Partial and Global Cooperation with Unilateral Commitment in the presence of Global Environmental Problems*

Jean-Christophe PEREAU† and Tarik TAZDAIT‡

Abstract

This paper focus on the link between the group cooperation and the unilateral commitment behaviour of some countries in the presence of global environmental problems. As we consider that this last behaviour occurs when bargaining failed, we call it a precautious commitment. We also show that the emergence of a non-coordinate global cooperation can result from a strategic action from the members of the coalition. The insiders of the coalition create an incentive for the nonmembers to reduce without coordination their emissions. Finally, when we introduce a environmental tax prescribed by the cooperating countries to the non-cooperating ones, cooperation becomes global and coordinate.

Keywords : Global Environmental Problems, Coalition, Unilateral Commitment, Nash Equilibrium, Environmental Tax;
JEL Classification : D74, Q28;

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†OEP, University of Marne-la-Vallée (Email : pereau@univ-mlv.fr) Cité Descartes, 5 bd Descartes, Champs sur Marne, Marne la Vallée Cedex 2, France and LEMMA, University of Littoral.

‡CNRS-EHESS-CIRED (Email : tazdait@centre-cired.fr) Jardin Tropical, 45 bis av de la belle Gabrielle, 94736 Nogent sur Marne, France and OEP, University of Marne-la-Vallée.

Non technical abstract

This paper deals with the question of cooperation within the scope of global environmental problems such as increasing greenhouse eœects or reduced ozone layer. These problem are global because all the countries in the world are involved and each country suffers from its own pollutant emissions but also suffers from the emissions of the other countries. So, in order to prevent the negative and irreversible consequences on climate change, countries have to reduce their emissions. Such problems require an international coordination of environmental problems. This leads to negotiation aiming at signing agreements concerning the reduction of pollutant emissions as carbon dioxide (CO_2). But, in practice, it appears that international agreements are only signed by a limited number of countries. The solution of a global problem does not imply a global cooperation. Cooperation is only partial and not global and it is more a rule than an exception. This matter of fact raises several questions : What happens when international bargaining failed ? How can you explain the individual behaviour of some countries ? How the signatories of an agreement can force the nonsignatories countries to join the coalition of cooperating countries ? In general, the theoretical literature considers that countries can decide whether or not to coordinate their policies with the other countries. But anyway, countries have decided to reduce their emissions. In this paper, we assume that countries can decide to foresee no environmental policy. This means that they decide to do nothing and only take advantage of the reductions of the cooperating countries without bearing any costs. This new strategy allows us to put forward a simple idea : when we extend the scope of countries strategies, we are able to highlight various kind of cooperation. So, our main objective is to set up a taxonomy of cooperation. We emphasize four kind of cooperation. Partial cooperation means that only at least two but never more than three countries decide to coordinate their reduction within a coalition while the other ones do nothing. A precautious unilateral commitment occurs when bargaining failed. Some countries decide to reduce their emission in an individual manner without coordination while the other ones do noting. As the reductions of these countries are lower compared to the case when bargaining succeed, it appears less costly for us to support the defection of the other countries. In the non coordinate global cooperation, we have both partial cooperation and a unilateral commitment movement, so two levels of reduction. By adding a new strategy, we show that the main characteristic of the coalition is to be incentive. The emergence of a coalition which never exceed two countries leads to a training effect which force the other countries to reduce their emissions. Finally, when we assume that the cooperating countries are able to

tax the non cooperating ones, cooperation becomes global and coordinate. The only way for the nonmembers of the coalition to avoid to pay the tax is to join the coalition. This tax can be consider as a barrier to entry.

CONTENTS

1 Introduction

This paper deals with the question of cooperation in the presence of global environmental problems such as increasing greenhouse effects. These problems are global in so far as they concern the whole planet not only by their scope but also by their irreversible consequences such as climate changes, ice melting and desertification. As Barrett [1], [2], [3], Carraro and Siniscalco [6], [7] or Chander and Tulkens [8] have pointed out, such as environmental problems require an international coordination of environmental policies. This leads to bargaining aiming at signing agreements concerning the reduction of pollutant emissions as carbon dioxide (CO_2). But in practice, only a subset of the countries involved in the pollution problem agrees upon pollution control measures. The solution of a global problem does not imply a global cooperation. Cooperation is only partial and not global.

