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RESUME

Ce travail étudie le lien entre le design des accords environnementaux internationaux et les décisions d'investissement des entreprises dans de nouvelles technologies de traitement de la pollution. Les deux types d'accords étudiés dans ce travail sont l'accord de norme uniforme avec transferts et l'accord de normes différenciées sans transfert. La principale question posée est celle du type d'accord environnemental international qui doit être annoncé et mis en œuvre par les pays de façon optimale au sens de Pareto. Ceci est effectué dans le cadre d'un modèle à plusieurs étapes où le secteur privé décide de réaliser un investissement irréversible, étant donné le niveau anticipé des normes de dépollution résultant des négociations bilatérales futures. Nos travaux mettent en évidence un résultat qui peut paraître contre intuitif: il est optimal, en présence de pays très hétérogènes, d'annoncer et de mettre en œuvre un accord de norme uniforme avec transferts lorsque le coût irrécupérable de l'installation de la technologie est faible et que les bénéfices marginaux de la dépollution globale sont élevés, tandis que ce n'est plus le cas lorsque le coût irrécupérable de l'installation de la technologie est élevé. Dans ce cas, la mise en œuvre de l'accord de norme uniforme avec transferts donne le même niveau de paiement que celui au point de menace de la négociation.

Mots-clés: accords, normes, transferts, adoption de technologie, investissement irréversible, négociation, pollution transfrontalière.

ABSTRACT

This paper studies the link between the design of international environmental agreements and the incentives for the private sector to invest in cleaner technologies. More specifically, it compares the performance, in the Pareto sense, of two types of agreement: an agreement on a uniform standard with transfers and an agreement on differentiated standards without transfers. To achieve this goal, we use a multi-stage game where the private sector anticipates its irreversible investment given the expected level of abatement standards, resulting from future bilateral negotiations. Our findings indicate that whenever countries are able to partially commit, the agreement on a uniform standard may be preferable, as it creates greater incentives for firms to invest in costly abatement technology. This result relies on the low level of the set-up cost of this technology. If this level is sufficiently high, the announcement and implementation of the agreement on a uniform standard with transfers is not optimal, because it takes away the incentive of all firms to invest in a new abatement technology.

Keywords: agreements, standards, transfers, technology adoption, irreversible investment, bargaining, transboundary pollution.

JEL: Q50, C71.

1 Introduction

In the light of scientific evidence indicating the responsibility of human activity for the climate change problem, the decision by the private sector to invest in environmentally friendly technologies is crucial. Global climate change is, by its nature, a public good problem. A firm which undertakes a clean-up activity does not fully capture the benefits of its effort, which leads to a sub-optimal level of investment. Moreover, if the investment in a cleaner technology represents a high level of sunk cost, the firm will not be willing to invest in a new environmental technology.

The aim of this paper is to investigate the link between the design of international environmental agreements (noted as *IEA's* hereafter) and the decision by firms to invest in new clean-up technologies, in the presence of a transboundary pollution problem across two countries. A study by the OECD (2005) points out that " *Clear and concrete objectives and targets under multilateral environmental agreements (MEAs) create a framework within which the business sector can both align its practices with MEA goals and seize new business opportunities. Some MEAs include clear objectives, e.g. those established under the Montreal and the Kyoto Protocols. Most MEAs, however, have general objectives, which cannot always be easily translated into concrete action by the private sector...*" (p.6). These statements indicate the importance of the design of IEA's in order to induce the business sector to undertake environmentally friendly action. In this paper, we analyze, both from the positive and normative points of view, the consequences of the type of IEA's on the decision by firms to invest in a new abatement technology. From this perspective, we consider two types of IEA's: an agreement on a uniform standard with transfers and an agreement on differentiated standards without transfers[1]. We mainly ask which one of the two agreements must be negotiated to give the right incentives to firms to invest in a new abatement technology, in the case of an excess of pollution.

Firstly, we consider an agreement on a uniform standard with transfers (UT). In this context, a uniform standard means a uniform percentage reduction rate of the emissions in a base year for all countries concerned by the environmental problem. In fact, the majority of IEA's on transboundary pollution problems are characterized by uniform standards (Hoel (1991), Finus, (2001)). Several theoretical arguments can explain the implementation of uniform standards[2]. The transfer payments are used in order to ensure the participation of some countries in the IEA. This type of mechanism, which associates a uniform emission reduction target with a side payment scheme, is illustrated by the Montreal Protocol on Substances that Deplete the

[1] In this paper, our aim is to analyse the consequences of these two types of IEA's, frequently observed in reality, on the decision by firms to invest in a new abatement technology. We do not try to explain why these two arrangements emerge.

[2] Some of these arguments are the following. The uniform rules could allow faster agreements thanks to the perceived "fair" character of these types of rules. They could also prevent transaction costs of the negotiation on differentiated standards in the presence of asymmetric information between countries.

Ozone Layer (1987)[3]. As Luken and Grof (2006) point out, *the implementation of the Protocol has reduced the consumption of ozone-depleting substances by more than 90%*. This Protocol specified an emission reduction of CFCs and halons by 20% based on the 1986 emission levels, to be accomplished by 1998. The Parties to the Montreal Protocol established the Multilateral Fund (MLF) in 1990. This fund consists of the contributions of 49 industrialized countries which help developing countries in the Protocol to cover their incremental costs in complying with the Protocol's provisions. Luken and Grof (2006, p.2) consider that the majority of the reduction in the consumption of ozone depleting substances is provided by the projects implemented by the MLF.

Secondly, we consider an agreement on differentiated standards without transfers (D). These agreements specify differentiated percentage reduction rates of the emissions of a base year for different countries. Here, differentiated emission reduction targets already capture the asymmetry across countries; hence side payments would not be necessary. This type of agreement is illustrated by the Kyoto Protocol on Climate Change (1997). This protocol imposes a uniform standard for some countries of transition (the Czech Republic, Estonia, Latvia, Lithuania, the Slovak Republic and Slovenia have agreed to reduce their 1990 emissions by 8%[4]) and differentiated standards across different groups of countries. For instance, the Burden Sharing Agreement in the EU implies differentiated standards on the base of the 1990 emissions (Austria: -13%, France: 0%, Greece: +25%[5])[6]. The Kyoto Protocol does not explicitly specify a side payment scheme across countries (Chander and Tulkens (2006), p.11). Transfers would be effected by the international trading in emission entitlements and the Clean Development Mechanism (Chander et al. (2002), p. 113; Barrett (2003), p. 361).

This paper analyzes how the design of IEA's by countries, whether agreements on a uniform standard with transfers or differentiated standards without transfers, affects the decision of national firms to invest in a new abatement technology. To do this, we use a multi-stage game with two asymmetric countries in terms of their benefits from global abatement. For the sake of simplicity, we assume the existence of a representative firm in each country. We study a model in which the choice of the type of agreement by countries and the choice of abatement technology by firms are endogenenous. The choice of the type of the agreement results from the outcome

[3]The Stockholm Convention on Persistent Organic Pollutants (POPs), signed in 2001, has a similar mechanism to the Montreal Protocol. This convention requires the signatory countries to remove the production and the recent intentional use of POPs. Furthermore, a mechanism of financial assistance is incorporated in the provisions of the convention to ensure the participation of the developing countries and the countries of transition in the convention.

[4]*Source*: Bailey (2003), p.183.

[5]*Source*: Bailey (2003), p.182.

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

of negotiations on different agreements. The choice of technology is determined by the comparison of the abatement costs associated with different technologies. This analysis is conducted in the following way. We first identify the effects of the future (negotiated) levels of abatement standards on the current investment decisions of firms. Then, we investigate the conditions under which it is beneficial for all countries to implement one of the agreements in order to obtain a higher level of welfare, in the contexts of irreversible investment by firms and a transboundary pollution problem across countries.

Our paper shows a result which could seem counter intuitive: in the presence of very asymmetric countries, the announcement and implementation of the uniform agreement with transfers is optimal when the level of sunk cost of investment is sufficiently low and the level of the marginal benefit from global abatement is sufficiently high. However, this result does not hold if the level of sunk cost is sufficiently high. In this case, the announcement and implementation of the uniform agreement with transfers takes away the incentives of the private sector to invest, and provides the same level of payoffs for countries who cooperate as for those at the threat point.

The question studied in this paper is in line with two branches of the literature. On the one hand, a part of the literature studies the relationship between national environmental regulation[7] (among others Arguedas and Hamoudi (2004), Bansal and Gangopadhyay (2005)) or international environmental regulation (Golombek and Hoel (2006)) and the decision to invest in technological change or adoption. Another branch of the literature is related to the hold-up problem in industrial organization (McLaren (1997), Muuls (2004))[8] [9].

Concerning the link between national environmental regulation and the decision to invest in technological adoption, Arguedas and Hamoudi (2004) investigate the conditions under which sanctions should depend on the environmental technology of the firm together with the degree of noncompliance. The paper essentially compares the welfare level for the regulator and the payoff level for the firm of two different investment decisions: to invest before the announcement of the national policy, or

[7] See Jaffe et al. (2002) for a survey of the literature.

[8] See for seminal papers Klein et al.(1978), Grossman and Hart (1986), and for recent applications to the EU enlargement Wallner (2003), to the marketable emission permits Gersbach and Glazer (1999).

[9] The paper by Buchholz and Konrad (1994), even though not completely related to these two branches of the literature, needs to be mentioned. Buchholz and Konrad (1994) study the choice between two abatement technologies in a two-stage game. They investigate the incentives of firms to strategically commit to choose a costly abatement technology. The choice of technology is simply reduced to the choice of unit emission reduction costs. The paper shows that it is individually rational for a country to choose a costly abatement technology to increase its bargaining position. This manifests via an increase in the payoff of the country at the threat point. This result comes from two assumptions. First, the investing firm and the government which conducts negotiations are considered as a unit identity. Secondly, the negotiating countries are assumed to be identical. Since the emission levels of the countries are strategic substitutes, then the other country abates more if one of the countries chooses a costly abatement technology.

after. The findings show that it is beneficial for both parties if the firm invests in technology before the policy is announced, in which case the firm has incentives to over-invest, which reduces inspection frequencies and expected penalties. Concerning the link between the national environmental regulation and the decision to invest in technological change, Bansal and Gangopadhyay (2005) study the incentives of a monopolistic firm to invest in R&D under regulatory standards, with the assumption that consumers are willing to pay for environmentally friendly technologies. They study the following regulations: the commitment policy which corresponds to setting standards and fines before the firm undertakes its innovation effort, and the *Best Available Technology* (BAT) based policy which corresponds to setting standards on the basis of the BAT and selecting a fine rate. The main result of the paper is that the commitment policy provides the right incentive for a firm to invest in R&D, because it reduces the uncertainty of innovation for firms.

To our knowledge, there is only the paper, by Golombek and Hoel (2006), which deals with the interaction between the design of IEA's and the decision to invest in technological change. They mainly compare two types of IEA in the presence of technology spillovers across countries: a tax agreement and a quota agreement. They show that the levels of abatement and investment in R&D are lower in the tax agreement than those in the quota agreement. The low levels of the technology subsidy for R&D investments and of the carbon tax in the tax agreement, imply lower levels of abatement and R&D investments, and thus create inefficiencies. For this reason, social costs are lower in the quota agreement. The advantage of considering a (n) country framework is, however, counter-balanced by the assumption that the countries, and the firms in each country, are identical.

The question of decision to invest studied in this paper is in some ways similar to the hold-up problem[10]. In a classical hold-up problem, a firm which considers a relation-specific investment for the production of a good could prefer not to invest if it anticipates the capture, by the consumer, of its rents in the future. In the case of IEA's, a hold-up problem can appear if countries are willing to capture the benefits of their firms, which undertake an investment in a new abatement technology, by imposing more stringent international abatement standards on them. McLaren (1997) analyzes a small country's gains from bilateral trade liberalization. The firms in this country anticipate future negotiations in favor of trade liberalization, then invest accordingly, i.e. by realizing irreversible investments in the export sector. In fact, the firms act as decentralized agents in the economy and reduce, by their complete specialization, the flexibility of the country when it bargains in the future. This manifests by the reduction of its bargaining position in equilibrium, expressed in concessions or side payments from the small country to the large one. Muuls (2004) studies the dynamic effects of irreversible investment on the bargaining position of

[10] It is a situation where the agent (the firm) must realize an initial investment before being in contact with the principal (the country). The reason behind this situation is that the agent and the principal could only meet once the investment is realized (Laffont and Martimort (2002), p.370).

countries in global negotiations on climate change. This is done in a two-countries, two-periods model. The paper assumes that governments can commit to issue marketable permits, whereas they could not commit to a strong penalty for not meeting the regulation. The main result of the paper is that there is an over-investment when firms anticipate a Nash bargained agreement, compared to the first-best investment level. Hence, the hold-up problem does not appear. This result is interpreted as being related to the global public good nature of the problem. The countries are linked by the benefits from global abatement and also on the cost side by permits.

The principal difference of our paper from the rest of the literature relies on the study of the effects of the announced type of IEA's on the decision to adopt technology by the private sector. Firms' choice of technology is based on the level of variable abatement costs and the level of sunk cost of investment in a new abatement technology. The simple two-country framework allows us to consider the case of asymmetric countries in terms of their valuation of the global abatement. Contrary to the approach of Buchholz and Konrad (1994), we let the country and the firm be decentralized agents in the economy. Our paper essentially stresses the importance of a partial commitment by the countries on the announced type of IEA's. However, the countries do not need to commit to the negotiated levels of the provisions of the agreement, such as the levels of abatement standards and transfers.

The article proceeds as follows. Section 2 represents the model and the timing of the game. Section 3 provides the description and the principal results of the game. This description first represents different negotiation problems associated with the agreements on uniform and differentiated standards (stage 3). Moreover, this description includes the study of two specific situations in terms of the decision to invest by firms (stage 2). The description finishes with the analysis of the optimal choice of the type of IEA's by countries (stage 1). Section 4 illustrates the theoretical results by numerical applications on a quadratic example. Finally, Section 5 concludes.

2 The model

We consider two countries facing a transboundary pollution problem. These countries cooperate for the welfare of both in order to mitigate this pollution problem. The countries are assumed to be asymmetric in terms of their benefits from global abatement or their degree of exposure to global pollution. We consider an environmentally conscious country ($ENCC$) (or a country very sensitive to global pollution), and a less environmentally conscious country ($LENCC$) (or a country less sensitive to global pollution). This terminology is adopted from Petrakis and Xepapadeas (1996).

