda)]}{(B(e_1) - (1+\lambda)t - \hat{N}B)}$$

The ratio of these two first-order conditions is:

$$\frac{(\partial V/\partial e_1)}{(\partial V/\partial t)} \Longleftrightarrow [B'(e_1) - C'(e_1)] = \frac{B'(e_1)}{-(1+\lambda)}$$

$$\Longleftrightarrow B'(e_1) = \frac{1+\lambda}{2+\lambda} C'(e_1)$$

The resolution of this equation will give us the value of the total abatement under the differentiated standard case, i.e. $e_1 = E_{ND}$. So we can calculate the welfare level for each of the countries:

$$NB_{1ND} = B(E_{ND}) - co - C(E_{ND}) + t$$

$$NB_{2ND} = B(E_{ND}) - (1+\lambda)t$$

In order to calculate the value of the transfer t, we have to use the second of the first-order conditions, i.e. $\frac{\partial V}{\partial t} = 0$. This gives us:

$$\begin{aligned} t &= B(E_{ND}) \times (\frac{2\gamma + \gamma\lambda - 1 - \lambda}{1+\lambda}) - (\gamma - 1) \times co - (\gamma - 1) \times C(E_{ND}) \\ &\quad -(\frac{2\gamma + \gamma\lambda - 1 - \lambda}{1+\lambda}) \times \hat{NB} \end{aligned}$$

In the next section, we will look at the comparison of the abatement levels under different regimes.

2.4 Abatement Level Comparisons

To sum up, we can write the first-order conditions under the Nash equilibrium, the uniform standard and the differentiated standard cases:

∘ Nash equilibrium: $B^{'}(\hat{E}) = C^{'}(\frac{\hat{E}}{2})$.
∘ Uniform standards: $B'(E_{NU}) = \frac{1}{2} \times C^{'}(\frac{E_{NU}}{2})$.
∘ Differentiated standards, imperfect transfers, i.e. $\lambda > 0$: $B'(E_{NDI}) = \frac{1+\lambda}{2+\lambda} \times C'(E_{NDI})$.
∘ Differentiated standards, perfect transfers, i.e. $\lambda = 0$: $B'(E_{NDP}) = \frac{1}{2} \times C'(E_{NDP})$.

If we realize a graphical representation of the respective curves on marginal benefit and marginal cost functions (see the figure 1), we observe the following order of the emission reductions:

$$E_{NDI} < E_{NDP} < \hat{E} < E_{NU}$$

So the two countries, when they both realize abatement efforts (i.e. uniform standard case), they abate more together than the case in which only the country 1 abates and the country 2 compensates it for this effort (i.e. differentiated standard case). Furthermore, the total abatement level is higher in the uniform case than the one at the Nash equilibrium. Finally, the total emission reduction is lower in the differentiated case than the one at the Nash equilibrium. The fact that only one country abates in the differentiated case leads to a very low effort in terms of abatement (Note that the points A, B, C, D in the figure correspond

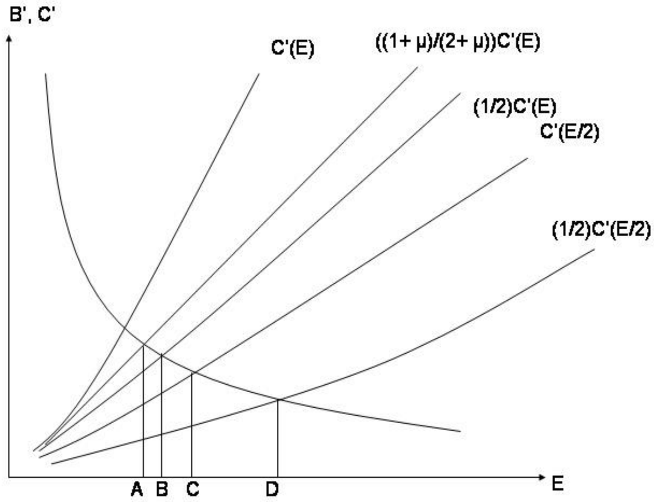

Figure 1:

respectively to the abatement levels E_{NDI}, E_{NDP}, $\hat{E}$, E_{NU} and the parameter μ corresponds to λ).

In the next section, we will look at the comparison of the welfare levels under different regimes.

2.5 Welfare Level Comparisons

The total net benefit functions (for both countries) under the Nash equibrium, the uniform standard and the differentiated standard cases are:

∘ Nash equilibrium: $T\hat{N}B = 2 \times \hat{N}B = 2 \times \left[B(\hat{E}) - co - C(\hat{E}/2) \right].$

∘ Uniform standards: $TNB_{NU} = 2 \times NB_{NU} = 2 \times [B(E_{NU}) - co - C(E_{NU}/2)]$.

∘ Differentiated standards: $TNB_{ND} = NB_{1ND} + NB_{2ND} = 2B(E_{ND}) - co - C(E_{ND}) - \lambda t$.

See the appendix (section 5.3) for a detailed discussion on the comparison of the welfare levels between different regimes. Here, we sum up the main results. Firstly, when we compare the welfare levels under the uniform standard case and the Nash equilibrium, we observe that a special condition on the slopes of benefit and cost functions must be validated to obtain the superiority of the uniform case on the Nash equlibrium. More interesting is the comparison of differentiated standards with the Nash equilibrium. We remark that the Nash equilibrium can outperform the differentiated standards, when the value of the fixed cost *co* is not so high, and this even when transfers are perfect ($\lambda = 0$). The high level of fixed costs *co* can, however, reverse this situation. Finally, we look at the comparison of the welfare levels between the differentiated versus uniform cases. Similarly, we note that the uniform standards can outperform the differentiated ones, when the value of the fixed cost is not so high, and this even when transfers are perfect. Again ,the high level of fixed costs *co* can reverse this situation.

We notice that in both the Fur Seal Treaty and the Montreal Protocol, the countries that offered the side payments were different from the countries that accepted them. In the fur seal case, the countries offering the side payment had their own breeding populations, and so could kill the seals on land - an option that was unavailable to the pelagic sealing nations. In the case of the Montreal Protocol, the countries offering the payment were rich and benefitted most from ozone layer protection; the countries accepting the payments were poor and benefitted less. So, we must take into account asymmetric countries.

3 Asymmetric Countries

The structure of the benefit and cost functions is as follows. The total benefit function of the country 1 is written as $B(e_1 + e_2)$ or $B(E)$ where $e_1 = \bar{E}_1 \times \beta_1$ and $e_2 = \bar{E}_2 \times \beta_2$ are respectively the abatement levels of the countries 1 and 2. Here, $\bar{E}_1$, $\bar{E}_2$ represent respectively, the level of emissions of the country 1 and the country 2 in a given year. The parameters β_1, β_2 are respectively, differentiated percentage emission reduction levels for the countries 1 and 2. B is an increasing and concave function of the variable $E = (\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)$, i.e. the total level of abatement. So we have $B^{'}(E) \geq 0$ and $B^{''}(E) \leq 0$.

The abatement cost function is written as $C_1 = C(e_1)$ for the country 1 and, $C_2 = C(e_2)$ for the country 2, where $e_1 = \bar{E}_1 \times \beta_1$ and $e_2 = \bar{E}_2 \times \beta_2$. The cost function is assumed to be increasing and convex, i.e. $C'(e) \geq 0$ and $C''(e) \geq 0$. We do not need to introduce fixed costs in the cost function in this case, because the countries are asymmetric regarding their benefit and cost functions.

To explain the existing asymmetry between the countries, we assume a simple structure:

Country 1: $B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)$ and $C_1 = C(\bar{E}_1 \times \beta_1)$

Country 2: $\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)$ and $C_2 = \delta C(\bar{E}_2 \times \beta_2)$

Then the parameters α and δ explain respectively, the differences on benefit and abatement cost functions between the countries.

The net benefit function can be expressed as $NB_1 = B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\bar{E}_1 \times \beta_1)$ for the country 1 and $NB_2 = \alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2)$ for the country 2.

We now pass to the the resolution of the Nash equilibrium, which is the threat point of the Nash Bargaining Solution.

3.1 Threat Point: Nash Equilibrium

The country 1's program is to maximize the following payoff function:

$$Max_{\beta 1} \left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\bar{E}_1 \times \beta_1) \right]$$

Now we remark that the choice variable of the countries is the percentage emission reduction level, β.

The first-order condition with respect to β_1 is:

$$\frac{\partial B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{\partial \beta_1} = \frac{\partial C(\bar{E}_1 \times \beta_1)}{\partial \beta_1}$$

$$\Longleftrightarrow B^{'}(E) = C^{'}(e_1)$$

where $E = \bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2$ and $e_1 = \bar{E}_1 \times \beta_1$.

Similarly, the country 2's program is to maximize the following payoff function:

$$Max_{\beta 2} \left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) \right]$$

The first-order condition with respect to β_2 is:

$$\frac{\partial \alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{\partial \beta_2} = \frac{\partial \delta C(\bar{E}_1 \times \beta_1)}{\partial \beta_2}$$

$$\Longleftrightarrow \alpha B^{'}(E) = \delta C^{'}(e_2)$$

where $e_2 = \bar{E}_2 \times \beta_2$.

The resolution of these equations will give us respectively, the abatement for the country 1, for the country 2 and the total abatement at the Nash equilibrium, i.e. $\hat{e}_1, \hat{e}_2, \hat{E}$. So we can calculate the welfare levels for each of the countries:

$$\hat{NB}_1 = B(\hat{E}) - C(\hat{e}_1)$$

$$\hat{NB}_2 = \alpha B(\hat{E}) - \delta C(\hat{e}_2)$$

Now, we will study the uniform abatement quota case, which represents the most frequent recommendation in a IEA. We will first consider the situation where there is no possibility of transfers between the countries.