The prisoner's dilemma is often used to describe transboundary environmental problems (Snidal [24], Ostrom [21]) As we know the issue of this game leads to a stable non-cooperative solution which is under-optimal according to Pareto. This solution is dominated by a cooperative solution which unfortunately cannot be reached spontaneously. According to the prisoner's dilemma, no agreement can be signed by all the countries. If a country was sure of the agreement of the other countries on a cooperative solution, it would be advised to desert by refusing the agreement and, as a consequence, obtaining a part of benefits resulting from the cooperative behaviour of the other countries without paying any costs. The economy of natural resources used to design this principle as the Tragedy of the Commons (Hardin [15]). However, practice shows that it is not the case since some agreements are effectively reached. The prisoner's dilemma repetition allows nevertheless to draw up the paradox. As the game perpetuates, actors are urged to cooperate (see Fudenberg and Tirole [14], Kreps et al [19]). Cooperation deducted from the prisoner's dilemma repetition should be global and not partial.

Strategic bargaining models seem an attractive theoretical framework to analyse the coordination of environmental policies (Chen [11], Rotillon et TazdaÔ[22], Rotillon et al [23]), but this theory depends on a crucial assumption. During the bargaining process, each country acts as if the status-quo point position remains unchanged when no agreement is reached. In this context, countries have no other choice than cooperation since non cooperation is the worst strategy. Cooperation should be global. Moreover, in case of a failure of international bargaining, this framework implies that countries act as if no bargaining have been taken place. Countries will continue

to adopt a non-cooperative strategy while due to irreversible consequences, their status-quo point has become worse. In case of a failure of international bargaining, some countries can decide to cooperate without coordination and reduce unilaterally their pollutant emissions. Hoel [16] analyses this kind of behaviour. He shows that this unilateral commitment is not efficient insofar as it creates an incentive for the non cooperating countries to rise their emissions. However, such a behaviour exists[1](Kaitala et al [17], [18]).

The aim of this paper is to build a general framework in order to characterize the reasons of a partial cooperation and the conditions under which countries are willing to reduce unilaterally without coordination their pollutant emissions. Particularly, we focus on the link between the group cooperation and the unilateral commitment behaviour of some countries. Contrary to Barrett's model (1991) where each country can decide whether or not to coordinate its strategy with the other countries, we assume in our paper that each country can either cooperate or defect. Defection or free-riding mean here that a country do not implement an environmental policy. This way of proceeding appears more relevant in the case of global pollution problem. The cooperation behaviour can occur inside a coalition when an agreement is reached or outside in case of a failure of international bargaining. We associate this last behaviour with a precautious unilateral commitment. This commitment differs from Hoel's model (1991) since it does not appear before the bargaining process. When countries have the choice between cooperation or defection, our results show analytically that an international agreement always involves a sub-group of countries. This result is based on the coalition stability introduced by D'Aspremont et al [12] in the context of cartel formation. A coalition is said to be stable if none of its members want to get out and none of the nonmembers want to get in. The explanation is well-known. There is a private cost for a country to belong to a coalition while the coalition's benefits appear as public goods for all the involved countries and not only for the cooperating ones. We also show that although this precautious commitment has less impact than the global cooperation, it has also a lower cost for the involved countries and it leads to reduce defection. The gains made by coordination of environmental policies are so important that it creates an incentive to defection while those made by a unilateral commitment movement are less important.

[1] On january 1st, 1990, Finland introduced a fossil energy tax which should lead to a 1% reduction in its emissions. Some European Unions countries adopted a policy of unilateral reductions at the same time and without any official community position having been settled. Norway acted in a similar manner by introducing a carbon tax.