Remember that there is one representative firm in each country. Each firm has rational expectations about the level of the abatement standard that will be negotiated in the future, and consequently it minimizes its abatement cost. The negotiated levels of abatement standards are determined by the use of the Nash bargaining solution (Nash (1950)) . The comparison of IEA's is realized on the base of the Pareto criteria. It is worthwhile to note that we consider a model of perfect expectations where all agents perfectly observe the actions of others and all states of nature.

2.1 Agents in the Economy

There are two types of agents in this economy: two countries and two firms, with one representative firm in each country.

2.1.1 Countries

The countries firstly announce the type of the IEA, whether the agreement on a uniform standard with transfers (UT) or the agreement on differentiated standards without transfers (D), then negotiate the precise levels of standards and transfers (A and A^* in the agreement D, $\bar{A}$ and t in the agreement UT).

The payoff functions of the ENCC and the LENCC are written, respectively, as follows:

$$\begin{aligned} NB(x) &= B(A+A^*) - C(A,x) - t \\ NB^*(x^*) &= \alpha B(A+A^*) - C(A^*,x^*) + t \end{aligned} \tag{1}$$

where A (resp. A^*) represents the negotiated level of the abatement standard of the ENCC (resp. LENCC) with $A \leq 1$ (resp. $A^* \leq 1$), x (resp. x^*) is the decision to invest of the firm in the ENCC (resp. LENCC), expressed in a binary way $x \in \{0,1\}$, and $t > 0$ are transfer payments across the countries. The function $B(.)$ is the benefit function from global abatement, with $B^{'}(.) > 0$ and $B^{''}(.) < 0$. The parameter α represents the asymmetry across the countries. Let $0 < \alpha < 1$ such that the LENCC has lower benefits from global abatement than the ENCC. The function $C(A,x)$ represents the abatement cost function of the firm of the ENCC, which depends on the negotiated level of the abatement standard, A, and on its own decision to invest in a new abatement technology, x.

2.1.2 Firms

The firms decide to invest ($x = 1$) or not ($x = 0$) in a new abatement technology. Consider a situation where national firms already have access to an abatement technology, which allows them to reduce their pollution. But the marginal abatement costs associated with this technology are high. These firms also have the possibility of investing in an alternative technology, which is associated with lower marginal abatement costs. But this initial investment represents some sunk cost. We assume that the firms of both countries have access to the same set of possible abatement technologies.

Concerning the functional forms, we assume that the abatement cost function is increasing and convex in the case of investment in a new technology, i.e. $C'(A\mid_{x=1}) > 0$ et $C''(A\mid_{x=1}) > 0$[11]. For the sake of simplicity, we use a linear abatement cost function in the case of non-investment, i.e. $C''(A\mid_{x=0}) = 0$. The choice of linearity is not crucial[12]. We assume that the marginal abatement costs in the case of investment are lower than those in the absence of investment[13]. This leads to the following functions of abatement cost for the firm of the ENCC:

$$\begin{aligned} C(A) &= \frac{A^2}{2} + F \qquad \text{if } x = 1 \\ C(A) &= A \qquad \text{if } x = 0 \end{aligned} \tag{2}$$

where $x = 1$ (resp. $x = 0$) represents the decision (resp. the absence) of investment in a new abatement technology and F, with $F > 0$, represents the sunk cost of installation of the new technology. This cost is independent of the scale of abatement and is *locked in (sunk) for some short length of time* (Tirole (1988), p.212). These costs can include the acquisition of a new plant and new machines (setup costs), or hiring and training new engineers.

The curves of the two abatement cost functions - in the case of investment and in the absence of investment - are illustrated in Figure 1.

2.2 Timing of the Game

We consider a multi-stage game under a perfect information environment. The game has four stages, and the timeline is represented in Figure 2.

Stage 1: The countries collectively announce the type of the IEA which will be negotiated in the future. In particular, they announce if they will negotiate an

[11] We use a convex variable abatement cost function in the case of investment, as do Muuls (2004) and Bansal and Gangopadhyay (2005). The difference of our abatement cost function from Muuls' is the use of a discrete technology choice variable, and also a sunk cost component. In the model of technology development of Bansal and Gangopadhyay (2005), the cost of investment in technology depends on R&D efforts.

[12] This choice of functional forms ensures the existence of interior solutions.

[13] This implies that the levels of the abatement standards are lower or equal to 1, $A \leq 1$. This interpretation is valid if we assume that the emission levels of a base year are the same for the two countries and are normalized to 1. We can express this relationship in the following way: $A = \beta \bar{E}$ and $A^* = \beta^* \bar{E}^*$ where $\beta \leq 1$ (*resp.* $\beta^* \leq 1$) is the percentage abatement rate for the ENCC (*resp.* LENCC), and $\bar{E}$ (*resp.* $\bar{E}^*$) is its emission level of a base year. To assume $\bar{E} = \bar{E}^* = 1$ allows us to have $A = \beta \leq 1$ and $A^* = \beta^* \leq 1$.

We could justify it in the following way. 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 could be only determined by their respective size of population, and not by their sensitivity to global pollution. We assume that the countries have the same size of population, which could lead them to have the same level of emissions in a base year in the past.

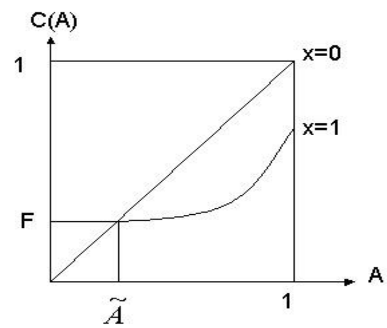

Figure 1: Abatement cost functions

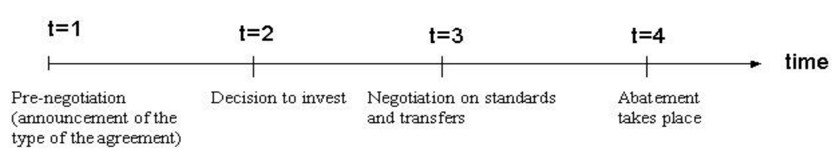

Figure 2: Timing of the game

agreement on a uniform standard with transfers or an agreement on differentiated standards without transfers. This collective decision between governments results from bilateral negotiations which are not explicitly modeled in this paper. This situation can be considered as a pre-negotiation phase (Barrett (2003), p.139). This situation can be interpreted in a different manner as well. As Barrrett (2003, p.139) emphasizes, countries first negotiate a convention, which establishes general principles, and then negotiate its "protocols" which prescribe precise obligations in specific domains. This is the case of the Vienna Convention (1985) and its associated Montreal Protocol (1987), the Framework-Convention of the United Nations on Climate Change (1992) and its associated Kyoto Protocol (1997). This stage of the game can thus be considered as an announcement stage following the signature of a convention, whereas the negotiation at stage 3 of the game can be considered as a negotiation on the different protocols of the convention.

Stage 2: The representative firm in each country decides whether to invest or not in a new abatement technology. This initial investment is irreversible, and therefore implies a sunk cost, but contributes to the reduction of the future marginal abatement costs. The lag between the decision to invest by firms and the negotiation process of governments could be justified by the time required for the investment in abatement activities. The investment of the private sector is a long-term activity in the sense that it takes time to construct new plants, to buy new machines and to hire and give training to new engineers[14].

It is important to note that we implicitly assume that the abatement decision of a firm is independent of its decision on production. This property holds for a specific class of clean-up technologies called "end-of-pipe", which represent the majority of the abatement technologies currently used by firms[15]. Skea (2000) reports that the proportion of end-of-pipe technologies in pollution control investment is 80% in Belgium, 82% in Germany and 87% in France.

Stage 3: The countries bargain over the precise levels of standards and transfers. If this is an agreement D, they negotiate the levels of differentiated standards (A and A^*). On the other hand, if this is an agreement UT, they negotiate the levels of the uniform standard ($\bar{A}$) and the transfer (t). Here, we consider cooperative behavior between governments in the sense that countries may prefer to improve their payoffs via a cooperative agreement. Thus we use the Nash bargaining solution as equilibrium, in order to analyze the outcome of negotiations.

It is important to note that we implicitly assume that the governments respect

[14] As Hall and Khan (2003) stress, since the technology often is a specific asset, employees need to be trained to operate the new technology. For example, in the case of the Kyoto Protocol, the substitution technologies keep evolving, which indicates the time required for the investment in new abatement technologies.

[15] "*End-of-pipe refers to equipment which can be attached to existing industrial processes in order to mitigate the environmental consequences of their operation*" (Skea (2000), p.338). In this sense, these abatement technologies are opposed to clean or "beginning-of-pipe" technologies.

their collective announcement of the type of the IEA, once the decisions to invest are taken by firms. This means that the governments are able to commit for a long span of time. This commitment could be justified in two ways. Firstly, the initial announcement could be thought as "cheap-talk" because the announcement on its own does not affect the payoffs of the countries. Secondly, the respect of the announcement could be necessary if the governments consider some reputation effects on the international level or fear international sanctions in other negotiations.

Stage 4: The representative firm in each country abates according to the abatement burden imposed by the agreement. We implicitly assume that the firm in each country completely complies with these regulations. This requires the assumption that the governments are able to commit to the stringency of a penalty for the firm which does not respect standards. If the governments could not commit to these penalties, the best response of a cost minimizing firm would be not to abate, and then not to realize the investment.

The extent of this work is limited to the case where the government only uses standards and transfers in order to induce the firm to invest. The governments control *ex post* the emission levels of their firms, but do not intervene in such a way as to attain a given objective of emission reduction. The decision to invest in a new abatement technology belongs entirely to firms[16].

It is worthwhile to note that there is an interaction between stages 2 and 3 of this game. The current decisions to invest by the firms affect the levels of abatement standards and transfers that will be negotiated in the future. Correspondingly, the anticipated levels of abatement standards and transfers that will be negotiated in the future have an impact on the current investment decisions of the firms.

2.3 Resolution of the Game

We use the method of backward induction in order to determine the sub-game perfect equilibrium of the game. At stage 4 of the game, we determine the total abatement costs of firms by using formula 2. We start the backward induction at stage 3 of the game, where the countries bargain over the levels of abatement standards and transfers, after they have announced the type of the IEA at stage 1 of the game and after they have observed the investment decisions of their firms at stage 2 of the game. Then, we examine at stage 2 of the game, if the firms decide to invest or not in a new abatement technology, after they have observed the collective announcement of the countries about the type of the IEA, and by anticipating the future levels of abatement standards that will be negotiated at stage 3 of the game. Finally, at stage

[16]Note also that we consider the IEA's which do not specify elements related to R&D investments. As Golombek and Hoel (2006) argue, the first reason is the difficulties in monitoring compliance of R&D policies, and the other reason is the observation that the Kyoto agreement does not include provisions related to R&D investments. Thus the IEA's considered in this paper do not include negotiation variables on technological issues.

1 of the game, we determine the collective announcement of the countries on the type of the IEA. This announcement is realized by anticipating the investment decisions of the firms in the future.

3 Description and Results of the Game

3.1 Stage 3: Negotiation of the effective levels of abatement standards

At this stage of the game, the countries negotiate the effective levels of abatement standards and transfers according to their collective announcement. As we have already mentioned, we use the Nash bargaining solution in order to determine the outcome of negotiations. In order to concentrate on the asymmetry of the countries in terms of their environmental tastes, we assume that the two countries have the same negotiation power.

Three situations of investment are possible[17]:

- Only the firm of the ENCC invests: $x = 1$ and $x^* = 0$
- All the firms invest: $x = x^* = 1$
- No firm invests: $x = x^* = 0$

In order to calculate the outcome of negotiations, we must first define the payoff levels at the threat point.

3.1.1 Nash Equilibrium

We assume that the countries choose Nash equilibrium strategies when they do not cooperate. The objective of the ENCC is to maximize its payoffs, taking the abatement level of the LENCC, A^*, as given:

$$\underset{A}{Max}\left[B(A + A^*) - x(\frac{A^2}{2} + F) - (1 - x)A\right] \qquad (3)$$
$$\text{s.c. } A \leq 1; A^* \leq 1$$

The program of the LENCC is written in a similar way, only its benefit function differs:

[17]Intuition leads us to say that the fourth situation, where only the firm of the LENCC invests, $x = 0$ and $x^* = 1$, cannot happen. We show this impossibility for a small value of α, in the neighborhood of $\alpha = 0$, in Appendix D2.

$$Max_{A^*}\left[\alpha B(A+A^*)-x^*(\frac{A^{*2}}{2}+F)-(1-x^*)A^*\right] \quad (4)$$
$$A\leq 1; A^*\leq 1$$

The first-order conditions for the ENCC and the LENCC are respectively:

$$\begin{cases} B^{'}(A+A^*)=Ax+(1-x) \\ B^{'}(A+A^*)=\dfrac{A^*x^*+(1-x^*)}{\alpha} \end{cases} \quad (5)$$

These conditions give the equality of the individual marginal benefits from global abatement to the individual marginal abatement costs.

In the following, we will define the levels of abatement and welfare at the Nash equilibrium in the case where only the firm of the ENCC invests ($x=1$ and $x^*=0$). The results for the two other couples of investment decision, $x=x^*=1$ and $x=x^*=0$, are provided respectively in Appendices B and C. If we consider the case where only the firm of the ENCC invests, the levels of abatement at the Nash equilibrium are defined in the following way:

$$\begin{aligned} \hat{A} &= 1 \\ \hat{A}^* &= B^{'-1}(\frac{1}{\alpha})-1 \end{aligned} \quad (6)$$

because the countries are asymmetric $0<\alpha<1$ and the levels of abatement cannot exceed 1.

These abatement levels at the Nash equilibrium give us the payoff levels $\overset{\wedge}{NB}$ and $\overset{\wedge}{NB}^*$ at the threat point of the negotiation:

$$\begin{aligned} \overset{\wedge}{NB} &= B(B^{'-1}(\frac{1}{\alpha}))-\frac{1}{2}-F \\ \overset{\wedge}{NB}^* &= \alpha B(B^{'-1}(\frac{1}{\alpha}))-B^{'-1}(\frac{1}{\alpha})+1 \end{aligned} \quad (7)$$

Once the payoffs at the Nash equilibrium are calculated, we can find the outcome of negotiations for the two types of IEA's and compare the negotiated abatement levels. We first start by analyzing the outcome of negotiation of an agreement of differentiated standards without transfers.