3.2 A Case with Uniform Standards without Possibility of Transfers

The NBS is written in the following way:

$$Max_\beta \left[\begin{array}{c} (B(\beta(\bar{E}_1 + \bar{E}_2)) - C(\beta\bar{E}_1) - \hat{NB}_1)^\gamma \\ \times(\alpha B(\beta(\bar{E}_1 + \bar{E}_2)) - \delta C(\bar{E}_2 \times \beta) - \hat{NB}_2)^{1-\gamma} \end{array} \right]$$

Here, we relax one of the four criteria satisfied by the NBS, which is the symmetry axiom. Now, we allow countries to have different bargaining powers in the negotiation, namely γ for the country 1 and $(1 - \gamma)$ for the country 2. As γ increases, the utility of the country 1 increases and vice versa. This asymmetric NBS satisfies all other axioms required by the axiomatic theory but it does not result in a unique solution since the solution depends upon the pair of bargaining powers.

We remark also the following constraint, $\beta_1 = \beta_2 = \beta$. The countries must decrease their emission levels by the same percentage. The readers can consult the appendix (section 5.1.1) for the entire resolution of the NBS in the uniform standard case without transfers.

The resolution of this program will give us respectively, the abatement for the country 1, for the country 2 and the total abatement at the uniform quota case without transfers, i.e. $e_{1NUS}, e_{2NUS}, E_{NUS}$. So we can calculate the welfare level for each of the countries:

$$NB_{1NUS} = B(E_{NUS}) - C(e_{1NUS})$$

$$NB_{2NUS} = \alpha B(E_{NUS}) - \delta C(e_{2NUS})$$

Now, we will study the uniform abatement quota case, with a possibility of transfers between the countries. These transfers are assumed to be imperfect, however.

3.3 A case with Uniform Standards with Possibility of Transfers

The NBS is written in the following way:

$$Max_{\beta,t}\left[\begin{array}{c}(B(\beta(\bar{E}_1+\bar{E}_2))-C(\beta\bar{E}_1)-\hat{NB}_1-(1+\lambda)t)^{\gamma}\\ \times(\alpha B(\beta(\bar{E}_1+\bar{E}_2))-\delta C(\bar{E}_2\times\beta)-\hat{NB}_2+t)^{1-\gamma}\end{array}\right]$$

We remark that we dispose two choice variables, which are the levels of the uniform percentage emission reduction β and the transfer t[5]. The readers can consult the appendix (section 5.1.2) for the entire resolution of the NBS in the uniform standard case with transfers.

The resolution of this program will give us respectively, the abatement for the country 1, for the country 2 and the total abatement at the uniform quota case with transfers, i.e. $e_{1NUT}, e_{2NUT}, E_{NUT}$. So, the welfare levels for each of the countries are:

$$NB_{1NUT} = B(E_{NUT}) - C(e_{1NUT}) - (1+\lambda)t$$

$$NB_{2NUT} = \alpha B(E_{NUT}) - \delta C(e_{2NUT}) + t$$

We will study in the next section the differentiated abatement quota case without a possibility of transfers between the countries.

3.4 A Case with Differentiated Standards without Possibility of Transfers

The NBS is written in the following way:

$$Max_{\beta_1,\beta_2}\left[\begin{array}{c}(B(\bar{E}_1\times\beta_1+\bar{E}_2\times\beta_2)-C(\beta_1\bar{E}_1)-\hat{NB}_1)^{\gamma}\\ \times(\alpha B(\bar{E}_1\times\beta_1+\bar{E}_2\times\beta_2)-\delta C(\bar{E}_2\times\beta_2)-\hat{NB}_2)^{1-\gamma}\end{array}\right]$$

Now, we dispose two specific percentage abatement levels for each country β_1 and β_2. The readers can consult the appendix (section 5.1.3) for the entire resolution of the NBS in the uniform standard case without transfers.

The resolution of this program will give us respectively, the abatement for the country 1, for the country 2 and the total abatement at the differentiated quota case without transfers, i.e. $e_{1NDS}, e_{2NDS}, E_{NDS}$. So the welfare levels for each of the countries are:

$$NB_{1NDS} = B(E_{NDS}) - C(e_{1NDS})$$

$$NB_{2NDS} = \alpha B(E_{NDS}) - \delta C(e_{2NDS})$$

Now we will study the differentiated abatement quota case with imperfect transfers between the countries.

[5] Note that the ineffiency of the transfers from the country 2 to the country 1, when $\delta > 1$, is proved in the appendix (section 5.5).

3.5 A Case with Differentiated Standards with Possibility of Transfers

The NBS is written in the following way:

$$Max_{\beta_1,\beta_2,t}\left[\begin{array}{c}(B(\bar{E}_1\times\beta_1+\bar{E}_2\times\beta_2)-C(\beta_1\bar{E}_1)-\hat{N}B_1-(1+\lambda)t)^{\gamma}\\ \times(\alpha B(\bar{E}_1\times\beta_1+\bar{E}_2\times\beta_2)-\delta C(\bar{E}_2\times\beta_2)-\hat{N}B_2+t)^{1-\gamma}\end{array}\right]$$

We remark that this case represents the richest configuration for the choice of the variables: we dispose β_1, β_2 and t. The readers can consult the appendix (section 5.1.4) for the entire resolution of the NBS in the uniform standard case without transfers.

The resolution of this program will give us respectively, the abatement for the country 1, for the country 2 and the total abatement at the differentiated quota case with transfers, i.e. $e_{1NDT}, e_{2NDT}, E_{NDT}$. So the welfare levels for each of the countries are:

$$NB_{1NDT}=B(E_{NDT})-C(e_{1NDT})-(1+\lambda)t$$

$$NB_{2NDT}=\alpha B(E_{NDT})-\delta C(e_{2NDT})+t$$

In the next section, we will pass to the comparison of the abatement levels under different regimes.

3.6 Abatement Level Comparisons

3.6.1 Abatement Levels at the Nash Equilibrium

We first try to compare the Nash equilibrium abatement levels of the countries. The first-order conditions at the Nash equilibrium are:

$$\text{Country 1:} \qquad B^{'}(E)=C^{'}(e_1) \tag{1}$$

$$\text{Country 2:} \qquad B^{'}(E)=\frac{\delta}{\alpha}C^{'}(e_2) \tag{2}$$

where $E=\bar{E}_1\times\beta_1+\bar{E}_2\times\beta_2$ and $e_1=\bar{E}_1\times\beta_1$, $e_2=\bar{E}_2\times\beta_{2.}$

We assume that the values of the asymmetry parameters are as follows:

i) $0<\alpha<1$: it means that the country 2 supports less damages from the global pollution compared to the country 1. So the country 2 benefits less from the global abatement, E.

ii) $\delta>1$: it means that the country 2 has higher costs of emission abatement than the country 1.

In these conditions, the ratio $\frac{\delta}{\alpha}$ is superior to 1. If we compare the right-hand side (RHS) of the equations (1) and (2), $C^{'}(e_1)$ must be superior to $C^{'}(e_2)$ to keep constant the left-hand side (LHS) of the equations. So we remark that the level of abatement for the country 1, e_1, is higher than the country $2's$. This could mean that the percentage emission reduction rate for the country 1, β_1 is higher than the country $2's$, β_2 under some conditions. These conditions are that the initial emission levels in a given year, $\bar{E}_1$ and $\bar{E}_2$ must be either equal or $\bar{E}_1$must be inferior to $\bar{E}_2$. We could claim that these are the emission levels resulting from a repeated Nash equilibrium framework for the two countries. Since the country 2 has lower net benefits from abatement than the country 1, it seems reasonable to assume that the past emission levels of the country 2 are higher than those of the country 1,i.e. $\bar{E}_1 < \bar{E}_2$.

3.6.2 Abatement Levels at the Differentiated Standards

Here, we try to compare the abatement levels of the two countries under differentiated standards without transfers.

The first-order conditions are:

$$\begin{aligned} \text{Country 1} \quad \Longleftrightarrow \quad & B'(E) \times \begin{bmatrix} \alpha B - \gamma\delta C(e_2) + (\gamma-1)\alpha C(e_1) \\ -\gamma \hat{NB}_2 + (\gamma-1)\alpha \hat{NB}_1 \end{bmatrix} \\ = \quad & C'(e_1)\left[\gamma\alpha B - \gamma\delta C(e_2) - \gamma \hat{NB}_2\right] \end{aligned}$$

$$\begin{aligned} \text{Country 2} \quad \Longleftrightarrow \quad & B'(E) \times \begin{bmatrix} \alpha B - \gamma\delta C(e_2) + (\gamma-1)\alpha C(e_1) \\ -\gamma \hat{NB}_2 + (\gamma-1)\alpha \hat{NB}_1 \end{bmatrix} \\ = \quad & \delta C'(e_2)\left[-(\gamma-1)B + (\gamma-1)C(e_1) + (\gamma-1)\hat{NB}_1\right] \end{aligned}$$

where $E = \bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2$ and $e_1 = \bar{E}_1 \times \beta_1, e_2 = \bar{E}_2 \times \beta_{2.}$

If we assume that the negociation powers of the countries are equal, i.e. $\gamma = 0.5$, we obtain the following structure of the RHS's of these equations:

RHS (country 1) : $C'(e_1)\left[\frac{1}{2}\alpha B - \frac{1}{2}\delta C(e_2) - \frac{1}{2}\hat{NB}_2\right]$

RHS (country 2) : $\delta C'(e_2)\left[\frac{1}{2}B - \frac{1}{2}C(e_1) - \frac{1}{2}\hat{NB}_1\right]$

Since $\hat{NB}_1 < \hat{NB}_2$ when the countries are asymmetric (see the section 3.7.1 below), and $0 < \alpha < 1$ and $\delta > 1$, then we can show that $C'(e_1) > C'(e_2)$. This could mean that the percentage emission reduction rate for the country 1, β_1 is higher than the country $2's$, β_2 (under the same conditions on $\bar{E}_1$ and $\bar{E}_2$).