The next step of the analysis conciliates this two kinds of behaviour. We develop a new framework which allows us to have both partial cooperation and unilateral commitment in the same static game. We suppose that when an agreement emerges, the non-signatories countries have the choice between unilateral commitment and defection. In this case, we show that the main characteristic of the coalition is to be incentive. The emergence of a small coalition creates an incentive for all the nonmembers to commit unilaterally. The benefits made by the initial coalition of size two are so low that the outsiders prefer to reduce without coordination their emissions rather than free-ride in order to improve their welfare. This training effect leads to a non-coordinate global cooperation. The global reduction of the pollutant emission will be higher than the previous one without training effect.

The last question of this paper is the following : how can we expand the initial coalition in order to highlight a coordinate and global cooperation? The solution to induce a larger cooperation consists either to put on a system of transfers from the signatories to the remaining ones (Chander and Tulkens [9], [10][2]), or either to suppose that countries adopt an environmental policy in an irreversible way (Carraro and Siniscalco [7]). The Carraro and Siniscalco's model [7] is based on commitment's assumption. They assume that there exist countries which commit in a irreversible way, whatever the behaviour of the other nations should be, those countries do not go back over their environmental policy. According to these authors, the sine qua non condition for the cooperation to take place is that some countries decide to commit f i rst to reduce their pollutant emissions. Without this condition, the introduction of transfers from the coalition's insiders to the outsiders does not increase the size of stable coalitions. Basing on commitment and stability concepts, Carraro and Siniscalco pick out a whole range of alternating outlines concerning the shape an agreement can take in order to make effective an international reduction of pollutant emissions. They ørst consider the case of a stable coalition where only a limited number of countries commit themselves irrevocably to cooperate. Then, they define a sequential commitment : the countries composing stable coalition are gradually joined by other countries which commit themselves as well to cooperate in an irreversible way. Finally, they examine the minimum commitment to the cooperation : the number of countries getting along to cooperate is such

[2] These works are based on the cooperative game theoretic concept of the γ-core. The coalitional stability idea behind this concept assumes that if a country deviates from the grand coalition, this will imply a complete disintegration of the coalition. Tulkens [?] confronts the two approaches of cooperative and noncooperative game in environmental bargaining.

that appropriate self-financed transfers from them can induce other countries to join the movement.

In this paper, global cooperation is feasible when we introduce a environmental tax prescribed by the cooperating countries to the non cooperating ones. We assume that countries which decide to reduce their pollutant emissions are those where the production is conform to ecological standards. In order to not penalize home's ørms which undertake the necessary investment, those countries decide to implement a tax on foreign's goods that are liable not to be conformed to ecological standards. A such configuration requires that the origin of the pollution comes from the consumption of a tradeable good between all the countries. In this case, our results show that an international agreement can lead to a global cooperation for a minimum global amount of tax. We interpret this tax as a barrier to entry.

This paper is organized as follows. In section 2, the general framework is introduced and the partial cooperation and precautious unilateral commitment strategies are defined. The section 3 analyse how the training effect due to the emergence of a small coalition can lead to a non-coordinate global cooperation. In section 4, we show under which conditions the introduction of an ecological tax prescribed by the cooperating countries to the non-cooperating ones can lead to a coordinate global cooperation. Finally, the last section concludes.

2 Partial Cooperation and Precautious Unilateral Commitment

2.1 The model

Assuming bargaining takes place among n identical countries, indexed by $i = 1, ..., n$. If an agreement is reached between j countries, $2 \leq j \leq n$, only the members of the j-size coalition will reduce their pollutant emissions. Let $\Pi_i^c(j)$ the payoffof a country i belonging to a j-size coalition and $\Pi\ ^c_{-i}(j-1)$ its payoff when it does not join the j-size coalition. We assume that the total number of signatories is common knowledge. In the event of failure of international bargaining, some countries can decide to commit unilaterally in order to reduce their pollutant emissions while the other ones decide to defect. We call this behaviour a precautious unilateral commitment. Countries behave individually and reduce their emissions without coordination. In this case, we suppose that a country does not know how many countries will

commit unilaterally. Let $\Pi_i^{nc}(k)$ the payoff of i when k countries (i included) adopt a unilaterally commitment strategy and $\Pi_{-i}^{nc}(k-1)$ its payoff when it adopts a free rider behaviour and takes advantage of the unilateral action of the $(k-1)$ other countries. Finally, when nobody reduces their pollutant emissions, we have $\Pi_{-i}^{nc}(0) = 0$.