3.1.2 Differentiated Standards without Transfers

The Nash bargaining solution writes:

$$\begin{aligned} & Max_{A,A^*}\left[B(A+A^*)-x(\frac{A^2}{2}+F)-(1-x)A-\overset{\wedge}{NB}\right]\times \\ & \left[\alpha B(A+A^*)-x^*(\frac{A^{*2}}{2}+F)-(1-x^*)A^*-\overset{\wedge}{NB}^*\right] \\ A & \leq 1; A^*\leq 1 \end{aligned} \tag{8}$$

If we note $V = U \times U^*$, given an interior solution, the first-order conditions are as follows:

$$\begin{aligned} \frac{\partial V}{\partial A} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial A}U+\frac{\partial U}{\partial A}U^*=0 \\ &\Longleftrightarrow \left[\alpha B^{'}(A+A^*)\right]U+\left[B^{'}(A+A^*)-xA-(1-x)\right]U^*=0 \end{aligned} \tag{9}$$

$$\begin{aligned} \frac{\partial V}{\partial A^*} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial A^*}U+\frac{\partial U}{\partial A^*}U^*=0 \\ &\Longleftrightarrow \left[\alpha B^{'}(A+A^*)-x^*A^*-(1-x^*)\right]U+\left[B^{'}(A+A^*)\right]U^*=0 \end{aligned} \tag{10}$$

If we take the ratio of the first-order conditions, we obtain:

$$\frac{\alpha B^{'}(A+A^*)}{[\alpha B^{'}(A+A^*)-x^*A^*-(1-x^*)]}=\frac{\left[B^{'}(A+A^*)-xA-(1-x)\right]}{B^{'}(A+A^*)} \tag{11}$$

which implicitly defines the contract curve where the solution lies. The contract curve represents the locus of points along which the indifferent curves of the two countries are tangent.

By rearranging the first-order conditions, we also have:

$$\begin{aligned} B^{'}(A+A^*)(\alpha U+U^*) &= xAU^*+(1-x)U^* \\ B^{'}(A+A^*)(\alpha U+U^*) &= x^*A^*U+(1-x^*)U \end{aligned} \tag{12}$$

which implicitly defines the “agreement locus” where the solution lies. This locus determines the specific point on the contract curve. This point represents the outcome of the international agreement on differentiated standards without transfers and is given by the Nash bargaining solution.

In our case where the ENCC invests and the LENCC does not invest ($x = 1$ and $x^* = 0$), Condition 11 becomes:

$$B^{'}(A+A^{*})=\frac{A}{1+\alpha A} \tag{13}$$

which is the expression of the marginal benefit from global abatement.
Condition 12 becomes:

$$\begin{aligned} B^{'}(A+A^{*})(\alpha U+U^{*}) &= AU^{*} \\ B^{'}(A+A^{*})(\alpha U+U^{*}) &= U \end{aligned} \tag{14}$$

which implies:

$$AU^{*}=U \tag{15}$$

As $A \leq 1$ by definition, the gains from cooperation of the LENCC (relative to its payoff at the threat point) are superior or equal to those for the ENCC, i.e. $U^{*} \geq U$, in the agreement of differentiated standards without transfers. This result can be explained in the following way. Since the LENCC benefits less from global abatement ($0<\alpha<1$) and its firm does not invest in a new technology, then its negotiated differentiated standard is low whereas that of the ENCC is high for the opposite reasons. Then, the low abatement costs of the LENCC compensate, in certain cases, for its low abatement benefits from global abatement. This, in turn, could make the LENCC better off compared to the ENCC.

We now analyze the outcome of negotiation for an agreement on a uniform standard with transfers.

3.1.3 Uniform Standard with Transfers

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

$$Max_{\bar{A},t}\left[B(\bar{A}+\bar{A})-x(\frac{\bar{A}^{2}}{2}+F)-(1-x)\bar{A}-t-N\hat{B}\right]\times \tag{16}$$
$$\left[\alpha B(\bar{A}+\bar{A})-x^{*}(\frac{\bar{A}^{2}}{2}+F)-(1-x^{*})\bar{A}+t-N\hat{B}^{*}\right]$$
$$\bar{A} \leq 1$$

In this program, the abatement standards must be equal between the countries, but transfers can be positive. We proceed in the same manner as the preceding sub-section.

If we note $V = U \times U^*$, given an interior solution, the first-order conditions are the following:

$$\begin{aligned}
\frac{\partial V}{\partial \bar{A}} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial \bar{A}}U + \frac{\partial U}{\partial \bar{A}}U^* = 0 \qquad (17)\\
&\Longleftrightarrow \left[2\alpha B^{'}(\bar{A}+\bar{A}) - x^*\bar{A} - (1-x^*)\right]U + \left[2B^{'}(\bar{A}+\bar{A}) - x\bar{A} - (1-x)\right]U^* = 0\\
\frac{\partial V}{\partial t} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial t}U + \frac{\partial U}{\partial t}U^* = 0 \Longleftrightarrow U - U^* = 0\\
&\Longleftrightarrow U = U^*
\end{aligned}$$

The gains from cooperation of the countries are identical in the presence of uniform standards with transfers. This result can be explained by the presence of side payments. In fact, the preferred level of the uniform standard diverges for the two countries. The fact that the LENCC benefits less from global abatement and its firm does not invest in a new technology decreases its preferred level, whereas the preferred level by the ENCC is higher since it benefits more from global abatement and its firm has lower marginal abatement costs thanks to the investment. Transfers allow an equal share of the negotiation surplus by the two countries.

This property leads to the following relationship:

$$\Longleftrightarrow U\left[2\alpha B^{'}(\bar{A}+\bar{A}) - x^*\bar{A} - (1-x^*) + 2B^{'}(\bar{A}+\bar{A}) - x\bar{A} - (1-x)\right] = 0 \qquad (18)$$

$$\Longleftrightarrow B^{'}(\bar{A}+\bar{A}) = \frac{\bar{A}(x+x^*) + 2 - x - x^*}{2(\alpha+1)} \text{ because } U \neq 0 \qquad (19)$$

which is the expression of the marginal benefit from global abatement.

In the following, we use the conditions on the expression of the marginal benefit from global abatement in different agreements, in order to compare the levels of differentiated standards with the level of the uniform standard[18].

3.1.4 Comparison of the Levels of Standards

The comparison of the abatement levels for the couples of decision of investment $x = 1$ et $x^* = 0$[19], $x = x^* = 1$ and $x = x^* = 0$ is provided respectively in Appendices

[18] It is easy to show, by using the first-order conditions, that the negotiated abatement levels are independent of the level of sunk cost F. Even though the level of sunk cost has a crucial role in the investment decision of the firms, it does not affect the negotiated abatement levels. This is so, because in the timing of the game, the levels of abatement standards and transfers are negotiated after the investment decision of the private sector and the abatement cost function is additively separable.

[19] Here, we use Conditions 13 and 19 on the expression of the marginal benefit from global abatement in order to compare the negotiated abatement levels in different agreements. The proof of Lemma 1, in this case, requires the technical assumption $B'(0) > \frac{1}{2}$ when $\alpha = 0$.

A1, B4 and C4. We obtain the following result:

Lemma 1 $\bar{A}$ is necessarily located between A and A^*, or more precisely $A^* < \bar{A} < A$ for very asymmetric countries (a small value of α, in the neighborhood of 0).

This lemma shows that for every possible configuration of the choice of investment of the firms, the level of the uniform standard is situated between the two differentiated standards when the countries are very asymmetric[20]. This result confirms the intuition that the LENCC abates less than the ENCC in the differentiated agreement when the firm of the former does not invest and the firm of the latter invests. Since the uniform standard reflects the preferences of both countries, its level is situated between the two levels of differentiated standards.

The task we should deal with now is the comparison of the levels of the uniform standard obtained from different configurations of investment (see Appendix E). This task is difficult to realize with the levels of differentiated standards. We find that $\bar{A}(x = x^* = 1) \geq \bar{A}(x = 1; x^* = 0) \geq \bar{A}(x = x^* = 0)$. This indicates that the uniform standard, when all the firms invest, is superior to or equal to that obtained when only the firm of the ENCC invests, and to that obtained when no firm invests. The investment of the firm contributes to the increase of the uniform standard.

3.2 Stage 2: Decision of investment of the firms

We analyze the investment choice of the firms according to the type of the IEA. The investment decision of a firm requires the satisfaction of two conditions: the *threshold* condition and the *cost* condition.The first condition implies that the negotiated abatement level exceeds the threshold abatement level $\tilde{A}$ above which it is advantegeous to invest:

- threshold condition: $A > \tilde{A}$

This threshold abatement level is found by the intersection of the two cost curves, the one when the firm invests, $(\frac{A^2}{2} + F)$, and the other when the firm does not invest, (A) :

$$\frac{A^2}{2} + F = A \Longleftrightarrow \frac{A^2}{2} - A + F = 0 \tag{20}$$

$$\Longleftrightarrow \tilde{A} = 1 - \sqrt{1 - 2F} \tag{21}$$

with $\tilde{A} \leq 1$ and $1 - 2F \geq 0 \Longleftrightarrow F \leq \frac{1}{2}$.

[20] When no firms invest, $x = x^* = 0$, this result always holds for every value of the parameter α, by the assumption on the form of the benefit function.

A firm has an interest in investing if the level of sunk cost is sufficiently low ($F \leq 1/2$). It is easy to check that the threshold abatement is an increasing and convex function of F.

It is important to note that the threshold condition is a necessary condition, but not a sufficient one. A firm will have the right incentives to invest in a new technology if the cost condition is also satisfied.

- cost condition: $C(A\mid_{x=1}) < C(A\mid_{x=0})$

Thus, a firm does not invest if its costs when it invests (with an implied level of the abatement standard) exceed those when it does not invest (with another implied level of the abatement standard), and this even if the negotiated abatement standard is higher than the threshold abatement level. This situation could illustrate the hold-up problem. The idea is the following: given that the firms have invested in a new abatement technology, the countries agree on higher levels of abatement standards. These high-level standards could make firms worse off compared to a situation of non-investment. More precisely, their costs in the case of investment could exceed those in the case of non-investment. Hence the firms could prefer not to invest.

We now describe all the permutations in firms' choice of investment (see Table 3). Firstly, we show in Appendix D2 that the LENCC never has incentives to invest in the differentiated agreement, when the parameter α is very small. Since the LENCC is not very sensitive to global pollution in this case, it has no interest in abating much, and this country's firm is not willing to invest. Then, we exclude from the analysis the case where no firm invests, no matter which type of agreement is implemented. This could be the case when the level of sunk cost is too high. Furthermore, it is impossible that only one country invests in the case of implementation of the uniform agreement. It is obvious that the investment decisions of the two countries could not diverge in the uniform agreement, because there is a common standard imposed on all the countries, and the firms dispose of the same set of possible abatement technologies. Finally,we did some simple numerical applications to check if it is possible that no firm invests when a differentiated agreement is announced (non-satisfaction of the threshold condition for the LENCC and non-satisfaction of the cost condition for the ENCC) and that all the firms invest when a uniform agreement is announced. For the values of the parameters of interest (satisfying the conditions on the concavity of objective and social welfare functions), we observe that this case cannot happen.

In this paper, we essentially focus on two situations for which the equilibrium is unique[21]. The first situation is the "*incentive uniform standard*". In this case, the

[21] A natural question is to ask why we deal with these two specific situations. In fact, the objective of the countries is to induce their firms to invest in a new abatement technology, because they obtain higher levels of gain from cooperation in this case (the UT agreement where all the firms invest) compared to all other cases (the UT agreement where no firm invests and the D agreement where only the firm of the ENCC invests).

D \ UT	x=0; $x^*=0$	x=0; $x^*=1$	x=1; $x^*=0$	x=1; $x^*=1$
x=0 $x^*=0$	Excluded from the analysis: F too high	Impossible: only one country invests in the agreement UT	Impossible: only one country invests in the agreement UT	Impossible : numerical simulations
x=0 $x^*=1$	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D
x=1 $x^*=0$	The agreement **D** is chosen **(proposition 1b)**	Impossible: only one country invests in the agreement UT	Impossible: only one country invests in the agreement UT	The agreement **UT** is chosen **(proposition 1a)**
x=1 $x^*=1$	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D	Impossible : LENCC never has incentives to invest in the agreement D

Figure 3: Investment decisions of firms

announcement and implementation of the uniform agrement with transfers gives an incentive to both countries to invest, whereas the announcement and implementation of the differentiated agreement without transfers would induce only the ENCC to invest. The other situation is the "*disincentive uniform standard*". In this case, following the announcement and implementation of the uniform agreement with transfers, no firm invests, whereas the announcement and implementation of the differentiated agreement without transfers would induce the ENCC to invest.

We now define the "incentive uniform standard" and the "disincentive uniform standard" cases.

Definition 1 *We call an incentive uniform standard (resp. a disincentive uniform standard) the situation where*

a) the countries collectively announce an agreement on a uniform standard with transfers

b) all the firms invest (resp. no firms invest)

c) the countries negotiate the precise levels of the uniform standard and the transfer

d) the firms abate according to the obligations of the agreement

In the following, we study the conditions of existence of the two situations. We start by the "incentive uniform standard" case.

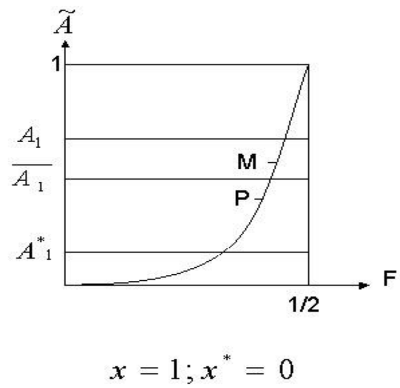

Figure 4: The "incentive" and "disincentive" uniform standards

a) Incentive uniform standard

It is a situation where the announcement and implementation of the uniform agrement with transfers gives an incentive to both countries to invest, whereas the announcement and implementation of the differentiated agreement without transfers would induce only the ENCC to invest. After the announcement of a uniform agrement with transfers, a firm invests if it anticipates a negotiated level of the uniform standard such that the threshold and the cost conditions are met. Or in other words, the level of the uniform standard exceeds the threshold abatement level above which it is advantegeous to invest, and the costs of the firm when it invests are lower than its costs when it does not invest. Figure 4 illustrates the incentive uniform standard from the point of view of the threshold condition. It represents the curve of the threshold abatement, in the case where only the firm of the ENCC invests. On the Y-ordinate of the figure, we also indicate the negotiated abatement standards - differentiated standards A_1 and A_1^* and the uniform standard $\bar{A}_1$ in the case $x = 1$ and $x^* = 0$ - that we know their ranking in the case of asymmetric countries .