It is simple to show that $e_1 > e_2$ in the differentiated case with imperfect transfers, under the same conditions.

3.6.3 Abatement Levels at the Nash Equilibrium and the Differentiated Standards with Transfers

Here, we try to compare the abatement levels of the two countries at the Nash equilibrium and the differentiated standard case with transfers.

The respective first-order conditions for the countries 1 and 2 at the Nash equilibrium and the differentiated standard case with transfers are:

$$\text{Country 1} \quad B'(E) = C'(e_1)$$

$$\text{Country 2} \quad B'(E) = \frac{\delta}{\alpha} C^{'}(e_2)$$

$$\text{Country 1} \quad B'(E) = \frac{C'(e_1)}{1 + (1 + \lambda)\alpha}$$

$$\text{Country 2} \quad B'(E) = \frac{1 + \lambda}{1 + (1 + \lambda)\alpha} \delta C'(e_2)$$

where $E = \bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2$ and $e_1 = \bar{E}_1 \times \beta_1, e_2 = \bar{E}_2 \times \beta_{2.}$

We observe that $C'(\hat{e}_1) < C'(e_{1NDT})$ (NDT indicates differentiated norms with transfers) because $\frac{1}{1+(1+\lambda)\alpha} < 1$. So we can conclude that $\hat{\beta}_1 < \beta_1^{NDT}$.

Similarly, we note that $C'(\hat{e}_2) < C'(e_{2NDT})$, because $\frac{1+\lambda}{1+(1+\lambda)\alpha} < \frac{1}{\alpha}$. So we can conclude that $\hat{\beta}_2 < \beta_2^{NDT}$.

The percentage abatement levels at the Nash equilibrium are lower than these under the differentiated standard case with transfers.

3.6.4 Abatement Levels under the Uniform versus Differentiated Standards with Transfers

Here, we compare the abatement levels under the uniform versus differentiated standard cases with transfers.

The first-order conditions in the uniform standard case are:

$$B'(E) = \frac{\bar{E}_1}{(\bar{E}_1 + \bar{E}_2)} \frac{C'(e_1)}{(1 + (1 + \lambda)\alpha)} + \frac{\bar{E}_2}{(\bar{E}_1 + \bar{E}_2)} \frac{(1 + \lambda)\delta C'(e_2)}{(1 + (1 + \lambda)\alpha)} \tag{1}$$

where $E = \beta(\bar{E}_1 + \bar{E}_2)$, $e_1 = \beta\bar{E}_1, e_2 = \beta\bar{E}_2$.

The respective first-order conditions, for the countries 1 and 2, in the differentiated standard case are:

$$B'(E) = \frac{C'(e_1)}{1 + (1 + \lambda)\alpha} \tag{2}$$

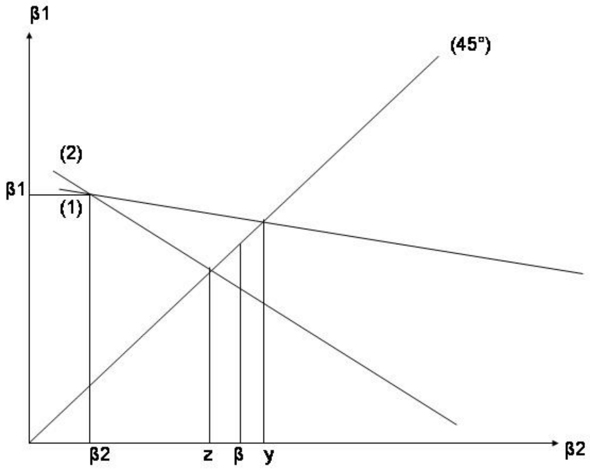

Figure 2:

$$B'(E) = \frac{1+\lambda}{1+(1+\lambda)\alpha}\delta C'(e_2) \tag{3}$$

where $E = \overline{E}_1 \times \beta_1 + \overline{E}_2 \times \beta_2$, $e_1 = \beta_1 \overline{E}_1, e_2 = \beta_2 \overline{E}_2$.

We propose below a graphical presentation to illustrate the position of the parameters β, β_1 and β_2 (see the figure 2).

First, we have to justify the situation of these parameters as they are placed in the figure 2. We know from the preceding section that $\beta_2 < \beta_1$ in the differentiated case when $\delta > 1$, $0 < \alpha < 1$ and when the noticed conditions on the initial emission levels are verified. Now, we have to describe the situation of the parameter β, the emission reduction rate in the uniform case.

The equations (2) and (3) will provide us a relation between β_1 and β_2. If we take into account the 45° line, we will have a variable $\beta = \beta_1 = \beta_2$ in the equation (2), which we will call y. Following the same logic, the equation (3) will give us another variable β called z. With these specifications, the equations (1), (2), (3) can be rewritten in the following way:

$$f(\beta) = \varepsilon g(\beta) + (1-\varepsilon)h(\beta) \tag{1'}$$

$$f(y) = g(y) \tag{2'}$$

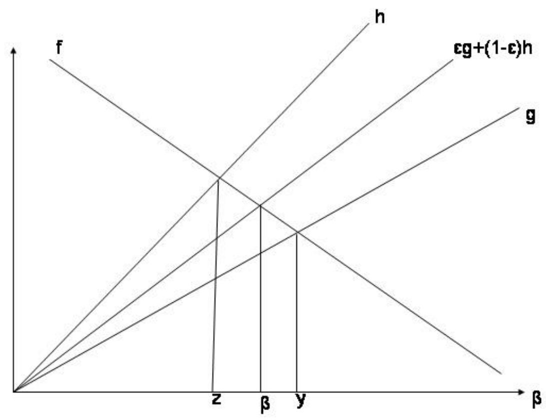

Figure 3:

$$f(z) = h(z) \tag{3'}$$

where $\varepsilon = \frac{\bar{E}_1}{(\bar{E}_1 + \bar{E}_2)}$ and $(1-\varepsilon) = \frac{\bar{E}_2}{(\bar{E}_1 + \bar{E}_2)}$.

We can do a graphical representation of these three new curves (see figure 3).

Since the curve (1') is located between the curves (2') and (3'), the variable β is located between those resulting from the equations (2') and (3'). The distance between β_1 and β_2 naturally depends on the respective slopes of the curves (2') and (3').

We now proceed to the comparison of the slopes of the equations (2') and (3'). We take the total differential of the equation (2):

$$B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)(d\beta_1 \bar{E} + d\beta_2 \bar{E}_2) = \frac{1}{(1+(1+\lambda)\alpha)} C''(\bar{E}_1 \times \beta_1) d\beta_1$$

$$\Longleftrightarrow (\frac{d\beta_2}{d\beta_1})_2 = \frac{\left[\frac{1}{(1+(1+\lambda)\alpha)} C''(\bar{E}_1 \times \beta_1) - B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\bar{E}_1\right]}{B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\bar{E}_2}$$

Similarly, we take the total differential of the equation (3):

$$B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)(d\beta_1 \bar{E} + d\beta_2 \bar{E}_2) = \frac{(1+\lambda)\delta}{(1+(1+\lambda)\alpha)} C''(\bar{E}_2 \times \beta_2) d\beta_2$$

$$\Longleftrightarrow (\frac{d\beta_2}{d\beta_1})_3 = \frac{B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\bar{E}_1}{\left[\frac{(1+\lambda)\delta}{(1+(1+\lambda)\alpha)} C''(\bar{E}_2 \times \beta_2) - B''(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\bar{E}_2\right]}$$

So the question is to know the sign of the term $(\frac{d\beta_2}{d\beta_1})_2 - (\frac{d\beta_2}{d\beta_1})_3$. Using the properties of the benefit function on the concavity and the cost function on the convexity ($B'' \leq 0$ and $C'' \geq 0$), we find that $(\frac{d\beta_2}{d\beta_1})_2 < (\frac{d\beta_2}{d\beta_1})_3$. So, the slope of the curve related to the equation (3') is higher than the one of the curve related to the equation (2').

With these properties, we observe that the percentage emission reduction rate in the uniform case with transfers, i.e. β, is between β_1 and β_2, the ones in the differentiated case with transfers.

In the next section, we will compare the welfare levels of the two countries.

3.7 Welfare Level Comparisons

We first compare the Nash equilibrium welfare levels of the countries.

3.7.1 Welfare Levels at the Nash Equilibrium

We assume for the sake of simplicity that $\alpha = 1$. Then the damage functions of the countries are assumed to be the same whereas, the only asymmetry existing between the countries is assumed to be one on the abatement cost functions, measured by the parameter δ.The net benefit functions of the countries are:

$$NB_1 = B(E) - C(e_1)$$

$$NB_2 = B(E) - \delta C(e_2)$$

We can write the following equality, by the envelope theorem:

$$\frac{\partial NB_2}{\partial \delta} = -C(e_2)$$

which is negative, because the abatement cost level of the country 2, $C(e_2)$ is positive.