Let us suppose that the threshold is presented by the point P on Figure 4. For a given level of sunk cost F, the announcement and implementation of differentiated standards gives the right incentives to the firm of the ENCC to invest (assuming that the cost condition is met), because the abatement standard of the ENCC exceeds the threshold, whereas they do not have the same effect for the firm of the LENCC, because the standard of the LENCC falls below the threshold. On the other hand, the announcement and implementation of the uniform standard gives the right incentives to both countries to invest (assuming that the cost condition is satisfied), because the uniform standard exceeds the threshold. This means that, in this case, the announcement and implementation of the uniform standard has a higher incentive effect ($x = x^* = 1$) than those of differentiated standards ($x = 1$ and $x^* = 0$).

We call A, A^* and $\bar{A}$ respectively the differentiated standard of the ENCC, the differentiated standard of the LENCC and the uniform standard. The negotiated abatement levels resulting from different investment decisions are written in the following way:

$x = 1, x^* = 0 \Longrightarrow A_1, A_1^*, \bar{A}_1$

$x = x^* = 1 \Longrightarrow A_2, A_2^*, \bar{A}_2$

$x = x^* = 0 \Longrightarrow A_3, A_3^*, \bar{A}_3$

We now characterize the conditions of existence of an "incentive uniform standard":

1) The firm in the LENCC does not invest in the agreement on differentiated standards without transfers.

$$\begin{aligned} &\text{threshold condition:} && A_1^* < \tilde{A} \text{ or} \\ &\text{cost condition:} && A_1^* > \tilde{A} \text{ and } A_1^* < \frac{A_2^{*2}}{2} + F \end{aligned}$$

2) The firm in the ENCC invests in the agreement on differentiated standards without transfers.

$$A_1 > \tilde{A} \text{ and } \frac{A_1^2}{2} + F < A_3$$

3) The firms in the ENCC and the LENCC invest in the agreement on a uniform standard with transfers.

$$\bar{A}_1 > \tilde{A} \text{ and } \frac{\bar{A}_2^2}{2} + F < \bar{A}_1 \text{ and } \frac{\bar{A}_2^2}{2} + F < \bar{A}_3$$

We now turn to the analysis of the "disincentive uniform standard".

b) Disincentive uniform standard

It is a situation where the announcement and implementation of the uniform agreement with transfers takes away the incentive of both countries to invest, whereas the announcement and implementation of the differentiated agreement without transfers would induce the ENCC to invest. This could happen because of two reasons. Firstly, the level of the uniform standard falls below the threshold abatement level (non-satisfaction of the threshold condition). Secondly, the firm does not invest because it anticipates higher abatement costs when it invests, compared to those when it does not invest (non-satisfaction of the cost condition). Figure 4 also illustrates the disincentive uniform standard from the point of view of the threshold condition.

Let us suppose that the threshold is presented by the point M on Figure 4. For a given level of sunk cost F, the announcement and implementation of differentiated standards leads to the same consequences in terms of investment decisions as in the "incentive uniform standard" case. On the other hand, the announcement and implementation of the uniform standard takes away the incentives of both countries to invest, because the uniform standard falls below the threshold. This means that, in this case, the announcement and implementation of the uniform standard has a lower incentive effect ($x = x^* = 0$) than that of differentiated standards ($x = 1$ and $x^* = 0$).

We now turn to the characterization of the conditions of existence of a "disincentive uniform standard":

1) The firm in the LENCC does not invest in the agreement on differentiated standards without transfers.

$$\begin{aligned} \text{threshold condition:} \quad & A_1^* < \tilde{A} \text{ or} \\ \text{cost condition:} \quad & A_1^* > \tilde{A} \text{ and } A_1^* < \frac{A_2^{*2}}{2} + F \end{aligned}$$

2) The firm in the ENCC invests in the agreement on differentiated standards without transfers.

$$A_1 > \tilde{A} \text{ and } \frac{A_1^2}{2} + F < A_3$$

These two conditions are common to the cases of "incentive uniform standard" and "disincentive uniform standard".

3) The firms in the ENCC and the LENCC do not invest in the agreement on a uniform standard with transfers.

$$\begin{aligned} \text{threshold condition} \ : \quad & \bar{A}_1 < \tilde{A} \text{ or} \\ \text{cost condition:} \quad & \bar{A}_1 > \tilde{A} \text{ and } \frac{\bar{A}_1^2}{2} + F > \bar{A}_3 \text{ and } \frac{\bar{A}_2^2}{2} + F > \bar{A}_3 \end{aligned}$$

c) Numerical illustration

In order to characterize the conditions of existence of the "incentive uniform standard" and "disincentive uniform standard" cases, we focus on the case of very asymmetric countries, i.e. the case where the parameter α is small (the LENCC is not very sensitive to global pollution), in the neighborhood of 0. In fact, there is no role to play for the type of IEA's in terms of the incentives to provide to the private sector to invest, when the countries are identical (the case of $\alpha = 1$). In this case, the countries have the same sensitivity to global abatement. Then the levels of differentiated standards are the same, the standard is uniform. Furthermore, we know that the national firms have, by definition, the same set of possible abatement technologies. Under these properties, the announcement and implementation of standards (no matter whether differentiated or uniform) leads either to the absence of investment or to full investment by all the firms, according to the level of sunk cost of investment. It turns out that the levels of welfare only depend on the existence or the absence of investment, and do not depend on the type of the IEA.

In Appendix F, we define the negotiated levels of standards regarding the investment decisions of firms, when $\alpha = 0$. By continuity, the results still hold in the neighborhood of $\alpha = 0$. Below, we summarize these results:

$$
\begin{aligned}
A_1^* &= A_2^* = A_3^* = 0 \text{ and } A_1 = A_2 = A = B'^{-1}(A) \text{ and } A_3 = B'^{-1}(1) \\
\bar{A}_1 &= 2B'(2\bar{A}_1) - 1 \text{ and } \bar{A}_2 = B'(2\bar{A}_2) \text{ and } \bar{A}_3 = \frac{1}{2}B'^{-1}(1)
\end{aligned}
$$

It is then possible to define the conditions related to the existence of the "incentive uniform standard" and "disincentive uniform standard" cases by using these expressions of abatement standards, which are usually defined as implicit functions. In order to simplify the interpretation of these conditions, we illustrate them by a quadratic example. We provide in Section 4 an illustration of the theoretical results by a quadratic example (quadratic benefit function) in the case where the LENCC is not very sensitive to global abatement ($\alpha = 0.001$). We provide here the results on the investment decision of the firms. In this case, we check the theoretical result obtained, that the LENCC never has incentives to invest if an agreement of differentiated standards is implemented. The reason is that the abatement standard is so low that it falls below the threshold. Then, we have a situation where the announcement and implementation of the agreement D leads only the ENCC to invest. Figure 5 illustrates the different values of sunk cost for which the "incentive uniform standard" and "disincentive uniform standard" cases happen. It represents the curve of the threshold abatement in the case where only the firm of the ENCC invests.

We notice, on the one hand, that the implementation of the agreement of uniform standards with transfers gives the right incentives to invest to all firms for a low value of sunk cost, i.e. $F < 0.3748$ ("incentive uniform standard"). The same agreement completely takes away the incentives to invest for both firms when the level of sunk

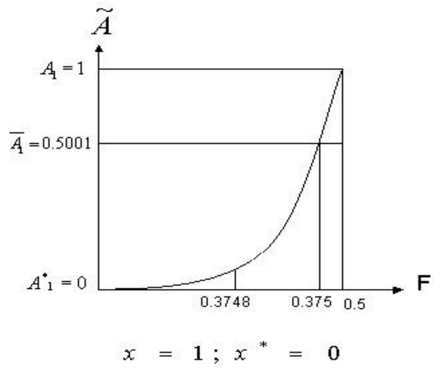

Figure 5: Example of investment decision

cost is high, i.e. $0.375 < F < O.5$, in which case the level of the uniform standard falls below the threshold abatement level ("disincentive uniform standard" related to the threshold condition). The absence of investment related to the cost condition is illustrated for a medium level of sunk cost, i.e. $0.3748 < F < 0.375$ ("disincentive uniform standard" related to the cost condition)[22].

We now study Stage 1 of the game.

3.3 Stage 1: Optimal choice of the type of the IEA

At this stage of the game, the countries optimally choose the type of the IEA. The optimality is defined in the Pareto sense. This means that the individual welfare of a country in the optimal agreement must exceed the one in the alternative agreement, and the other country must obtain at least the same individual welfare as in the alternative agreement.

We present here the principal proposition of the paper.

Proposition 1 *a) In the case of very* asymmetric *countries (small α), the announcement and implementation of the agreement of uniform standards with*

[22] In the simpler particular case where the abatement cost function is linear, $C = \left[x\frac{A}{F_2} + (1-x)A\right] + xF$ where F_2 is a constant superior to 1, and where the benefit function is linear, the uniform standard is always an incentive, and never a disincentive.

transfers is optimal for each country if the level of sunk cost is sufficiently low (F low) and if the marginal benefits from global abatement are sufficiently high ($B^{'}(.)$ high) [**incentive uniform standard**].

b) It is no longer optimal for a higher level of sunk cost (F high) [**disincentive uniform standard**].

In order to show this proposition, we will analyze the conditions under which it is beneficial or not for the countries to announce the agreement of uniform standards with transfers, when they anticipate that all the firms will invest, or that no firm will invest. To show part (a) of the proposition, we will show in Proposition (1a), the optimality of the announcement of the uniform agreement with transfers in the case where the countries anticipate that their firms will invest. In order to show part (b) of the proposition, we will show in Proposition (1b) the sub-optimality of the announcement of the uniform agreement with transfers in the case where the countries anticipate that their firms will not invest.

a) Incentive uniform standard

The property of subgame perfect equilibrium of the model requires that the announcement (and implementation) of the uniform agreement with transfers is optimal, when the firms in the ENCC and the LENCC invest. The individual welfare of a country in this case then needs to exceed the welfare which would prevail in the differentiated agreement without transfers when only the firm of the ENCC invests. The other country must obtain at least the same individual welfare as in the latter agreement.

The condition we are looking for is the following:

$$\text{(ENCC)} \quad \left[B(\bar{A}+\bar{A}) - \frac{\bar{A}^2}{2} - F - t - \hat{NB}_2\right] \geq \left[B(A+A^*) - \frac{A^2}{2} - F - \hat{NB}_1\right] \tag{22}$$

$$\text{(LENCC)} \quad \left[\alpha B(\bar{A}+\bar{A}) - \frac{\bar{A}^2}{2} - F + t - \hat{NB}_2^*\right] \geq \left[\alpha B(A+A^*) - A^* - \hat{NB}_1^*\right]$$

and for one of the two countries,
the inequality is strict.

where $\hat{NB}_1$ (resp. $\hat{NB}_1^*$) and $\hat{NB}_2$ (resp. $\hat{NB}_2^*$) represent respectively the levels of welfare of the ENCC (resp. LENCC) at the threat point of the negotiations when the investment decisions are $x = 1$, $x^* = 0$ and $x = x^* = 1$.

Our reference point in the analysis of welfare is the situation where the LENCC has no sensitivity to global pollution, i.e. $\alpha = 0$[23].

[23]See Appendix G1 for the proof of this proposition and Appendix G2 for an illustration of the

Proposition 1a *In the case where $\alpha = 0$, the uniform agreement with transfers when all the firms invest, dominates in the Pareto sense, the differentiated agreement without transfers when only the firm of the ENCC invests, if $(B'(2\bar{A}))$ is sufficiently large.*

We can find a similar result for a small value of α, in the neighborhood of $\alpha = 0$, using a continuity argument of the optimal social welfare functions (or the functions of the Nash bargaining solution) at the differentiated agreement when only the firm of the ENCC invests and at the uniform agreement when both firms invest. By *Berge's theorem of the maximum* (de la Fuente (2000)), it can be shown that the social welfare function and the set of maximizers change continuously with the parameters, given that the objective function is continuous. Since our functions of the Nash bargaining solution are continuous, the superior (in the sense of Pareto) result of the uniform agreement when all firms invest over the differentiated agreement, when only the firm of the ENCC invests, holds for a small value of the parameter α, in the neighborhood of $\alpha = 0$.

This result can be summarized and explained in the following way. In the presence of very asymmetric countries, the announcement (and implementation) of a uniform agreement with transfers is optimal, if the level of sunk cost is sufficiently low and the level of the marginal benefit from global abatement is sufficiently high. In the presence of a low sunk cost of investment, the announcement (and implementation) of the uniform agreement with transfers induces all the firms to invest in a new abatement technology, whereas that of the differentiated agreement without transfers induces only the firm of the ENCC to invest. In the presence of a high marginal benefit from global abatement, the implementation of the uniform agreement with transfers, when all the firms invest, provides better levels of gain from cooperation than that of the differentiated agreement without transfers, where only the firm of the ENCC invests. In fact, the existence of a side payment scheme compensates for the additional abatement efforts in the LENCC in the uniform agreement, and therefore induces it to participate in the cooperative agreement.

We can interpret these results in the following way. In the presence of a country which is not very environmentally conscious (LENCC), - which would agree on a very low abatement standard in the negotiations of a differentiated agreement -, it is Pareto-improving for the countries to announce in advance that they will negotiate a uniform agreement with transfers in the future, in order to induce the firm of the LENCC to invest. In fact, the firm of the LENCC would anticipate a higher abatement standard in this case compared to that which would prevail in the negotiation of differentiated standards. Furthermore, it anticipates that this level of the uniform standard will maintain its incentives to invest in terms of total abatement costs. Hence the firm of the LENCC prefers to invest. This result depends, however, on a low level of sunk cost of investment in the new abatement technology.

same proposition by a quadratic example with $\alpha = 0$.

b) Disincentive uniform standard

The property of subgame perfect equilibrium of the model requires that the announcement (and implementation) of the differentiated agreement without transfers is optimal for each country, when only the firm of the ENCC invests. The individual welfare of a country in this case then needs to exceed the welfare which would prevail in the uniform agreement with transfers when no firm invests. The other country must obtain at least the same individual welfare as in the latter agreement.

The condition we are looking for is the following:

$$\begin{aligned}
&(\text{ENCC}) \quad \left[B(A+A^*) - \frac{A^2}{2} - F - \hat{N}B_1\right] \geq \left[B(\bar{A}+\bar{A}) - \bar{A} - t - \hat{N}B_3\right] \qquad (23)\\
&(\text{LENCC}) \quad \left[\alpha B(A+A^*) - A^* - \hat{N}\overset{*}{B_1}\right] \geq \left[\alpha B(\bar{A}+\bar{A}) - \bar{A} + t - \hat{N}\overset{*}{B_3}\right]
\end{aligned}$$

and for one of the two countries, the inequality is strict.

where $\hat{N}B_1$ (resp. $\hat{N}\overset{*}{B_1}$) and $\hat{N}B_3$ (resp. $\hat{N}\overset{*}{B_3}$) represent respectively the levels of welfare of the ENCC (resp. LENCC) at the threat point of the negotiations when the investment decisions are $x = 1$, $x^* = 0$ and $x = x^* = 0$.

Our reference point in the analysis of welfare is still the situation where the LENCC has no sensitivity to global pollution, i.e. $\alpha = 0$.

Proposition 1b *In the case where $\alpha = 0$, the differentiated agreement without transfers when only the firm of the ENCC invests dominates, in the Pareto sense, the uniform agreement with transfers when no firm invests.*

We show[24] that the payoffs of cooperation do not improve upon the non-cooperative outcome in both the uniform agreement when no firm invests and the differentiated agreement when only the firm of the ENCC invests. We can find a similar result for a small value of α, in the neighborhood of $\alpha = 0$, using a continuity argument of the optimal social welfare functions in the differentiated case when only the firm of the ENCC invests and in the uniform case when no firm invests.

In order to have an idea of the welfare levels of the countries, we should investigate those at the respective threat points of the countries, when $\alpha = 0$. It is easy to show that, in the two cases where only the firm of the ENCC invests and where no firm invests, the payoff of the LENCC at the threat point is zero. Using a quadratic example, we evaluate the payoff levels of the ENCC at the Nash equilibrium in both these cases. We find that the ENCC prefers to invest rather than not to invest at its threat point, when the level of sunk cost is lower than (1/2), which is the maximum

[24] See Appendix G3 for the proof of this proposition.

allowable level of sunk cost given the definition of the threshold abatement. Consequently, it is individually rational for the ENCC to invest at the Nash equilibrium, when the LENCC does not invest, if the level of sunk cost is lower than 1/2.

Our findings indicate that, in the presence of very asymmetric countries, the announcement and implementation of the uniform agreement with transfers is not optimal if the level of sunk cost is sufficiently high. For such a level of sunk cost, the announcement and implementation of the uniform agreement takes away the incentives of the firm in the ENCC to invest. Moreover, the implementation of this agreement, in the case where no firm invests, is not able to generate positive gains from cooperation for each country.

We can interpret these results in the following way. In the presence of a high level of sunk cost, the announcement and implementation of the uniform agreement removes the incentives of the firm in the LENCC as well as the firm in the ENCC to invest in a new abatement technology. There are two reasons for that to happen: on the one hand, the level of the uniform standard could not exceed the threshold abatement level (because the sunk cost is high); on the other hand, given that the firms have invested in a new abatement technology, the negotiated level of the uniform standard will be higher, which is more costly for the firms. By anticipating this, the firms prefer not to invest. It is the fear of a hold-up by the countries which induces the firms not to invest in a costly abatement technology.

In order to simplify the interpretation of the conditions related to the existence of the situations "incentive uniform standard" and "disincentive uniform standard", we will provide an example with a quadratic benefit function, in the case of very asymmetric countries (α small). Then, we illustrate the results by a numerical application.

4 A Numerical Illustration: Quadratic Case

The benefit function has the following form:

$$B(A + A^*) = b(A + A^*) - \frac{d}{2}(A + A^*)^2 \tag{24}$$

where $b > 0$, $d > 0$, $B^{'}(.) > 0$ and $B^{''}(.) < 0$. Here, the parameters b and d explain the environmental preferences of the countries, or in other words, they describe how the global pollution affects the payoffs of the countries.

In the case where the parameter α is null ($\alpha = 0$), this specification of the benefit function leads to the following negotiated abatement levels:

$$
\begin{aligned}
A_1 &= \frac{b}{1+d};\ A_1^* = 0;\ \bar{A}_1 = \frac{2b-1}{1+4d};\\
A_2 &= \frac{b}{1+d};\ A_2^* = 0;\ \bar{A}_2 = \frac{b}{1+2d};\\
A_3 &= \frac{b-1}{d};\ A_3^* = 0;\ \bar{A}_3 = \frac{b-1}{2d}
\end{aligned}
$$

Given these levels of negotiated standards, we can finally write, in an explicit way, the conditions of existence of the situations "incentive uniform standard" and "disincentive uniform standard" (see Appendix H for more detail).

a) Incentive uniform standard

The condition which leads to the emergence of the situation "incentive uniform standard" can be reduced to the following condition on the value of sunk cost F:

$$
\begin{aligned}
F &< \min\{\left[\frac{1}{2}-\frac{1}{2}(1-\frac{2b-1}{1+4d})^2\right], \left[\frac{2b-1}{1+4d}-\frac{1}{2}(\frac{b}{1+2d})^2\right], \\
&\left[\frac{1}{2}-\frac{1}{2}(1-\frac{b}{1+d})^2\right], \left[\frac{b-1}{d}-\frac{1}{2}(\frac{b}{1+d})^2\right], \\
&\left[\frac{b-1}{2d}-\frac{1}{2}(\frac{b}{1+2d})^2\right], \left[\frac{1}{2}\right]\}
\end{aligned}
\tag{25}
$$

For the appropriate values of the parameters b and d, all the terms on the righthandside of the inequality are strictly positive; hence the situation "incentive uniform standard" from the point of view of investment decision emerges. In fact, for this particular level of sunk cost, the announcement (and implementation) of differentiated standards gives the incentives to invest only to the firm of the ENCC. In contrast, the announcement (and implementation) of uniform standard induces both firms to invest in a new abatement technology.

b) Disincentive uniform standard

The conditions which lead to the emergence of the situation "disincentive uniform standard" can be reduced to two distinct conditions on the value of sunk cost F:

$$
\begin{aligned}
\text{* (threshold condition)}\ \left[\frac{1}{2}-\frac{1}{2}(1-\frac{2b-1}{1+4d})^2\right] &< F < \min\{\left[\frac{1}{2}-\frac{1}{2}(1-\frac{b}{1+d})^2\right], \\
&\left[\frac{b-1}{d}-\frac{1}{2}(\frac{b}{1+d})^2\right], \left[\frac{1}{2}\right]\}
\end{aligned}
\tag{26}
$$

$$* \text{ (cost condition) } \max \left\{ \left[\frac{b-1}{2d} - \frac{1}{2}(\frac{b}{1+2d})^2 \right], \left[\frac{b-1}{2d} - \frac{1}{2}(\frac{2b-1}{1+4d})^2 \right] \right\} (27)$$
$$< \quad F < \min\{ \left[\frac{1}{2} - \frac{1}{2}(1 - \frac{b}{1+d})^2 \right], \left[\frac{b-1}{d} - \frac{1}{2}(\frac{b}{1+d})^2 \right],$$
$$\left[\frac{1}{2} - \frac{1}{2}(1 - \frac{2b-1}{1+4d})^2 \right], \left[\frac{1}{2} \right] \}$$

On the one hand, given that a value of sunk cost verifying Condition 26 exists, the situation "disincentive uniform standard" because of the threshold condition arises. In fact, for this particular value of sunk cost, the implementation of differentiated standards gives the incentives to invest only to the firm of the ENCC, whereas the adoption of a uniform standard removes this incentive. When an agreement on a uniform standard with transfers is announced and implemented, no firm invests because the level of the uniform standard falls below the threshold abatement.

One the other hand, given that a value of sunk cost verifying Condition 27 exists, the situation "disincentive uniform standard" because of the cost condition arises. For this particular value of sunk cost, the same outcome results as for the threshold condition. But the reason behind the absence of investment is different: when a uniform agreement is implemented, even though the level of the uniform standard exceeds the threshold abatement, the firms prefer not to invest, because their abatement costs are lower in this case than they would be if they decided to invest.

We now illustrate the results of the model by a numerical example based on a quadratic benefit function.

c) Numerical illustration

We did some numerical applications by moving the parameters b and d. We control for the constraint that the negotiated abatement levels are lower or equal to 1, for the constraints on the concavity of the objective and social welfare functions, for the positivity of the payoffs from cooperation and the gains from cooperation of the countries. The conditions on the concavity of the social welfare function in the case of differentiated standards without transfers are verified for the high values of the parameters b and d moving from 750 to 1000, and for which the difference $(b-d)$ is equal to 1. We consider the following values of the parameters: $\alpha = 0.001$; $b = 750$; $d = 749$

We provide the negotiated levels of standards and transfers, the payoff levels from cooperation and the gains from cooperation corresponding to these values of the parameters in Tables 1, 2 and 3:

We have already provided, in the preceding section, the numerical results concerning the investment decision of the firms. Here, we describe the welfare levels of the countries with regard to the type of the negotiated IEA, taking into account the

	$\hat{A};\hat{A}^*$	$\hat{NB};\hat{NB}^*$
$(x=1, x^*=0)$ $(F=0.2)$	$1;0$	$374.8;0.3755$
$(x=1, x^*=0)$ $(F=0.4)$	$1;0$	$374.6;0.3755$
$(x=x^*=1)$ $(F=0.2)$	$0.999;0.0009$	$374.8009;0.1754$
$(x=x^*=0)$ $(F=0.4)$	$1;0$	$374.5;0.3755$

Table 1: The levels of standards and payoffs at the Nash equilibrium

	Standards; t	$NB;NB^*$
D $(x=1, x^*=0)$ $(F=0.2)$	$A=1;A^*=0$	$374.8;0.3755$
D $(x=1, x^*=0)$ $(F=0.4)$	$A=1;A^*=0$	$374.6;0.3755$
UT $(x=x^*=1)$ $(F=0.2)$	$\bar{A}=0.5003;t=0.24$	$374.9255;0.30008$
UT $(x=x^*=0)$ $(F=0.4)$	$\bar{A}=0.5=t$	$374.5;0.3755000173$

Table 2: The levels of standards and payoffs of cooperation

	$NB-\hat{NB}$	$NB^*-\hat{NB}^*$
D $(x=1, x^*=0)$ $(F=0.2)$	0	0
D $(x=1, x^*=0)$ $(F=0.4)$	0	0
UT $(x=x^*=1)$ $(F=0.2)$	0.1245846	0.12458459
UT $(x=x^*=0)$ $(F=0.4)$	0	0.173×10^{-7}

Table 3: The levels of gains from cooperation in the agreements

different permutations of investment decision by firms. Our numerical results illustrate our theoretical findings: the implementation of the uniform agreement when both firms invest is the only agreement which ensures positive gains from cooperation for each country. The other negotiations, which are the uniform agreement when no firm invests and the differentiated agreement when only the firm of the ENCC invests, lead to the same payoffs from cooperation as those at the respective threat points for each country. It is interesting to highlight the evolution of the payoffs at the threat point for different pairs of investment decision. Given the movement from ($x = 1$, $x^* = 0$) to ($x = x^* = 1$), for instance, the investment decision of the firm in the LENCC considerably reduces the bargaining position of its government in the international negotiations. This manifests in the reduction of its payoff at the threat point and correspondingly that of cooperation. This result is in line with the findings of McLaren (1997) on a small country's bargaining position in the negotiations of trade liberalization.

The results of this paper, contrary to Muuls' study (2004), show that some Nash bargained cooperative agreements cannot solve the problems of absence of investment by the private sector. We show that the type of the bargained IEA, as well as the level of sunk cost of the installation of the new abatement technology are the crucial factors which determine the decision of firms to invest in environmentally-friendly technologies.

5 Conclusion

In this paper, we have studied the link between the design of international environmental agreements and the decision by the private sector to invest in a new abatement technology. From this perspective, we have essentially compared the performance, in the Pareto sense, of two second-best IEA's, an agreement on a uniform standard with transfers and an agreement on differentiated standards without transfers, by using a multi-stage game.

Our findings indicate a result which could seem counter intuitive. In the presence of very asymmetric countries, the announcement and implementation of a uniform agreement with transfers is optimal, if the level of sunk cost is sufficiently low and the level of the marginal benefit from global abatement is sufficiently high. In this case, the implementation of the uniform agreement with transfers induces all the firms to invest in a new abatement technology. Moreover, this agreement is the only one which generates positive gains from cooperation for each country. In the presence of a low level of sunk cost of investment, the sufficiently high level of the uniform standard, which plays the role of a signal to firms to invest, and the presence of transfer payments, which satisfy the participation constraint of the country less sensitive to pollution, mean that a constraining agreement on a uniform standard is preferred by very asymmetric countries to the differentiated agreement. Our findings also indicate the sub-optimality of the announcement and implementation of the uniform agreement with transfers in the presence of very asymmetric countries, if the level of sunk cost is sufficiently high. In this case, the announcement and implementation of the uniform agreement takes away the incentives of all firms to invest. Moreover, the implementation of this agreement in this case is not able to generate positive gains from cooperation for each country.

This paper essentially shows that whenever countries are able to partially commit, uniform standards may be preferable as they create higher incentives for firms to undertake investment in costly abatement technology. The countries only need to commit to the announced type of IEA's, and not to the negotiated levels of the provisions of the agreement, such as the levels of abatement standards and transfers. From a normative point of view, the countries could use the following mechanism in order to give incentives to firms to invest in a new abatement technology, and to obtain for themselves higher levels of gain from cooperation. The countries would collectively announce that a uniform agreement with transfers would be negotiated in the future. Given this announcement, and conditional on the low levels of the sunk cost of investment, the firms would invest. The best thing that the countries could do is, first, to give enough time for firms to invest in a new technology, and then to negotiate the precise levels of the uniform standard and the transfer, taking into account the investment decisions of their firms.