If there is no asymmetry between the countries, i.e. $\delta = 1$ (symmetry case), then the welfare levels of the two countries are naturally equal. When the asymmetry between the countries increases ($\lambda > 1$), the welfare level of the country 2 decreases by the above lemma whereas, the welfare level of the country

1 is unaffected. So the welfare of the country 1 is superior to the country $2'$s at the Nash equilibrium, when the countries are asymmetric.

For the comparison of the welfare levels under a uniform standard (with or without transfers) and a differentiated standard (with or without transfers) cases, we will especially refer to the concept of the *Pareto frontier*. The readers could consult the appendix for the proofs (section 5.4). Here, we will try to sum up the main results and interpret them.

First, it is interesting to look at if the *NBS with imperfect transfers* gives an *efficient* (in the sense of Pareto) *bargaining procedure*. We can verify it from a simple example. Suppose that the countries 1 and 2 bargain over a variable (x) and a transfer (t). The two countries' aggregate utility levels (without transfer) are noted as $U_1(x)$ and $U_2(x)$. So the simple NBS consists on solving the following program:

$$Max_{x,t}\left[U_1(x)-(1+\lambda)t\right]\times\left[U_2(x)+t\right]$$

The first-order conditions with respect to x and t are:

$$\frac{U_1^{'}(x)}{U_1(x)-(1+\lambda)t}=\frac{-U_2^{'}(x)}{U_2(x)+t}$$

$$\frac{(1+\lambda)}{U_1(x)-(1+\lambda)t}=\frac{1}{U_2(x)+t}$$

The ratio of these first-order conditons gives us:

$$U_1^{'}(x)+(1+\lambda)U_2^{'}(x)=0$$

The *Pareto optimality* condition derives from the resolution of the following program:

$$Max_{x,t}\left[U_1(x)-(1+\lambda)t\right]$$

$$s.t. \qquad \left[U_2(x)+t\right]\geq \bar{U_2}$$

The first-order conditions with respect to x and t are:

$$U_1^{'}(x)+\mu U_2^{'}(x)=0$$

$$-(1+\lambda)+\mu=0$$

with μ the Lagrangian multiplier related to the constraint $\left[U_2(x)+t\right]\geq \bar{U_2}$. These conditions turn out to be the same as the preceding condition of the simple NBS:

$$U_1^{'}(x)+(1+\lambda)U_2^{'}(x)=0$$

So we remark that the NBS with imperfect transfers derives from an *efficient* bargaining procedure. Under this property, we can start to study the welfare comparisons. Firstly, we can look at the comparison of the uniform case *with* transfers and differentiated case *with* transfers.

3.7.2 Welfare Levels at the Uniform versus Differentiated Cases with Transfers

We suppose a situation where the country 2 is in the differentiated standard case with transfers whereas the country 1 stays in a uniform case with transfers. We would like to know if the total welfare level (for the two countries) can be increased if the country 1 also moves into the differentiated standard case. So, we maintain constant the welfare level of the country 2 (its indifference curve in the differentiated case does not change) and the transfer level in the uniform standard case. We investigate the conditions under which the welfare of the country 1 can be elevated. Remember that the net benefit functions of the countries are:

$$NB_1 = B(\beta_1 \bar{E}_1 + \beta_2 \bar{E}_2) - C(\beta_1 \bar{E}_1) - (1+\lambda)t$$

$$NB_2 = \alpha B(\beta_1 \bar{E}_1 + \beta_2 \bar{E}_2) - \delta C(\beta_1 \bar{E}_1) + t$$

What we would like to investigate is to know if $dNB_1 > 0$ when $dNB_2 = 0$, with:

$$dNB_1 = \frac{\partial NB_1}{\partial \beta_1} d\beta_1 + \frac{\partial NB_1}{\partial \beta_2} d\beta_2$$

$$dNB_2 = \frac{\partial NB_2}{\partial \beta_1} d\beta_1 + \frac{\partial NB_2}{\partial \beta_2} d\beta_2$$

We will remark that there is no an improvement upon the welfare level of the country 1 ($dNB_1 = 0$) by a movement from the uniform standard case to the differentiated one when:

$$\delta(1 + \alpha + \alpha\lambda) = \alpha + \delta^2(1 + \lambda)$$

So in general cases except the very specific configuration of the parameters' value, given by the above relationship, the welfare level of the country 1 can be improved by a movement into the differentiated standard case. Thus, it is possible to find a better arrangement (i.e. differentiated case) than the uniform case in terms of welfare.

Following the same procedure of demonstration, we can show that it is possible to find a differentiated case *without* transfers which can improve upon the uniform case *without* transfers, when $\delta \neq 1$ (and when α is assumed to be equal to 1). Thus an existing asymmetry on the abatement cost functions between the countries implies that it is possible to find a better arrangement (i.e. differentiated case without transfers) than the uniform case without transfers in terms of welfare.

3.7.3 General Treatment of the Welfare Levels

In order to have a general idea for the comparison of different regimes, we can first look at the performance in terms of welfare of a rule (uniform or differentiated) *with* transfers and another rule (uniform or differentiated) *without* transfers. We can claim that we dispose a larger choice set under a rule incorporating transfers compared to the one without transfers. With the rule incorporating transfers, we can prefer not to use the transfers, in which case the benefit levels between the two rules are equal. Or we can prefer the rule with transfers to the one without transfers when the former gives a welfare improvement upon the latter. The preceding results can be claimed only when the bargaining procedure is efficient, which is a condition validated by the NBS with imperfect transfers. So we can conclude that it is possible to find a better arrangement in terms of efficiency, i.e. differentiated standards with transfers, than can improve upon the differentiated case without transfers. The same result is valid for the uniform standard case also.

It is possible to apply the same reasoning for the comparison of a *differentiated* rule (with or without transfers) and a *uniform* rule (with or without transfers). In this case, the rule which offers a larger choice set,namely the differentiated one outperforms the uniform rule. This finding can be claimed because the bargaining procedure is efficient. So we can conclude that it is possible to find a better arrangement in terms of efficiency, i.e. differentiated standards with transfers, than can improve upon the uniform case with transfers. The same result is also valid for the superiority of the differentiated standards without transfers on the uniform ones without transfers.

If we put all together these results, it turns out that the differentiated rules with transfers outperform the uniform rules without transfers. It is an interesting result in the sense that the imperfection of the transfers in the differentiated case, which represents a cost for the country 1, could cause the superiority of the uniform standards without transfers (especially for the countries with a low degree of asymmetry). Nonetheless in the framework of the NBS we used, the differentiated standards always dominate on the uniform abatement standards. The imperfection of the transfers between the countries does not affect the superiority of the differentiated rules on the uniform ones in terms of efficiency. It is always possible to find an arrangement that improves upon a uniform rule. This new arrangement is differentiated pollution abatement standards.

4 Conclusion

This paper deals with the efficiency comparison of uniform versus differentiated pollution abatement standards in the case of a transboundary pollution problem. The emissions of the two countries adversely affect each of them. The most recommended rule in international environmental agreements in the presence of such a pollution problem is the imposition of uniform percentage emission reductions for all of the countries. The efficiency criteria would recommend, however, the use of differentiated emission reduction quotas specified for each country. These differentiated rules would respect the different caracteristics of the countries (abatement and damage functions, preferences).

To understand the frequent use of uniform rules, we use a cooperative game theoretic framework given by the Nash bargaining solution. We assume that the countries cooperatively bargain on the percentage emission reductions and the transfers when there is possibility of transfers between the countries. We study also all the cases where there is a imperfect transferability of transfers between the countries.

Our findings indicate that the differentiated rules (with or without transfers) outperform the uniform rules (with or without transfers). This result means that it is always possible to find a better arrangement (in the sense of Pareto efficiency), that will be done by differentiated standards other than the uniform rules. The most interesting result is that the differentiated rules with transfers always outperform the uniform rules without transfers. So the imperfection of the transfers in the differentiated case, which represents a cost for the country 1, does not prevent the superiority of differentiated standards even when the degree of asymmetry between the countries is low. These results are naturally related to the efficiency of the bargaining procedure implied by the Nash bargaining solution.

The analysis has been limited in scope. First, we have assumed that there are only two countries and hence the international negotiation is bilateral. In reality, there is a large number of countries affected by the global pollution problems, such as global warming or ozone layer depletion and by regional pollution problems, such as acid rain or regional seas' pollution. Second, we have compared two particular instruments, namely uniform versus differentiated standards. We have not considered the efficiency of economic instruments like uniform or differentiated effluent taxes. Third, complete information is an essential prerequisite in order to determine the Nash bargaining solution. One should expect, however that governments try to influence a decision in its favor and therefore will not reveal their environmental preferences. So the problem of asymmetric information between the countries should be analysed in a different context.