This work has considered some important aspects of IEA's, such as the type of standards imposed on countries and the existence of a side payment scheme across countries. As the OECD study (2005, p.14) points out, the Montreal Protocol's success relies on *the involvement of industry to innovate, invest in, and transfer technologies*. In this paper, we have only considered monetary transfers across countries. The introduction of technological transfers, - which could be modeled as a payment of the sunk cost of investment of the firm in the less sensitive country by the most sensitive country -, or of technological spillovers, would, directly affect the incentives of the private sector to invest. Our paper, however, mainly emphasizes the role of the type of international environmental agreement in giving incentives to firms to invest. It is worth to noting that, behind the success of the Montreal Protocol, there are other measures included in the Protocol, which encourage private sector involvement and investment. We have not considered, for instance, trade-related incentives in the form of trade restrictions between parties and non-parties and opportunities for market creation for alternatives to ozone-depleting substances, which have played an important role in the involvement of the business sector.

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Appendix

A- Reference Case: $x = 1$ and $x^* = 0$

A1- Comparison of the abatement levels (Proof of Lemma 1)

Proof. We will first show that A and A^* cannot simultaneously be lower than $\bar{A}$. If A and A^* are lower than $\bar{A}$, then we have:

$$B^{'}(A + A^*) > B^{'}(\bar{A} + \bar{A})$$

because B is a decreasing function, $B^{'}(A + A^*) = \frac{A}{1+\alpha A}$ and $B^{'}(\bar{A} + \bar{A}) = \frac{\bar{A}+1}{2(\alpha+1)}$.

We need to check if $(\frac{A}{1+\alpha A})$ is higher than $(\frac{\bar{A}+1}{2(\alpha+1)})$, given that $A < \bar{A}$. For that, we will first compare the functions $f(x) = \frac{x}{1+\alpha x}$ and $g(x) = \frac{x+1}{2(\alpha+1)}$, where x is a positive variable with $x \leq 1$. We find that the function $f(x) = \frac{x}{1+\alpha x}$ is lower or equal to the function $g(x) = \frac{x+1}{2(\alpha+1)}$[25]. Since the function $g(x)$ is increasing, we have $g(\bar{A}) > g(A) \geq f(A)$. Hence, we find that:

$$g(\bar{A}) > f(A) \Longleftrightarrow \frac{\bar{A}+1}{2(\alpha+1)} > \frac{A}{1+\alpha A}$$

which contradicts our initial assumption. This shows that A and A^* cannot simultaneously be lower than $\bar{A}$.

Now, we will show that A^* is lower than $\bar{A}$ for a low value of parameter α. Let us first consider the extreme case $\alpha = 0$ in which the optimal abatement levels, respectively at the differentiated and the uniform cases are defined by:

$$\begin{aligned} A^* &= 0 \text{ and } B'(A) = A \\ B'(2\bar{A}) &= \frac{\bar{A}+1}{2} \end{aligned}$$

We observe that $\bar{A}$ is positive whenever $B'(0) > \frac{1}{2}$. Under this condition, we show that $A^* < \bar{A}$ for a value of $\alpha = 0$. Hence, under the same condition we have $A > \bar{A}$. We can find a similar result for a small value of α, in the neighborhood of $\alpha = 0$, using a continuity argument of the functions $A^*(\alpha)$ and $\bar{A}(\alpha)$ at the optimum. By Berge's theorem of the maximum, it can be shown that the social welfare function and the set of maximizers change continuously with the parameters, given that the objective function is continuous. Since we have a continuous objective function, we can deduce that $A^* < \bar{A} < A$ for small value of α, in the neighborhood of $\alpha = 0$. ■

B- Case 2: $x = x^* = 1$

B1- Nash equilibrium

The first-order conditions for the ENCC and the LENCC are respectively:

[25] $f(x) = \frac{x}{1+\alpha x} \leq g(x) = \frac{x+1}{2(\alpha+1)}$
$\Longleftrightarrow 2(\alpha+1)x \leq (1+\alpha x)(x+1)$
$\Longleftrightarrow 0 \leq (1-x)(1-\alpha x)$
which is true given that $x \leq 1$ and $(1-\alpha x) > 0$ with α being lower than 1.

$$
\begin{aligned}
B^{'}(A+A^{*}) &= A \\
B^{'}(A+A^{*}) &= \frac{A^{*}}{\alpha} \\
\text{which implies } A &= A^{*}\frac{1}{\alpha} \text{ where } A > A^{*}
\end{aligned}
$$

These conditions lead to the following abatement levels at the threat point:

$$
\begin{aligned}
\hat{A} &= \frac{1}{\alpha+1}B^{'-1}(\hat{A}) \\
\hat{A}^{*} &= \frac{\alpha}{1+\alpha}B^{'-1}(\hat{A})
\end{aligned}
$$

These abatement levels give us the payoffs at the threat point when both firms invest, $\hat{N}B$ and $\hat{N}B^{*}$, respectively for the ENCC and the LENCC:

$$
\begin{aligned}
\hat{N}B &= B(B^{'-1}(\hat{a})) - \frac{1}{2(1+\alpha)^2}(B^{'-1}(\hat{a}))^2 - F \\
\hat{N}B^{*} &= \alpha B(B^{'-1}(\hat{a})) - \frac{\alpha^2}{2(1+\alpha)^2}(B^{'-1}(\hat{a}))^2 - F
\end{aligned}
$$

B2- Differentiated standards without transfers

If we arrange the first-order conditions, we have:

$$
\frac{\alpha B^{'}(A+A^{*})}{\left[\alpha B^{'}(A+A^{*})-A^{*}\right]} = \frac{\left[B^{'}(A+A^{*})-A\right]}{B^{'}(A+A^{*})}
$$

$$
\Longleftrightarrow B^{'}(A+A^{*}) = \frac{AA^{*}}{A^{*}+\alpha A} \tag{28}
$$

If we arrange the first-order conditions in a different way, we also have:

$$
\begin{aligned}
B^{'}(A+A^{*})(\alpha U+U^{*}) &= AU^{*} \\
B^{'}(A+A^{*})(\alpha U+U^{*}) &= A^{*}U
\end{aligned}
$$

which implies:

$$
AU^{*} = A^{*}U
$$

If $A > A^{*}$, we obtain the superiority of the gains from cooperation of the ENCC to those for the LENCC, i.e. $U > U^{*}$, and vice versa.

B3- Uniform standard with transfers

As we have already showed (Equation 17), the gains from cooperation of the countries are the same in the presence of uniform standard with transfers, i.e. $U = U^*$. This property modifies the first-order condition with respect to $\bar{A}$ and gives the following:

$$\Longleftrightarrow U\left[2\alpha B'(\bar{A}+\bar{A}) - \bar{A} + 2B'(\bar{A}+\bar{A}) - \bar{A}\right] = 0$$

$$\Longleftrightarrow B'(\bar{A}+\bar{A}) = \frac{\bar{A}}{(\alpha+1)} \tag{29}$$

B4- Comparaison of the levels of standards

Our objective is to compare the levels of standards resulting from the two agreements. To do this, we use Equations 28 and 29.

Proposition 2 *$\bar{A}$ is necessarily between A and A^*.*

Proof. We will first show that A and A^* cannot simultaneously be lower than $\bar{A}$. If $A < \bar{A}$ and $A^* < \bar{A}$, then we would have:

$$B'(A + A^*) > B'(\bar{A}+\bar{A}) \Longleftrightarrow \frac{AA^*}{A^* + \alpha A} > \frac{\bar{A}}{(\alpha+1)} \tag{30}$$

There are two sub-cases to study, $A^* > A$ or $A^* < A$.

a) If $A^* > A$, as $\frac{1}{\frac{A^*}{A}+\alpha} < \frac{1}{(\alpha+1)}$ and $A^* < \bar{A}$, then $\frac{A^*}{\frac{A^*}{A}+\alpha} < \frac{\bar{A}}{(\alpha+1)}$, which is contradictory to Condition (c1).

b) If $A^* < A$, as $\frac{1}{1+\alpha\frac{A}{A^*}} < \frac{1}{(\alpha+1)}$ and $A < \bar{A}$, then $\frac{A}{1+\alpha\frac{A}{A^*}} < \frac{\bar{A}}{(\alpha+1)}$, which is contradictory to Condition (c1).

These results show the impossibility of having $A < \bar{A}$ and $A^* < \bar{A}$. There are two possibilities left: one of the differentiated standards or both of them exceed the level of the uniform standard. We now show, by similar reasoning, that A and A^* cannot simultaneously be higher than $\bar{A}$.

If $A > \bar{A}$ and $A^* > \bar{A}$, then we would have:

$$B'(A + A^*) < B'(\bar{A}+\bar{A}) \Longleftrightarrow \frac{AA^*}{A^* + \alpha A} < \frac{\bar{A}}{(\alpha+1)} \tag{31}$$

There are two sub-cases to examine, $A^* > A$ or $A^* < A$.

a) If $A^* > A$, as $\frac{1}{1+\alpha\frac{A}{A^*}} > \frac{1}{(\alpha+1)}$ and $A > \bar{A}$, then $\frac{A}{1+\alpha\frac{A}{A^*}} > \frac{\bar{A}}{(\alpha+1)}$, which is contradictory to Condition (c2).

b) If $A^* < A$, as $\frac{1}{\frac{A^*}{A}+\alpha} > \frac{1}{(\alpha+1)}$ and $A^* > \bar{A}$, then $\frac{A^*}{\frac{A^*}{A}+\alpha} > \frac{\bar{A}}{(\alpha+1)}$, which is contradictory to Condition (c2).

These results show the impossibility of having $A > \bar{A}$ and $A^* > \bar{A}$. Consequently, $\bar{A}$ is necessarily between A and A^*. ■

Proposition 3 *$A > A^*$ for a small value of α, in the neighborhood of $\alpha = 0$.*

Proof. We have $AU^* = A^*U$.

Let us suppose that $A \leq A^*$, then we have $U^* \geq U$

$\Longleftrightarrow \left[\alpha B(A+A^*) - \frac{A^{*2}}{2} - \alpha B(\hat{A}+\hat{A}^*) + \frac{\hat{A}^{*2}}{2}\right] \geq$

$\left[B(A+A^*) - \frac{A^2}{2} - B(\hat{A}+\hat{A}^*) + \frac{\hat{A}^2}{2}\right]$

$\Longleftrightarrow (A^*-A)(A^*+A) \leq 2\left[(\alpha-1)B(A+A^*) + (1-\alpha)B(\hat{A}+\hat{A}^*) - \frac{\hat{A}^2}{2} + \frac{\hat{A}^{*2}}{2}\right]$

where $\hat{A} = \frac{\hat{A}^*}{\alpha}$.

$$\Longleftrightarrow (A^*-A)(A^*+A) \leq 2\left[(\alpha-1)\left[B(A+A^*) - B(\hat{A}+\hat{A}^*)\right] + \frac{\hat{A}^{*2}(\alpha-1)(\alpha+1)}{2\alpha^2}\right] \tag{32}$$

The lefthandside of Condition 32 is positive or zero. This condition can be rejected if the righthandside is negative. We know that $\frac{\hat{A}^{*2}(\alpha-1)(\alpha+1)}{2\alpha^2}$ is negative because $\alpha < 1$. We now check if the difference $\left[B(A+A^*) - B(\hat{A}+\hat{A}^*)\right]$ is positive or zero.

It can be useful to remember the respective first-order conditions at the threat point and the differentiated standard case for the ENCC and the LENCC respectively:

$B'(\hat{A}+\hat{A}^*) = \hat{A}$ and $B'(\hat{A}+\hat{A}^*) = \frac{\hat{A}^*}{\alpha}$

$B'(A+A^*) = \frac{AU^*}{\alpha U+U^*}$ and $B'(A+A^*) = \frac{A^*U}{\alpha U+U^*}$

We can compare the levels of standards at the threat point and at cooperation with differentiated standards, for the case $\alpha = 0$. We notice that these levels are given by the following relationships:

$\hat{A}^* = 0$ and $B'(\hat{A}) = \hat{A}$

$A^* = 0$ and $B'(A) = A$

Since these optimal standards at the threat point and at cooperation are defined in the same manner, we can conclude that the total abatement at the threat point

$(\hat{A} + \hat{A}^*)$ is equal to that at cooperation $(A + A^*)$. We can find a similar result for a small value of α, in the neighborhood of $\alpha = 0$, using a continuity argument of the functions $A(\alpha)$ and $A^*(\alpha)$ at the optimum. Under this property, we can claim that the difference $\left[B(A + A^*) - B(\hat{A} + \hat{A}^*)\right]$ is zero, which leads to the negativity of the righthandside of Condition 32, and then leads us to reject the condition. Consequently, it is impossible to have $A \leq A^*$, then we have $A > A^*$ for a small value of α, in the neighborhood of $\alpha = 0$. ■

These results contribute to the classification of the abatement levels in the case where the firms in the ENCC and the LENCC invest. We have $A^* < \overline{A} < A$ under the conditions specified above.

C- Case 3: $x = x^* = 0$

C1- Nash equilibrium

The first-order conditions for the ENCC and the LENCC are respectively:

$$\begin{aligned} B'(A + A^*) &= 1 \\ \alpha B'(A + A^*) - 1 &< 0 \end{aligned}$$

These conditions imply the following abatement levels at the threat point:

$$\begin{aligned} \hat{A} &= B'^{-1}(1) \\ \hat{A}^* &= 0 \end{aligned}$$

Then, the payoffs at the threat point when none of the firms invest, $\overset{\wedge}{NB}$ and $\overset{\wedge}{NB}^*$, for the ENCC and the LENCC are respectively:

$$\begin{aligned} \overset{\wedge}{NB} &= B(B'^{-1}(1)) - B'^{-1}(1) \\ \overset{\wedge}{NB}^* &= \alpha B(B'^{-1}(1)) \end{aligned}$$

C2- Differentiated standards with transfers

If we arrange the first-order conditions, we have:

$$\frac{\alpha B'(A + A^*)}{[\alpha B'(A + A^*) - 1]} = \frac{[B'(A + A^*) - 1]}{B'(A + A^*)}$$

$$\Longleftrightarrow B'(A + A^*) = \frac{1}{1 + \alpha}$$

If we arrange the first-order conditions in a different way, we also have:

$$\begin{aligned} B^{'}(A+A^{*})(\alpha U+U^{*}) &= U^{*} \\ B^{'}(A+A^{*})(\alpha U+U^{*}) &= U \end{aligned}$$

which implies:

$$U^{*}=U$$

We obtain the equality of the gains from cooperation across the ENCC and the LENCC, in the presence of differentiated standards without transfers.

C3- Uniform standard with transfers

As we have already showed (Equation 17), the gains from cooperation of the countries are identical in the presence of uniform standards with transfers. This property modifies the first-order condition with respect to $\bar{A}$ and gives us:

$$\Longleftrightarrow U\left[2\alpha B^{'}(\bar{A}+\bar{A})-1+2B^{'}(\bar{A}+\bar{A})-1\right]=0$$

$$\Longleftrightarrow B^{'}(\bar{A}+\bar{A})=\frac{1}{(\alpha+1)}$$

C4- Comparison of the levels of standards

Proposition 4 *The level of the uniform standard is the average of the levels of the differentiated standards.*

Proof. The optimality conditions are identical in the cases of differentiated standards without transfers and uniform standards with transfers, and are equal to:

$$B^{'}(A+A^{*})=\frac{1}{(\alpha+1)}=B^{'}(\bar{A}+\bar{A})$$

This identity implies the following relationship:

$$A+A^{*}=2\bar{A}\Longleftrightarrow\bar{A}=\frac{A+A^{*}}{2}$$

■

Proposition 5 *Given the assumption that the benefit function $B(.)$ is increasing and concave, A is superior to A^{*}.*

Proof. We have $U=U^{*}$
$\Longleftrightarrow\left[B(A+A^{*})-A-\hat{N}B\right]=\left[\alpha B(A+A^{*})-A^{*}-\hat{N}B^{*}\right]$ where

$\overset{\wedge}{NB}^* = \alpha B(\hat{A})$ and $\overset{\wedge}{NB} = B(\hat{A}) - \hat{A}$ with $\hat{A}^* = 0$ and $\hat{A} = B'^{-1}(1)$.

$\Longleftrightarrow A = A^* + (1-\alpha)B(A+A^*) + (\overset{\wedge}{NB}^* - \overset{\wedge}{NB})$

We know that $(1-\alpha)B(A+A^*) > 0$. We will have $A > A^*$ if

$$\left[(1-\alpha)B(A+A^*) + (\overset{\wedge}{NB}^* - \overset{\wedge}{NB})\right] > 0 \tag{33}$$

We have $\overset{\wedge}{NB}^* - \overset{\wedge}{NB} = (\alpha-1)B(\hat{A}) + \hat{A} = (\alpha-1)B(B'^{-1}(1)) + B'^{-1}(1)$.

Condition 33, then, becomes: $(1-\alpha)\left[B(A+A^*) - B(B'^{-1}(1))\right] + B'^{-1}(1) > 0$

$\Longleftrightarrow (1-\alpha)\left[B(B'^{-1}(\frac{1}{1+\alpha})) - B(B'^{-1}(1))\right] + B'^{-1}(1) > 0$ because $B'(A+A^*) = \frac{1}{1+\alpha}$.

This condition is always satisfied by the concavity of the benefit function $B(.)$. Then, we have $A > A^*$. ■

D- Case 4: $x = 0$ and $x^* = 1$ $\left(\alpha = 0\right)$

D1- Nash equilibrium

The first-order conditions for the ENCC and the LENCC are respectively:

$$\begin{aligned} B'(A+A^*) &= 1 \\ \hat{A}^* &= 0 \end{aligned}$$

because the payoff of the LENCC is equal to $(-\frac{A^{*2}}{2} - F)$.

These conditions imply the following abatement levels at the threat point:

$$\begin{aligned} \hat{A} &= B'^{-1}(1) \\ \hat{A}^* &= 0 \end{aligned}$$

D2- Differentiated standards without transfers

The first-order condition for the LENCC is the following:

$$B'(A+A^*)U^* = A^*U$$

where $U^* = -\frac{A^{*2}}{2}$. Since a positive value of A^* implies a negative U, the optimal value of A^* is equal to zero.

The first-order condition for the LENCC is the following:

$$B'(A+A^*) = 1$$

These conditions imply the following abatement levels in the differentiated case:

$$
\begin{aligned}
A_4 &= B^{'-1}(1) \\
A_4^* &= 0
\end{aligned}
$$

For the situation $x = 0$ and $x^* = 1$ to emerge, some conditions must be satisfied:

1) The firm in the ENCC does not invest in the agreement on differentiated standards without transfers.

$$
\begin{aligned}
\text{threshold condition:} &\qquad A_4 < \widetilde{A} \text{ or} \\
\text{cost condition:} &\qquad A_4 > \widetilde{A} \text{ and } A_4 < \frac{A_2^2}{2} + F
\end{aligned}
$$

2) The firm in the LENCC invests in the agreement on differentiated standards without transfers.

$$
A_4^* > \widetilde{A} \text{ and } \frac{A_4^{*2}}{2} + F < A_3^*
$$

We observe that, in the case $\alpha = 0$, Condition 2 is not satisfied, because $A_4^* = 0 < \widetilde{A}$, given the definition of the threshold abatement $0 < \widetilde{A} \leq 1$. We can find a similar result for a small value of α, in the neighborhood of $\alpha = 0$, using a continuity argument of the functions $A^*(\alpha)$ and $A(\alpha)$ at the optimum. We deduce that $x = 0$ and $x^* = 1$ is impossible for a small value of α, in the neighborhood of $\alpha = 0$.

E- Comparison of the levels of the uniform standard

Proposition 6 $\qquad \bar{A}(x = x^* = 1) \geq \bar{A}(x = 1; x^* = 0).$

Proof. For $x = 1$ and $x^* = 0$, we have $B'(\bar{A} + \bar{A}) = \frac{\bar{A}+1}{2(\alpha+1)}$. We call $\bar{A}_1$ this uniform standard.

For $x = x^* = 1$, we have $B'(\bar{A} + \bar{A}) = \frac{\bar{A}}{(\alpha+1)}$. We call $\bar{A}_2$ this uniform standard.

If $\bar{A}_1 > \bar{A}_2$, then we would have $\bar{A}_1 + 1 > \bar{A}_2 + 1 > 2\bar{A}_2$.

As $\bar{A}_1 > \bar{A}_2$, we have:

$\Longleftrightarrow B'(\bar{A}_1 + \bar{A}_1) < B'(\bar{A}_2 + \bar{A}_2) \Longleftrightarrow \frac{\bar{A}_1+1}{2(\alpha+1)} < \frac{\bar{A}_2}{(\alpha+1)} \Longleftrightarrow \bar{A}_1 + 1 < 2\bar{A}_2$. This result is contradictory to the former assumption. Hence, we have $\bar{A}_1 \leq \bar{A}_2$. ■

Proposition 7 $\qquad \bar{A}(x = x^* = 0) \leq \bar{A}(x = 1; x^* = 0).$

Proof. For $x = 1$ and $x^* = 0$, we have $B'(\bar{A} + \bar{A}) = \frac{\bar{A}+1}{2(\alpha+1)}$. We call $\bar{A}_1$ this uniform standard.

For $x = x^* = 0$, we have $B'(\bar{A} + \bar{A}) = \frac{1}{(\alpha+1)}$. We call $\bar{A}_3$ this uniform standard.

If $\bar{A}_3 > \bar{A}_1$, then we would have $B'(\bar{A}_3 + \bar{A}_3) < B'(\bar{A}_1 + \bar{A}_1) \iff \frac{1}{(\alpha+1)} < \frac{\bar{A}_1+1}{2(\alpha+1)} \iff \bar{A}_1 > 1$, which is impossible because the maximal abatement level is equal to 1. Hence, we have $\bar{A}_3 \leq \bar{A}_1$. ■

F- Negotiated Abatement Levels for $\alpha = 0$ (not to be published)

At the *Nash equilibrium*, the program of the ENCC is as follows:

$$\begin{aligned} Max_A & \left[B(A + A^*) - x(\frac{A^2}{2} + F) - (1 - x)A \right] \\ A & \leq 1; A^* \leq 1 \end{aligned}$$

The program of the LENCC is written in a similar way:

$$\begin{aligned} Max_{A^*} & \left[-x^*(\frac{A^{*2}}{2} + F) - (1 - x^*)A^* \right] \\ A & \leq 1; A^* \leq 1 \end{aligned}$$

The first-order conditions for the ENCC and the LENCC are respectively:

$$\begin{aligned} B'(A + A^*) &= Ax + (1 - x) \\ -A^*x^* - (1 - x^*) &= 0 \end{aligned}$$

★ In the case that the ENCC invests and the LENCC does not invest ($x = 1$ and $x^* = 0$), the first-order conditions for the ENCC and the LENCC imply:

$$\begin{aligned} \hat{A}^* &= 0 \\ \hat{A} &= B'^{-1}(\hat{a}) \end{aligned}$$

★ In the case that the ENCC and the LENCC invest ($x = x^* = 1$), the first-order conditions for the ENCC and the LENCC imply the same relationships:

$$\begin{aligned} \hat{A}^* &= 0 \\ \hat{A} &= B'^{-1}(\hat{a}) \end{aligned}$$

★ In the case that the ENCC and the LENCC do not invest ($x = x^* = 0$), the first-order conditions for the ENCC and the LENCC become:

$$\begin{aligned} \overset{\wedge}{A^*} &= 0 \\ \hat{A} &= B^{'-1}(1) \end{aligned}$$

In cooperation with the agreement of *differentiated standards without transfers*, the Nash bargaining solution is written in the following way:

$$\begin{aligned} & Max_{A,A^*} \begin{bmatrix} B(A+A^*) - x(\frac{A^2}{2} + F) - (1-x)A \\ -\{B(\hat{A} + \overset{\wedge}{A^*}) - x(\frac{\hat{A}^2}{2} + F) - (1-x)\hat{A}\} \end{bmatrix} \times \\ & \begin{bmatrix} -x^*(\frac{A^{*2}}{2} + F) - (1-x^*)A^* \\ -\{-x^*(\frac{\overset{\wedge}{A^*}^2}{2} + F) - (1-x^*)\overset{\wedge}{A^*}\} \end{bmatrix} \\ A &\leq 1; A^* \leq 1 \end{aligned}$$

If we note $V = U \times U^*$, given an interior solution, the first-order conditions are as follows:

$$\begin{aligned} \frac{\partial V}{\partial A} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial A}U + \frac{\partial U}{\partial A}U^* = 0 \\ &\Longleftrightarrow \left[B^{'}(A+A^*) - xA - (1-x)\right] U^* = 0 \end{aligned}$$

$$\begin{aligned} \frac{\partial V}{\partial A^*} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial A^*}U + \frac{\partial U}{\partial A^*}U^* = 0 \\ &\Longleftrightarrow \left[-x^*A^* - (1-x^*)\right] U + \left[B^{'}(A+A^*)\right] U^* = 0 \end{aligned}$$

★ In the case that the ENCC invests and the LENCC does not invest ($x = 1$ and $x^* = 0$), the first-order conditions imply:

$$A_1^* = 0 \text{ and } A_1 = B^{'-1}(A_1)$$

which are the same conditions as those at the Nash equilibrium. This property could lead to identical levels of abatement at the threat point and at cooperation. In this case, given that $\alpha = 0$, at cooperation with differentiated standards, each country receives what it gets at the threat point.

★ In the case that the ENCC and the LENCC invest ($x = x^* = 1$), the first-order conditions imply:

$$A_2^* = 0 \text{ and } A_2 = B'^{-1}(A_2)$$

because $U^* = -\frac{A^{*2}}{2}$.

★ In the case that the ENCC and the LENCC do not invest ($x = x^* = 0$), the first-order conditions are:

$$A_3^* = 0 \text{ and } A_3 = B'^{-1}(1)$$

because $U^* = -A^*$.

In cooperation with the agreement on a *uniform standard with transfers*, the Nash bargaining solution is written in the following way:

$$Max_{\bar{A},t} \left[\begin{array}{c} B(\bar{A} + \bar{A}) - x(\frac{\bar{A}^2}{2} + F) - (1-x)\bar{A} - t \\ -\{B(\hat{A} + \hat{A}^*) - x(\frac{\hat{A}^2}{2} + F) - (1-x)\hat{A}\} \end{array} \right] \times$$
$$\left[\begin{array}{c} -x^*(\frac{\bar{A}^2}{2} + F) - (1-x^*)\bar{A} + t \\ -\{-x^*(\frac{\hat{A}^{*2}}{2} + F) - (1-x^*)\hat{A}^*\} \end{array} \right]$$
$$\bar{A} \leq 1$$

If we note $V = U \times U^*$, given an interior solution, the first-order conditions are:

$$\begin{aligned} \frac{\partial V}{\partial t} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial t}U + \frac{\partial U}{\partial t}U^* = 0 \Longleftrightarrow U - U^* = 0 \Longleftrightarrow U = U^* \\ \frac{\partial V}{\partial \bar{A}} &= 0 \Longleftrightarrow \frac{\partial U^*}{\partial \bar{A}}U + \frac{\partial U}{\partial \bar{A}}U^* = 0 \\ &\Longleftrightarrow B'(\bar{A} + \bar{A}) = \frac{\bar{A}(x + x^*) + 2 - x - x^*}{2} \end{aligned}$$

★ In the case that the ENCC invests and the LENCC does not invest ($x = 1$ and $x^* = 0$), the marginal benefit of the ENCC becomes:

$$\Longleftrightarrow B'(2\bar{A}) = \frac{\bar{A} + 1}{2} \Longleftrightarrow \bar{A}_1 = 2B'(2\bar{A}_1) - 1$$

★ In the case that the ENCC and the LENCC invest ($x = x^* = 1$), the marginal benefit of the ENCC is:

$$\Longleftrightarrow B'(2\bar{A}) = \bar{A} \Longleftrightarrow \bar{A}_2 = B'(2\bar{A}_2)$$

★ In the case that the ENCC and the LENCC do not invest ($x = x^* = 0$), the marginal benefit of the ENCC is:

$$\Longleftrightarrow B^{'}(2\bar{A}) = 1 \Longleftrightarrow \bar{A}_3 = \frac{1}{2}B^{'^{-1}}(1)$$

G- Optimal choice of the type of the IEA

G1- Proof of Proposition 1a

Proof. We investigate the following condition:

$\left[B(\bar{A}+\bar{A}) - \frac{\bar{A}^2}{2} - F - t - \hat{N}B_2\right] \geq \left[B(A+A^*) - \frac{A^2}{2} - F - \hat{N}B_1\right]$

$\left[\alpha B(\bar{A}+\bar{A}) - \frac{\bar{A}^2}{2} - F + t - \hat{N}B_2^*\right] \geq \left[\alpha B(A+A^*) - A^* - \hat{N}B_1^*\right]$ and for one of the two countries, the inequality is strict.