5 Proofs

5.1 The Resolution of the NBS in Different Regimes

5.1.1 The Uniform Standard case without Transfers

If we note as V the value function, the first-order condition with respect to β is:

$$\frac{\partial V}{\partial \beta} = 0 \Longleftrightarrow \frac{\gamma \left[\frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2) - \frac{\partial C}{\partial \beta}(\beta \bar{E}_1)\right]}{\left[B(\beta(\bar{E}_1 + \bar{E}_2)) - C(\beta \bar{E}_1) - \hat{N}B_1\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2) - \delta \frac{\partial C}{\partial \beta}(\beta \bar{E}_2)\right]}{\left[\alpha B(\beta(\bar{E}_1 + \bar{E}_2)) - \delta C(\bar{E}_2 \times \beta) - \hat{N}B_2\right]}$$

$$\Longleftrightarrow \frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2) \left[\begin{array}{c} \alpha B - \gamma\delta C(\bar{E}_2 \times \beta) \\ +(\gamma-1)\alpha C(\beta \bar{E}_1) - \gamma \hat{N}B_2 + (\gamma - 1)\alpha \hat{N}B_1 \end{array}\right]$$

$$= \frac{\partial C}{\partial \beta}(\beta \bar{E}_1)\left[\gamma\alpha B - \gamma\delta C(\bar{E}_2 \times \beta) - \gamma \hat{N}B_2\right]$$

$$+\frac{\partial C}{\partial \beta}(\beta \bar{E}_2)\left[-(\gamma-1)\delta B + (\gamma-1)\delta C(\beta \bar{E}_1) + (\gamma-1)\delta \hat{N}B_1\right]$$

$$\Longleftrightarrow (\bar{E}_1 + \bar{E}_2)B^{'}(E) \left[\begin{array}{c} \alpha B - \gamma\delta C(e_2) \\ +(\gamma-1)\alpha C(e_1) - \gamma \hat{N}B_2 + (\gamma - 1)\alpha \hat{N}B_1 \end{array}\right]$$

$$= \bar{E}_1 C'(e_1)\left[\gamma\alpha B - \gamma\delta C(e_2) - \gamma \hat{N}B_2\right]$$

$$+\bar{E}_2 \delta C'(e_2)\left[-(\gamma-1)B + (\gamma-1)C(e_1) + (\gamma-1)\hat{N}B_1\right]$$

where $E = \beta(\bar{E}_1 + \bar{E}_2)$, $e_1 = \beta \bar{E}_1, e_2 = \beta \bar{E}_2$.

5.1.2 The Uniform Standard case with Transfers

If we note as V the value function, the first-order condition with respect to β is:

$$\frac{\partial V}{\partial \beta} = 0 \Longleftrightarrow \frac{\gamma \left[\frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2) - \frac{\partial C}{\partial \beta}(\beta \bar{E}_1)\right]}{\left[B(\beta(\bar{E}_1 + \bar{E}_2)) - C(\beta \bar{E}_1) - \hat{N}B_1 - (1+\lambda)t\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2) - \delta \frac{\partial C}{\partial \beta}(\beta \bar{E}_2)\right]}{\left[\alpha B(\beta(\bar{E}_1 + \bar{E}_2)) - \delta C(\bar{E}_2 \times \beta) - \hat{N}B_2 + t\right]}$$

Similarly, the first-order condition with respect to t is:

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow \frac{\gamma\left[-(1+\lambda)\right]}{\left[B(\beta(\bar{E}_1 + \bar{E}_2)) - C(\beta \bar{E}_1) - \hat{N}B_1 - (1+\lambda)t\right]}$$

$$= \frac{(\gamma - 1)}{\left[\alpha B(\beta(\bar{E}_1 + \bar{E}_2)) - \delta C(\beta \bar{E}_2) - \hat{N}B_2 + t\right]}$$

The ratio of these two first-order conditions is:

$$\frac{(\partial V/\partial \beta)}{(\partial V/\partial t)} \Longleftrightarrow \frac{\left[\frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2)) - \frac{\partial C}{\partial \beta}(\beta \bar{E}_1)\right]}{-(1+\lambda)}$$

$$= \left[\alpha \frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2)) - \delta \frac{\partial C}{\partial \beta}(\beta \bar{E}_2)\right]$$

$$\Longleftrightarrow \frac{\partial B}{\partial \beta}(\beta(\bar{E}_1 + \bar{E}_2)) \times (1 + (1+\lambda)\alpha) = \frac{\partial C}{\partial \beta}(\beta \bar{E}_1) + (1+\lambda)\delta \frac{\partial C}{\partial \beta}(\beta \bar{E}_2)$$

$$\Longleftrightarrow (\bar{E}_1 + \bar{E}_2)B'(E) = \frac{C'(e_1)\bar{E}_1}{(1 + (1+\lambda)\alpha)} + \frac{(1+\lambda)\delta C'(e_2)\bar{E}_2}{(1 + (1+\lambda)\alpha)}$$

In order to calculate the value of transfers, we have to use the second of the first-order conditions, i.e. $\frac{\partial V}{\partial t} = 0$. This gives us:

$$t_{NUT} = B(E_{NUT}) \times \left(\frac{\gamma(1+\lambda)\alpha + (\gamma - 1)}{-(1+\lambda)}\right) + \frac{(\gamma-1)}{(1+\lambda)} \times C(e_{1NUT})$$
$$+\gamma\delta C(e_{2NUT}) + \frac{(\gamma-1)}{(1+\lambda)} \times \hat{N}B_1 + \gamma \hat{N}B_2$$

where $E = \beta(\bar{E}_1 + \bar{E}_2)$, $e_1 = \beta \bar{E}_1, e_2 = \beta \bar{E}_2$.

5.1.3 The Differentiated Standard case without Transfers

If we note as V the value function, the first-order condition with respect to β_1 is:

$$\frac{\partial V}{\partial \beta_1} = 0 \Longleftrightarrow \frac{\gamma\left[\frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)\right]}{\left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\beta_1 \bar{E}_1) - \hat{N}B_1\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\right]}{\left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) - \hat{N}B_2\right]}$$

Similarly, the first-order condition with respect to β_2 is:

$$\frac{\partial V}{\partial \beta_2} = 0 \Longleftrightarrow \frac{\gamma\left[\frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\right]}{\left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\beta_1 \bar{E}_1) - \hat{N}B_1\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta \frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2)\right]}{\left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) - \hat{N}B_2\right]}$$

The ratio of these first-order conditions is:

$$\frac{(\partial V/\partial \beta_1)}{(\partial V/\partial \beta_2)} \Longleftrightarrow \frac{\left[\frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)\right]}{\frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}$$

$$= \frac{\alpha \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{\left[\alpha \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta \frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2)\right]}$$

$$\Longleftrightarrow 1 = \frac{\frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{\frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)} + \frac{\alpha}{\delta} \frac{\frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{\frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2)}$$

$$\Longleftrightarrow 1 = \frac{B'(E)}{C'(e_1)} + \frac{\alpha}{\delta} \frac{B'(E)}{C'(e_2)}$$

where $E = \bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2$, $e_1 = \beta_1 \bar{E}_1, e_2 = \beta_2 \bar{E}_2$.
If we develop the first one of the first-order conditions, we obtain:

$$\begin{aligned}
\frac{\partial V}{\partial \beta_1} &= 0 \Longleftrightarrow \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) \times \\
&\left[\begin{array}{c} \alpha B - \gamma \delta C(\bar{E}_2 \times \beta_2) \\ +(\gamma - 1)\alpha C(\beta_1 \bar{E}_1) - \gamma \hat{N} B_2 + (\gamma - 1)\alpha \hat{N} B_1 \end{array} \right] \\
&= \frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1) \left[\gamma \alpha B - \gamma \delta C(\bar{E}_2 \times \beta_2) - \gamma \hat{N} B_2 \right]
\end{aligned}$$

$$\begin{aligned}
\Longleftrightarrow \quad & B'(E) \times \left[\begin{array}{c} \alpha B - \gamma \delta C(e_2) \\ +(\gamma - 1)\alpha C(e_1) - \gamma \hat{N} B_2 + (\gamma - 1)\alpha \hat{N} B_1 \end{array} \right] \\
= \quad & C'(e_1) \left[\gamma \alpha B - \gamma \delta C(e_2) - \gamma \hat{N} B_2 \right]
\end{aligned} \tag{1}$$

If we develop the second one of the first-order conditions, we obtain:

$$\begin{aligned}
\frac{\partial V}{\partial \beta_2} &= 0 \Longleftrightarrow \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) \times \\
&\left[\begin{array}{c} \alpha B - \gamma \delta C(\bar{E}_2 \times \beta_2) \\ +(\gamma - 1)\alpha C(\beta_1 \bar{E}_1) - \gamma \hat{N} B_2 + (\gamma - 1)\alpha \hat{N} B_1 \end{array} \right] \\
&= \frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2) \left[-(\gamma - 1)\delta B + (\gamma - 1)\delta C(\beta_1 \bar{E}_1) + (\gamma - 1)\delta \hat{N} B_1 \right]
\end{aligned}$$

$$\begin{aligned}
\Longleftrightarrow \quad & B'(E) \times \left[\begin{array}{c} \alpha B - \gamma \delta C(e_2) \\ +(\gamma - 1)\alpha C(e_1) - \gamma \hat{N} B_2 + (\gamma - 1)\alpha \hat{N} B_1 \end{array} \right] \\
= \quad & \delta C'(e_2) \left[-(\gamma - 1)B + (\gamma - 1)C(e_1) + (\gamma - 1)\hat{N} B_1 \right]
\end{aligned} \tag{2}$$

5.1.4 The Differentiated Standard case with Transfers

If we note as V the value function, the first-order condition with respect to β_1 is:

$$\frac{\partial V}{\partial \beta_1} = 0 \Longleftrightarrow \frac{\gamma\left[\frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)\right]}{\left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\beta_1 \bar{E}_1) - \hat{N} B_1 - (1+\lambda)t\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\right]}{\left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) - \hat{N} B_2 + t\right]}$$

Similarly, the first-order condition with respect to β_2 is:

$$\frac{\partial V}{\partial \beta_2} = 0 \Longleftrightarrow \frac{\gamma\left[\frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)\right]}{\left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\beta_1 \bar{E}_1) - \hat{N} B_1 - (1+\lambda)t\right]}$$

$$= \frac{(\gamma - 1)\left[\alpha \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta \frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2)\right]}{\left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) - \hat{N} B_2 + t\right]}$$

Finally, the first-order condition with respect to t is:

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow \frac{\gamma\left[-(1+\lambda)\right]}{\left[B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\beta_1 \bar{E}_1) - \hat{N} B_1 - (1+\lambda)t\right]}$$

$$= \frac{(\gamma - 1)}{\left[\alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2) - \hat{N} B_2 + t\right]}$$

The ratio of the first and second conditions is:

$$\frac{(\partial V / \partial \beta_1)}{(\partial V / \partial \beta_2)} \Longleftrightarrow 1 = \frac{B'(E)}{C'(e_1)} + \frac{\alpha}{\delta}\frac{B'(E)}{C'(e_2)}$$

where $E = \bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2$, $e_1 = \beta_1 \bar{E}_1, e_2 = \beta_2 \bar{E}_2$.
The ratio of the first and third conditions is:

$$\frac{(\partial V / \partial \beta_1)}{(\partial V / \partial t)} \Longleftrightarrow \frac{\frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)}{-(1+\lambda)}$$

$$= \alpha \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)$$

$$\Longleftrightarrow \frac{\partial B}{\partial \beta_1}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) = \frac{\frac{\partial C}{\partial \beta_1}(\beta_1 \bar{E}_1)}{1+(1+\lambda)\alpha}$$

$$\Longleftrightarrow B'(E) = \frac{C'(e_1)}{1+(1+\lambda)\alpha} \tag{1}$$

The ratio of the second and third conditions is:

$$\begin{aligned}
\frac{(\partial V/\partial \beta_2)}{(\partial V/\partial t)} &\Longleftrightarrow \frac{\frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2)}{-(1+\lambda)} \\
&= \alpha \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta \frac{\partial C}{\partial \beta_2}(\bar{E}_2 \times \beta_2)
\end{aligned}$$

$$\Longleftrightarrow \frac{\partial B}{\partial \beta_2}(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) = \frac{1+\lambda}{1+(1+\lambda)\alpha}\delta \frac{\partial C}{\partial \beta_2}(\beta_2 \bar{E}_2)$$

$$\Longleftrightarrow B'(E) = \frac{1+\lambda}{1+(1+\lambda)\alpha}\delta C'(e_2) \tag{2}$$

In order to calculate the value of transfers, we have to use the third condition, i.e. $\frac{\partial V}{\partial t} = 0$. This gives us:

$$\begin{aligned}
t_{NDT} &= B(E_{NDT}) \times (\frac{\gamma(1+\lambda)\alpha + (\gamma-1)}{-(1+\lambda)}) + \frac{(\gamma-1)}{(1+\lambda)} \times C(e_{1NDT}) \\
&\quad + \gamma\delta C(e_{2NDT}) + \frac{(\gamma-1)}{(1+\lambda)} \times N\hat{B}_1 + \gamma N\hat{B}_2
\end{aligned}$$

5.2 The Direction of the Transfers between the Countries

Here, we want to prove the inefficiency of the transfers from the country 2 to the country 1 (and not from the country 1 to the country 2) when there exists an asymmetry between the countries on the abatement cost function ($\delta > 1$).

For the uniform standard case with transfers from the country 2 to the country 1, the Nash bargaining problem can be expressed as follows:

$$\begin{aligned}
&Max_{\beta,t}\left[B(\beta(\bar{E}_1 + \bar{E}_2) - C(\beta\bar{E}_1) - N\hat{B}_1 + t\right]^{\gamma} \times \\
&\left[\alpha B(\beta(\bar{E}_1 + \bar{E}_2) - \delta C(\beta\bar{E}_2) - N\hat{B}_2 - (1+\lambda)t\right]^{(1-\gamma)}
\end{aligned}$$

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

$$\frac{\partial V}{\partial t} = 0 \Longleftrightarrow \frac{\gamma}{B(E) - C(e_1) - \overset{\wedge}{NB}_1 + t} = \frac{(\gamma - 1)(-(1+\lambda))}{\alpha B(E) - \delta C(e_2) - \overset{\wedge}{NB}_2 - (1+\lambda)t}$$

$$\begin{aligned} \Longleftrightarrow \quad & \gamma\alpha B(E) - \gamma\delta C(e_2) - \gamma \overset{\wedge}{NB}_2 - \gamma(1+\lambda)t \\ = \quad & (1+\lambda)(1-\gamma)B(E) - (1+\lambda)(1-\gamma)C(e_1) \\ & -(1+\lambda)(1-\gamma)\overset{\wedge}{NB}_1 + (1+\lambda)(1-\gamma)t \end{aligned}$$

$$\begin{aligned} \Longleftrightarrow \quad & B(E)\left[\gamma\alpha + (1+\lambda)(\gamma - 1)\right] - \gamma\delta C(e_2) + (1+\lambda)(1-\gamma)C(e_1) \\ & -\gamma\overset{\wedge}{NB}_2 + (1+\lambda)(1-\gamma)\overset{\wedge}{NB}_1 \\ = \quad & t\left[(1+\lambda)(1-\gamma) + \gamma(1+\lambda)\right] \end{aligned}$$

$$\begin{aligned} \Longleftrightarrow \quad & t = B(E)\left(\frac{\gamma\alpha + (1+\lambda)(\gamma-1)}{1+\lambda}\right) - \frac{\gamma}{1+\lambda}\delta C(e_2) \\ & +(1-\gamma)C(e_1) - \frac{\gamma}{1+\lambda}\overset{\wedge}{NB}_2 + (1-\gamma)\overset{\wedge}{NB}_1 \end{aligned}$$

We make the following simplifying assumptions:

$$\gamma = 1/2; \alpha = 1; \lambda = 0.$$

Then, the level of transfers becomes:

$$\Longleftrightarrow t = (1/2)\left[C(e_1) - \delta C(e_2)\right] + (1/2)\left[\overset{\wedge}{NB}_1 - \overset{\wedge}{NB}_2\right]$$

$$\Longleftrightarrow t - \frac{1}{2}C(e_1) + \frac{1}{2}\delta C(e_2) = (1/2)\left[\overset{\wedge}{NB}_1 - \overset{\wedge}{NB}_2\right]$$

$$\Longleftrightarrow t + \frac{1}{2}\left[B(E) - C(e_1)\right] - \frac{1}{2}\left[B(E) - \delta C(e_2)\right] = (1/2)\left[\overset{\wedge}{NB}_1 - \overset{\wedge}{NB}_2\right]$$

$$\Longleftrightarrow t + \frac{1}{2}\left[U_1 - U_2\right] = (1/2)\left[\overset{\wedge}{NB}_1 - \overset{\wedge}{NB}_2\right]$$

where U_1 and U_2 represent respectively, the gross benefit functions (without considering transfers) of the countries 1 and 2.

We remark that if the difference $[U_1 - U_2]$ is superior to the difference $\left[\overset{\wedge}{NB}_1 - \overset{\wedge}{NB}_2\right]$, then the transfers from the country 2 to the country 1 must be negative. Or expressed differently, if the difference $\left[U_1 - \overset{\wedge}{NB_1}\right]$, the gain of the country 1 in the new arrangement compared to the Nash equilibrium is superior to the difference $\left[U_2 - \overset{\wedge}{NB_2}\right]$, the supplementary gain of the country 2, then the transfers are negative.

$\left[U_1 - \overset{\wedge}{NB_1}\right] >? \left[U_2 - \overset{\wedge}{NB_2}\right]$

To see this, we make an additional simplifying assumption: $\bar{E}_1 = \bar{E}_2 = \bar{E}$. So, we obtain:

$$\left[B(E) - C(e) - \overset{\wedge}{NB_1}\right] >? \left[B(E) - \delta C(e) - \overset{\wedge}{NB_2}\right]$$

$$\Longleftrightarrow [-C(e) + \delta C(e)] + \left[\overset{\wedge}{NB_2} - \overset{\wedge}{NB_1}\right] >?0$$

We remark that if the countries are completely symmetric, $\delta = 1$, the above expression is equal to 0. When the asymmetry between the countries increases, $\delta \nearrow$, the first derivative of the above expression with respect to δ is equal to $\left[C(e) - C(\overset{\wedge}{e_2})\right]$ which is positive because $e > \overset{\wedge}{e_2}$ (because of the assumption $\delta > 1$). This means that when the abatement costs of the country 2 is higher to the country $1's$ ($\delta > 1$), the transfers from the country 2 to the country 1 are negative. So, the natural direction of the transfers is from the country 1 to the country 2.

5.3 Comparison of the Welfare Levels in the case of Symmetric Countries

5.3.1 Uniform Standards / Nash Equilibrium

The difference of the total net benefits under the uniform standards and the Nash equilibrium is:

$$TNB_{NU} - \overset{\wedge}{TNB} = 2 \times \left[B(E_{NU}) - C(E_{NU}/2) - B(\hat{E}) + C(\hat{E}/2)\right]$$

We know that $\hat{E} < E_{NU}$. So,

· $B(E_{NU}) - B(\hat{E}) > 0$ because the benefit function is increasing.

· $C(E_{NU}) > C(\hat{E}) \Longleftrightarrow C(E_{NU}/2) > C(\hat{E}/2) \Longleftrightarrow C(\hat{E}/2) - C(E_{NU}/2) < 0$ because the cost function is increasing.