In the case where only the firm in the ENCC invests and $\alpha = 0$, we can verify that the Nash equilibrium is defined by $\hat{A}^* = 0$ and $B^{'}(\hat{A}) = \hat{A}$. The payoff levels at the Nash equilibrium are equal to $\hat{N}B_1 = B(B^{'-1}(\hat{A}_1)) - \frac{1}{2}(B^{'-1}(\hat{A}_1))^2 - F$ and $\hat{N}B_1^* = 0$. The levels of differentiated standards are characterized in the same way by $A^* = 0$ and $B^{'}(A) = A$. This property leads to the equality of the payoff levels with the differentiated agreement without transfers when only the firm of the ENCC invests, and those at the threat point. Similarly, we can check that the Nash equilibrium is defined by $\hat{A}^* = 0$ and $B^{'}(\hat{A}) = \hat{A}$ when both firms invest and $\alpha = 0$. The payoff levels at the Nash equilibrium are now equal to $\hat{N}B_2 = B(B^{'-1}(\hat{A}_2)) - \frac{1}{2}(B^{'-1}(\hat{A}_2))^2 - F$ and $\hat{N}B_2^* = -F$.

Our objective is to find a specific contract which Pareto-dominates the agreement on differentiated standards defined above. This alternative contract is a contract on a uniform standard with a side payment scheme. The payoff of the LENCC must be positive after the receipt of side payments, given the constraint that the payoff of the ENCC after the payment of transfers exceeds that at the threat point:

$$\text{We define t, such that } t = \frac{\bar{A}^2}{2} + F + \hat{N}B_2^* + \varepsilon \text{ where } \varepsilon > 0 \tag{34}$$

$$B(2\bar{A}) - \frac{\bar{A}^2}{2} - F - t > \hat{N}B_2 \Longrightarrow B(2\bar{A}) - \bar{A}^2 - 2F - \hat{N}B_2^* - \varepsilon > \hat{N}B_2$$

By using the expression of payoffs at the threat point $\hat{N}B_2$ and $\hat{N}B_2^*$, Condition 34 takes the following form:

$$\left[B(2\bar{A}) - \bar{A}^2 - \varepsilon\right] > \left[B(\hat{A}) - \frac{\hat{A}^2}{2}\right] \text{ where } \varepsilon > 0 \tag{35}$$

We can find a level of the uniform standard, assuming that it exists, which maximizes the lefthandside of this condition, and which allows us to check Condition 35:

$$Max_{\bar{A}}\left[B(2\bar{A}) - \bar{A}^2 - \varepsilon\right] > \left[B(\hat{A}) - \frac{\hat{A}^2}{2}\right] \text{ where } \varepsilon > 0 \tag{36}$$

This condition can be satisfied if the function $B(2\bar{A})$ increases sufficiently fast, or if $B'(2\bar{A})$ is sufficiently large.Under this condition, the specific contract on a uniform standard with transfers gives positive gains from cooperation for each country, and therefore, Pareto-dominates the agreement on differentiated standards without transfers. Here we have found specific levels of $\bar{A}$ and t such that this particular contract on a uniform standard outperforms the agreement on differentiated standards. Hence, the maximum of the program with uniform standards (the agreement on a uniform standard with transfers) Pareto-dominates the agreement on differentiated standards without transfers. ■

G2- Illustration of Proposition 1a: quadratic example with $\alpha = 0$

The benefit function has the following form:

$$B(A + A^*) = b(A + A^*) - \frac{d}{2}(A + A^*)^2$$

where $b > 0$ and $d > 0$.

We know that the Nash equilibrium is defined by $\hat{A}^* = 0$ and $B'(\hat{A}) = \hat{A}$ for $\alpha = 0$. With the assumed specification of the benefit function, we obtain:

$$\begin{aligned} B(A) &= b(A) - \frac{d}{2}(A)^2 \\ B'(A) &= A \Longleftrightarrow b - dA = A \Longleftrightarrow \hat{A} = \frac{b}{d+1} \end{aligned}$$

By introducing this expression of the abatement level at the Nash equilibrium in the righthandside of Condition 36, we obtain:

$$B(\hat{A}) - \frac{\hat{A}^2}{2} = b(\hat{A}) - \hat{A}^2\frac{(d+1)}{2} = \frac{b^2}{2(d+1)}$$

The maximum of the expression (with respect to $\bar{A}$) in the lefthandside of Condition 36, $\left[B(2\bar{A}) - \bar{A}^2 - \varepsilon\right]$, is obtained by $B^{'}(2\bar{A}) = \bar{A}$. The specification of the benefit function gives us this specific level of the uniform standard:

$$B^{'}(2\bar{A}) = \bar{A} \Longleftrightarrow b - 2d\bar{A} = \bar{A} \Longleftrightarrow \bar{A} = \frac{b}{1+2d}$$

When we introduce this expression of the uniform standard in the lefthandside of Condition 36, we obtain:

$$\begin{aligned}\left[B(2\bar{A}) - \bar{A}^2 - \varepsilon\right] &= \left[b(2\bar{A}) - \frac{d}{2}(2\bar{A})^2 - \bar{A}^2 - \varepsilon\right] \\ &= \frac{2b^2}{1+2d} - (2d+1)\frac{b^2}{(1+2d)^2} - \varepsilon\end{aligned}$$

If we divide by (b^2) both sides of Condition 36, we have:

$$\frac{2}{1+2d} - \frac{(2d+1)}{(1+2d)^2} - \frac{\varepsilon}{b^2} > \frac{1}{2(d+1)}$$

The limit of this condition when $b \to \infty$, is as follows:

$$\frac{2}{1+2d} - \frac{(2d+1)}{(1+2d)^2} > \frac{1}{2(d+1)} \Longleftrightarrow 3 > 2.$$

G3- Proof of Proposition 1b

Proof. We investigate the following condition:

$\left[B(A+A^*) - \frac{A^2}{2} - F - \hat{NB}_1\right] \geq \left[B(\bar{A}+\bar{A}) - \bar{A} - t - \hat{NB}_3\right]$

$\left[\alpha B(A+A^*) - A^* - \hat{NB}_1^*\right] \geq \left[\alpha B(\bar{A}+\bar{A}) - \bar{A} + t - \hat{NB}_3^*\right]$ and for one of the two countries, the inequality is strict.

In the case where only the firm in the ENCC invests and $\alpha = 0$, we know from the proof of Proposition 1a that the abatement levels at the Nash equilibrium and the agreement on differentiated standards are characterized in the same way. This property leads to the equality of the payoff levels whether the countries cooperate or not. Similarly, we can check that the Nash equilibrium is defined by $\hat{A}^* = 0$ and $B^{'}(\hat{A}) = 1$, when no firm invests and $\alpha = 0$. The levels of payoffs at the Nash equilibrium are equal to: $\hat{NB}_3 = B(B^{'-1}(1)) - B^{'-1}(1)$ and $\hat{NB}_3^* = 0$.

We know from Equation 17 that the maximum of the program with uniform standards when no firm invests, implies the equality of the gains from cooperation for the two countries, i.e. $U = U^*$. This property modifies the first-order condition with respect to $\bar{A}$, and gives the following condition:

$$\begin{aligned} U\left[B'(2\bar{A})(2\alpha+2)-2\right] &= 0 \Longleftrightarrow B'(2\bar{A}) = \frac{1}{\alpha+1} \\ &\Longleftrightarrow 2\bar{A} = B'^{-1}(\frac{1}{\alpha+1}) \Longleftrightarrow \bar{A} = \frac{1}{2}B'^{-1}(\frac{1}{\alpha+1}) \end{aligned} \quad (37)$$

When the parameter α is zero, the uniform standard is equal to:

$$\bar{A} = \frac{1}{2}B'^{-1}(1) \quad (38)$$

In order to find the value of transfers t, we use the equality of the gains from cooperation across the countries:

$$\begin{aligned} U &= U^* \Longleftrightarrow B(2\bar{A}) - \bar{A} - t - \hat{N}B_3 = \alpha B(2\bar{A}) - \bar{A} + t - \hat{N}B_3^* \\ \Longleftrightarrow\ t &= \frac{1-\alpha}{2}B(2\bar{A}) - \frac{1}{2}\hat{N}B_3 + \frac{1}{2}\hat{N}B_3^* \end{aligned} \quad (39)$$

When the parameter α is zero, the level of transfers is given by:

$$t = \frac{1}{2}B(2\bar{A}) - \frac{1}{2}\hat{N}B_3 + \frac{1}{2}\hat{N}B_3^* \Longleftrightarrow t = \frac{1}{2}B(2\bar{A}) - \frac{1}{2}\hat{N}B_3 \quad (40)$$

We can now investigate the gains from cooperation for the agreement of uniform standards with transfers when no firm invests:

$$U = U^* = \left[B(2\bar{A}) - \bar{A} - t - \hat{N}B_3\right] = \left[\begin{array}{c} B(2\tfrac{1}{2}B'^{-1}(1)) - (\tfrac{1}{2}B'^{-1}(1)) - \\ \tfrac{1}{2}B(2\tfrac{1}{2}B'^{-1}(1)) + \tfrac{1}{2}\hat{N}B_3 - \hat{N}B_3 \end{array}\right] = 0 \quad (41)$$

We note that the gains from cooperation are zero in both cases of a uniform standard with transfers, when no firm invests, and of differentiated standards without transfers, when the firm of the ENCC invests. ■

H- Conditions of Existence of the "Incentive Uniform Standard" and "Disincentive Uniform Standard" Cases ($\alpha = 0$) (not to be published)

Given the negotiated standards with $\alpha = 0$, the conditions of existence of the situation "incentive uniform standard" take the following forms:

$$1)\ A_1^* < \tilde{A} \Longleftrightarrow 0 < 1 - \sqrt{1-2F}$$

which is satisfied, given that $0 < \tilde{A} \leq 1$.

$$2i)\ \bar{A}_1 > \tilde{A} \iff \frac{2b-1}{1+4d} > 1-\sqrt{1-2F} \iff F < \frac{1}{2}-\frac{1}{2}(1-\frac{2b-1}{1+4d})^2$$

$$\begin{aligned}
2ii)\ \frac{\bar{A}_2^2}{2}+F &< \bar{A}_1 \iff \frac{1}{2}(\frac{b}{1+2d})^2+F < \frac{2b-1}{1+4d} \iff \\
F &< \frac{2b-1}{1+4d}-\frac{1}{2}(\frac{b}{1+2d})^2 \text{ and} \\
\frac{\bar{A}_2^2}{2}+F &< \bar{A}_3 \iff \frac{1}{2}(\frac{b}{1+2d})^2+F < \frac{b-1}{2d} \iff \\
F &< \frac{b-1}{2d}-\frac{1}{2}(\frac{b}{1+2d})^2
\end{aligned}$$

$$\begin{aligned}
3i)\ A_1 &> \tilde{A} \iff \frac{b}{1+d} > 1-\sqrt{1-2F} \iff F < \frac{1}{2}-\frac{1}{2}(1-\frac{b}{1+d})^2 \\
3ii)\ \frac{A_1^2}{2}+F &< A_3 \iff \frac{1}{2}(\frac{b}{1+d})^2+F < \frac{b-1}{d} \iff \\
F &< \frac{b-1}{d}-\frac{1}{2}(\frac{b}{1+d})^2
\end{aligned}$$

We also have an additional condition on the level of sunk cost, $F \leq 1/2$, implied by the constraint $\tilde{A} \leq 1$.

The conditions of existence of the situation "disincentive uniform standard" take the following forms:

$$\begin{aligned}
1)\ A_1^* &< \tilde{A} \iff 0 < 1-\sqrt{1-2F} \\
\text{which is satisfied, given that } 0 &< \tilde{A} \leq 1.
\end{aligned}$$

$$\begin{aligned}
2i)\ A_1 &> \tilde{A} \iff \frac{b}{1+d} > 1-\sqrt{1-2F} \iff F < \frac{1}{2}-\frac{1}{2}(1-\frac{b}{1+d})^2 \\
2ii)\ \frac{A_1^2}{2}+F &< A_3 \iff \frac{1}{2}(\frac{b}{1+d})^2+F < \frac{b-1}{d} \iff F < \frac{b-1}{d}-\frac{1}{2}(\frac{b}{1+d})^2
\end{aligned}$$

$$\begin{aligned}
3.1)\ (\text{threshold condition})\bar{A}_1 &< \tilde{A} \iff \frac{2b-1}{1+4d} < 1-\sqrt{1-2F} \iff \\
F &> \frac{1}{2}-\frac{1}{2}(1-\frac{2b-1}{1+4d})^2
\end{aligned}$$

$$\begin{aligned}
\text{3.2.i) (cost condition)}\bar{A}_1 &> \tilde{A} \Longleftrightarrow \frac{2b-1}{1+4d} > 1-\sqrt{1-2F} \Longleftrightarrow \\
F &< \frac{1}{2}-\frac{1}{2}(1-\frac{2b-1}{1+4d})^2 \\
\text{3.2.ii) } \frac{\bar{A}_1^2}{2}+F &> \bar{A}_3 \Longleftrightarrow \frac{1}{2}(\frac{2b-1}{1+4d})^2+F > \frac{b-1}{2d} \Longleftrightarrow \\
F &> \frac{b-1}{2d}-\frac{1}{2}(\frac{2b-1}{1+4d})^2 \text{ and} \\
\frac{\bar{A}_2^2}{2}+F &> \bar{A}_3 \Longleftrightarrow \frac{1}{2}(\frac{b}{1+2d})^2+F > \frac{b-1}{2d} \Longleftrightarrow \\
F &> \frac{b-1}{2d}-\frac{1}{2}(\frac{b}{1+2d})^2
\end{aligned}$$

We also introduce the additional condition on the level of sunk cost, $F \leq 1/2$.