We would like to know the sign of the following expression:

$$\left[B(E_{NU}) - B(\hat{E})\right] + \left[C(\hat{E}/2) - C(E_{NU}/2)\right]$$

The proof is straigthforward. We note E_{NU} as x and $\hat{E}$ as y. We would like to know under what conditions the expression $[B(x) - B(y)]$ is superior to the expression $[C(x/2) - C(y/2)]$. We proceed in the following way:

$$\frac{[B(x) - B(y)]}{(1/2)(x - y)} > \frac{[C(x/2) - C(y/2)]}{(1/2)(x - y)}$$

given that $x > y$, i.e. $E_{NU} > \hat{E}$.

$$\Longleftrightarrow \frac{\frac{B(x)-B(y)}{(1/2)(x-y)}}{\frac{C(x/2)-C(y/2)}{(1/2)(x-y)}} > 1$$

$$\Longleftrightarrow \frac{1}{2} \times \frac{\frac{B(x)-B(y)}{(1/2)(x-y)}}{\frac{C(x/2)-C(y/2)}{(\frac{x}{2}-\frac{y}{2})}} > \frac{1}{2}$$

$$\Longleftrightarrow \frac{\frac{B(x)-B(y)}{(x-y)}}{\frac{C(x/2)-C(y/2)}{(\frac{x}{2}-\frac{y}{2})}} > \frac{1}{2}$$

$$\Longleftrightarrow \frac{B(x) - B(y)}{(x - y)} > \frac{1}{2} \times \frac{C(x/2) - C(y/2)}{(\frac{x}{2} - \frac{y}{2})}$$

So, we remark that the expression $\left[B(E_{NU}) - B(\hat{E})\right]$ $+ \left[C(\hat{E}/2) - C(E_{NU}/2)\right]$ is positive when the absolute value of the benefit function's slope between E_{NU} and $\hat{E}$ is higher than the half of the absolute value of the cost function's slope between $(E_{NU}/2)$ and $(\hat{E}/2)$.

We remark that the uniform emission reduction case can outperform the Nash equilibrium when the above condition is verified.

In the next section, we will compare the welfare levels under the differentiated standard case and the Nash equilibrium.

5.3.2 Differentiated Standards / Nash Equilibrium

The difference of the total net benefits under the differentiated standards and the Nash equilibrium, given the level of transfers t, is:

$$\begin{aligned} TNB_{ND} - T\hat{N}B &= B(E_{ND}) \times \left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right] \\ &\quad -B(\hat{E}) \times \left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right] \\ &\quad -C(E_{ND}) \times (1-\lambda(\gamma-1)) \\ &\quad +C(\hat{E}/2) \times \left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right] \\ &\quad +co \times \left[\frac{1+\lambda(1-\gamma)}{1+\lambda}\right] \end{aligned}$$

We know that $\hat{E} > E_{ND}$. So,

· $B(\hat{E}) > B(E_{ND}) \iff B(E_{ND}) - B(\hat{E}) < 0$ because the benefit function is increasing.

We know that the expression $\left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right]$ is positive and superior to 2 when $\gamma = 0.5$ (same negociation power). So we have:

$\left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right] \times \left[B(E_{ND}) - B(\hat{E})\right] < 0.$

· $C(\hat{E}) > C(E_{ND})$ because the cost function is increasing.

The expression $C(\hat{E}/2)$ is multiplied by $\left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right]$ which is superior to 2 and the expression $C(E_{ND})$ is multiplied by $(1-\lambda(\gamma-1))$ which is superior to 1 but inferior to 2, when $\gamma = 0.5$. So the answer is not obvious.

· The expression co is multiplied by $\left[\frac{1+\lambda(1-\gamma)}{1+\lambda}\right]$ which is positive but inferior to 1, when $\gamma = 0.5$.

In order to simplify our task of comparison, we can assume that transfers are perfect, i.e. $\lambda = 0$. In this case, the difference term on cost functions becomes:

$\left[C(\hat{E}/2) \times 2 - C(E_{ND})\right]$.

If we divide this expression by 2, we obtain:

$\left[C(\hat{E}/2) - C(E_{ND}) \times \frac{1}{2}\right]$ which is *negative* under the assumptions that the cost function is convex and $C(0) = 0$.

So, we can conclude that the Nash equilibrium can outperform the differentiated standards case, when the value of the fixed cost is not so high, and this even when transfers are perfect. The high level of fixed costs co can, however reverse this situation.

In the next section, we will compare the welfare levels under the differentiated standard and the uniform standard cases.

5.3.3 Differentiated Standards / Uniform Standards

The difference of the total net benefits under the differentiated and uniform standards, given the level of transfers t,is:

$$\begin{aligned} TNB_{ND} - TNB_{NU} &= B(E_{ND}) \times \left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right] \\ &\quad -2 \times B(E_{NU}) + 2C(E_{NU}/2) - C(E_{ND}) \times (1-\lambda(\gamma-1)) \\ &\quad +co \times [1+\lambda(\gamma-1)] \\ &\quad +\hat{N}B \times \left[\frac{\lambda}{1+\lambda}(2\gamma+\gamma\lambda-1-\lambda\right] \end{aligned}$$

We know that $E_{NU} > E_{ND}$. So

· $B(E_{NU}) - B(E_{ND}) > 0$ because the benefit function is increasing.

The expression $B(E_{ND})$ is multiplied by $\left[\frac{2+3\lambda-2\lambda\gamma-\gamma\lambda^2+\lambda^2}{1+\lambda}\right]$ which is superior to 2 and the expression $B(E_{NU})$ is multiplied by 2, when $\gamma = 0.5$. So the answer is not obvious.

· $C(E_{NU}) > C(E_{ND})$ because the cost function is increasing.

The expression $C(E_{NU}/2)$ is multiplied by 2 and the expression $C(E_{ND})$ is multiplied by $(1-\lambda(\gamma-1))$ which is superior to 1 but inferior to 2, when $\gamma = 0.5$. So the answer is not obvious.

· The expression co is multiplied by $[1+\lambda(\gamma-1)]$ which is positive but inferior to 1, when $\gamma = 0.5$.

· The expression $\hat{N}B$ is multiplied by $\left[\frac{\lambda}{1+\lambda}(2\gamma+\gamma\lambda-1-\lambda\right]$ which is *negative*, when $\gamma = 0.5$.

In order to simplify our task of comparison, we can assume again that transfers are perfect, i.e. $\lambda = 0$. In this case, the difference term on benefit functions becomes:

$2 \times [B(E_{ND}) - B(E_{NU})]$ which is *negative*.

Similarly, the difference term on cost functions becomes:

$[C(E_{NU}/2) \times 2 - C(E_{ND})]$.

If we divide this expression by 2, we obtain:

$\left[C(E_{NU}/2) - C(E_{ND}) \times \frac{1}{2}\right]$ which is *negative* under the assumptions that the cost function is convex and $C(0) = 0$.

So, we can conclude that the uniform standards can outperform the differentiated ones, when the value of the fixed cost is not so high, and this even when transfers are perfect. The high level of fixed costs co can, however reverse this situation.

5.4 Comparison of the Welfare Levels in the case of Asymmetric Countries

5.4.1 The Uniform case *with* Transfers and the Differentiated case *with* Transfers

Suppose a situation where the country 2 is in the differentiated standard case whereas the country 1 stays in a uniform case. We would like to know if the total welfare level (for the two countries) can be increased if the country 1 also moves into the differentiated standard case. So, we maintain constant the welfare level of the country 2 (its indifference curve in the differentiated case does not change) and the transfer level in the uniform standard case. We investigate the conditions under which the welfare of the country 1 can be elevated.

$$dNB_1 = \frac{\partial NB_1}{\partial \beta_1} d\beta_1 + \frac{\partial NB_1}{\partial \beta_2} d\beta_2 >?0 \tag{1}$$

$$dNB_2 = \frac{\partial NB_2}{\partial \beta_1} d\beta_1 + \frac{\partial NB_2}{\partial \beta_2} d\beta_2 = 0 \tag{2}$$

The net benefit functions of the countries are:

$$NB_1 = B(\beta_1 \bar{E_1} + \beta_2 \bar{E_2}) - C(\beta_1 \bar{E_1}) - (1+\lambda)t$$

$$NB_2 = \alpha B(\beta_1 \bar{E_1} + \beta_2 \bar{E_2}) - \delta C(\beta_1 \bar{E_1}) + t$$

The first derivatives of the net benefit functions with respect to percentage emission reduction levels β_1 and β_2 are:

$$\frac{\partial NB_1}{\partial \beta_1} = B^{'}(E)\bar{E_1} - C^{'}(e_1)\bar{E_1}$$

$$\frac{\partial NB_1}{\partial \beta_2} = B^{'}(E)\bar{E_2}$$

$$\frac{\partial NB_2}{\partial \beta_1} = \alpha B^{'}(E)\bar{E_1}$$

$$\frac{\partial NB_2}{\partial \beta_2} = \alpha B^{'}(E)\bar{E_2} - \delta C^{'}(e_2)\bar{E_2}$$

We know that $\beta_{2NDT} < \beta_{NUT} < \beta_{1NDT}$, $\hat{\beta_1} < \beta_{1NDT}$ and $\hat{\beta_2} < \beta_{2NDT}$ where the subscript NDT indicates differentiated norms with transfers and NUT indicates uniform norms with transfers. This ranking of the percentage emission reduction levels implies that we are in the decreasing side of the curve $NB2(\beta_2)$, so we have $\frac{\partial NB_2}{\partial \beta_2} < 0$. It is clear that the sign of the derivative $\frac{\partial NB_2}{\partial \beta_1}$ is positive.

From the equation 2, we can write:

$$d\beta_2 = -d\beta_1 \frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}$$

Given the properties of the sign of the first derivatives $\frac{\partial NB_2}{\partial \beta_2}$ and $\frac{\partial NB_2}{\partial \beta_1}$, the ratio $\frac{d\beta_2}{d\beta_1}$ is positive. This means that the two percentage emission reduction levels β_1 and β_2 must increase together in order to make accept the country 2 the new arrangement ($dNB_2 = 0$).

We can rewrite the equation 1 in the following way:

$$dNB_1 = \frac{\partial NB_1}{\partial \beta_1} d\beta_1 + \frac{\partial NB_1}{\partial \beta_2} (-d\beta_1 \frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}) >?0$$

$$\Longleftrightarrow d\beta_1 \left[\frac{\partial NB_1}{\partial \beta_1} - \frac{\partial NB_1}{\partial \beta_2} (\frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}) \right] >?0$$

We remark that if the marginal substitution rates of the countries are equal, then $dNB_1 = 0$. So the following condition mustn't be validated, in order to obtain an improvement of the country $1's$ welfare:

$$\frac{\frac{\partial NB_1}{\partial \beta_1}}{\frac{\partial NB_1}{\partial \beta_2}} = \frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}$$

$$\Longleftrightarrow \frac{B'(E)\bar{E_1} - C'(e_1)\bar{E_1}}{B'(E)\bar{E_2}} = \frac{\alpha B'(E)\bar{E_1}}{\alpha B'(E)\bar{E_2} - \delta C'(e_2)\bar{E_2}}$$

$$\Longleftrightarrow \alpha B'(E)^2 - \alpha B'(E)C'(e_1) - B'(E)\delta C'(e_2) + \delta C'(e_1)C'(e_2) = \alpha B'(E)^2$$

$$\Longleftrightarrow \delta C'(e_1)C'(e_2) = B'(E)\left[\alpha C'(e_1) + \delta C'(e_2)\right] \quad (3)$$

Now we will use the optimality conditions ($\frac{\partial V/\partial \beta}{\partial V/\partial t}$) of the uniform standard case with transfers to replace the expression $B'(E)$ in the equation 3. The optimality condition of the uniform standard case with transfers is:

$$(\bar{E_1} + \bar{E_2})B'(E) = \frac{C'(e_1)\bar{E_1}}{(1 + (1+\lambda)\alpha)} + \frac{(1+\lambda)\delta C'(e_2)\bar{E_2}}{(1 + (1+\lambda)\alpha)}$$

To simplify our task, we assume that $\bar{E_1} = \bar{E_2} = \bar{E}$. Given this assumption, the abatement level of the country 1 will be naturally equal to the country $2's$ under the uniform standard case, i.e. $e_1 = \beta\bar{E} = e_2$. So,we obtain:

$$B'(E) = \frac{C'(e)}{2(1+(1+\lambda)\alpha)} + \frac{(1+\lambda)\delta C'(e)}{2(1+(1+\lambda)\alpha)}$$

If we replace the above optimality condition in the equation 3, we obtain:

$$\Longleftrightarrow \delta C'(e)^2 = \left[\frac{C'(e)}{2(1+(1+\lambda)\alpha)} + \frac{(1+\lambda)\delta C'(e)}{2(1+(1+\lambda)\alpha)}\right][(\alpha+\delta)C'(e)]$$

$$\Longleftrightarrow \delta\,[2(1+(1+\lambda)\alpha)] = (1+\delta(1+\lambda))(\alpha+\delta)$$

$$\Longleftrightarrow \delta(1+\alpha+\alpha\lambda) = \alpha+\delta^2(1+\lambda)$$

In order to simplify further our task, we assume that the transfers between the countries are made in a perfect manner, i.e. $\lambda = 0$. Then we obtain:

$$\delta(1+\alpha) = \alpha+\delta^2$$

$$\Longleftrightarrow \delta = \alpha$$

We can conclude that in a case where the asymmetry parameters between the countries, the one on the damage function α and the other on the abatement cost function δ have the same value, the welfare level of the country 1 cannot be increased by a movement from the uniform standard case to the differentiated one, when the transfers are perfect. In all the cases where the asymmetry parameters are not equal ($\alpha \neq \delta$), the total welfare of the countries can be improved by a movement from the uniform standard case to the differentiated one.

5.4.2 The Uniform case *without* Transfers and the Differentiated case *without* Transfers

We do the same reasoning as the preceding section. We suppose a situation where the country 2 is in the differentiated standard case whereas the country 1 stays in a uniform case. We maintain constant the welfare level of the country 2 (its indifference curve in the differentiated case does not change). We would like to know if the total welfare level (for the two countries) can be increased if the country 1 also moves into the differentiated standard case.

$$dNB_1 = \frac{\partial NB_1}{\partial \beta_1} d\beta_1 + \frac{\partial NB_1}{\partial \beta_2} d\beta_2 >?0 \tag{4}$$

$$dNB_2 = \frac{\partial NB_2}{\partial \beta_1} d\beta_1 + \frac{\partial NB_2}{\partial \beta_2} d\beta_2 = 0 \tag{5}$$

The net benefit functions of the countries are:

$$NB_1 = B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - C(\bar{E}_1 \times \beta_1)$$

$$NB_2 = \alpha B(\bar{E}_1 \times \beta_1 + \bar{E}_2 \times \beta_2) - \delta C(\bar{E}_2 \times \beta_2)$$

We can rewrite the equation 4 in the following way (as in the preceding section):

$$dNB_1 = \frac{\partial NB_1}{\partial \beta_1} d\beta_1 + \frac{\partial NB_1}{\partial \beta_2}(-d\beta_1 \frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}) >?0$$

$$\Longleftrightarrow d\beta_1 \left[\frac{\partial NB_1}{\partial \beta_1} - \frac{\partial NB_1}{\partial \beta_2}(\frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}) \right] >?0$$

We remark again that if the marginal substitution rates of the countries are equal, then $dNB_1 = 0$. So, the following condition mustn't be validated, in order to obtain an improvement of the country $1's$ welfare:

$$\frac{\frac{\partial NB_1}{\partial \beta_1}}{\frac{\partial NB_1}{\partial \beta_2}} = \frac{\frac{\partial NB_2}{\partial \beta_1}}{\frac{\partial NB_2}{\partial \beta_2}}$$

which implies:

$$\Longleftrightarrow \delta C'(e_1)C'(e_2) = B'(E)\left[\alpha C'(e_1) + \delta C'(e_2)\right] \tag{6}$$

Now we will use the optimality condition ($\partial V/\partial \beta = 0$) of the uniform standard case without transfers to replace the expression $B'(E)$ in the equation 6. The optimality condition of the uniform standard case without transfers is:

$$\begin{aligned}
\Longleftrightarrow \quad & (\bar{E}_1 + \bar{E}_2)B'(\beta((\bar{E}_1 + \bar{E}_2)) \\
& \left[\begin{array}{c} \alpha B(\beta((\bar{E}_1 + \bar{E}_2)) - \gamma\delta C(\bar{E}_2 \times \beta) \\ +(\gamma-1)\alpha C(\beta\bar{E}_1) - \gamma \hat{N}B_2 + (\gamma-1)\alpha \hat{N}B_1 \end{array} \right] \\
= \quad & \bar{E}_1 C'(\beta\bar{E}_1) \\
& \left[\gamma\alpha B(\beta((\bar{E}_1 + \bar{E}_2)) - \gamma\delta C(\bar{E}_2 \times \beta) - \gamma \hat{N}B_2 \right] \\
& +\bar{E}_2 \delta C'(\bar{E}_2 \times \beta) \\
& \left[-(\gamma-1)B(\beta((\bar{E}_1 + \bar{E}_2)) + (\gamma-1)C(\beta\bar{E}_1) + (\gamma-1)\hat{N}B_1 \right]
\end{aligned}$$

To simplify our task, we assume that $\bar{E}_1 = \bar{E}_2 = \bar{E}$. Given this assumption, the abatement level of the country 1 will be naturally equal to the country $2's$ under the uniform standard case, i.e. $e_1 = \beta\bar{E} = e_2$. So,we obtain:

$$\iff B'(E) = \frac{1}{2}C'(e)$$

$$\times \frac{\left[\gamma\alpha B(E) - \gamma\delta C(e) - \gamma \hat{N} B_2\right]}{\left[\alpha B(E) - \gamma\delta C(e) + (\gamma-1)\alpha C(e) - \gamma \hat{N} B_2 + (\gamma-1)\alpha \hat{N} B_1\right]}$$

$$+\frac{1}{2}\delta C'(e)$$

$$\times \frac{\left[-(\gamma-1)B(E) + (\gamma-1)C(e) + (\gamma-1)\hat{N} B_1\right]}{\left[\alpha B(E) - \gamma\delta C(e) + (\gamma-1)\alpha C(e) - \gamma \hat{N} B_2 + (\gamma-1)\alpha \hat{N} B_1\right]}$$

If we replace the above optimality condition in the equation 6 and we use two simplifying assumptions $\gamma = 1/2$ and $\alpha = 1$, we obtain:

$$\iff 2\delta = (1+\delta)$$

$$\iff \delta = 1$$

We remark that in case of the symmetry between the countries ($\alpha = 1, \delta = 1$), the welfare level of the country 1 cannot be increased by a movement from the uniform standard case to the differentiated one. In all the *general* cases where there exists an asymmetry on the abatement cost levels between the countries ($\alpha = 1, \delta \neq 1$), the total welfare of the countries can be improved by a movement from the uniform standard case to the differentiated one.

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