Let Φ_i^k (resp. Θ_i^{k-1}) the probability that k (resp. $k-1$) countries commit unilaterally knowing that i cooperates (resp. defects). We have :

$$\begin{aligned} \Phi_i^k &= p(k \text{ countries } \in K/i \in K) \\ \Theta_i^{k-1} &= p(k-1 \text{ countries } \in K-1/i \notin K-1) \end{aligned}$$

where K (resp. $K-1$) is the set of the k (resp. $k-1$) countries, $2 \leq k \leq n$, which commit unilaterally in the event of failure of international bargaining. We note J the set of the members of the coalition of size j.

The behaviour of a country i, $i \in n$, is given by the matrix :

$i/.$	Coalition	No-Coalition
C	$\Pi_i^c(j)$	$\Pi_i^{nc}(k,1)$
D	$\Pi_{-i}^c(j-1)$	$\Pi_{-i}^{nc}(k-1,0)$

with

$$\Pi_i^{nc}(k,1) = \Phi_i^k \Pi_i^{nc}(k) + \Phi_i^1 \Pi_i^{nc}(1) \quad (1)$$

$$\Pi_{-i}^{nc}(k-1,0) = \Theta_i^{k-1} \Pi_{-i}^{nc}(k-1) + \Theta_i^0 \Pi_{-i}^{nc}(0) = \Theta_i^{k-1} \Pi_{-i}^{nc}(k-1) \quad (2)$$

Eq(1) states that in case of failure of bargaining, k countries (i included) can decide to reduce unilaterally their pollutant emissions with a probability Φ_i^k or only one country with a probability Φ_i^1. When a country i acts as a free-rider, it takes advantage of the unilateral actions of the $k-1$ other countries with a probability Θ_i^{k-1}.

As Barrett [1], the ith country's payoff function can be written :

$$\Pi_i = b[aQ_{+n} - \frac{1}{2n} Q_{+n}^2] - \frac{c}{2} q_i^2 \quad (3)$$

where a, b and $c > 0$ are positive parameters, Q_{+n} is global abatement and q_i the abatement of the country i. Each country gets benefit from global reductions of pollution. The gross benefit function is concave and increases in Q_{+n}. The abatement costs faced by each country depend only on its own abatement, the cost function is convex and increases in q_i. Eq (3) designs the net benefits of a country i.

The j-size cooperative solution is given by the following maximization program :

$$\max_{q_1,\ldots,q_j} bj[aQ_{+j} - \frac{1}{2n}Q_{+j}^2] - \frac{c}{2}\sum_{i=1}^{j} q_i^2 \tag{4}$$

with $Q_{+j} = \sum_{i=1}^{j} q_i$, this yields :

$$Q^c = \frac{abj^2n}{bj^2 + cn} \text{ and } q_i^c = \frac{abjn}{bj^2 + cn} \tag{5}$$

The payoff of a country belonging to the j-size coalition is :

$$\Pi_i^c(j) = \frac{a^2b^2j^2n}{2(bj^2 + cn)} \tag{6}$$

When an agreement is not reached, only k countries will decide to commit unilaterally taking as given the behaviour of the other countries. So they play Nash strategy and act as singletons. Formally, this is written :

$$\max_{q_i} b[a(q_i + Q_{-(k-1)}) - \frac{1}{2n}(q_i + Q_{-(k-1)})^2] - \frac{c}{2}q_i^2 \tag{7}$$

where $Q_{-(k-1)} = Q - q_i$ is the $(k-1)$'s pollutant abatement. The solution is :

$$Q^{nc} = \frac{abkn}{bk + cn} \text{ and } q_i^{nc} = \frac{abn}{bk + cn} \tag{8}$$

$$\Pi_i^{nc}(k) = \frac{a^2b^2n(bk^2 + 2ckn - cn)}{2(bk + cn)^2} \tag{9}$$

Remark 1
For $k = j > 1$, we have :

$$\Pi_i^c(k) - \Pi_i^{nc}(k) > 0 \text{ and } Q^c - Q^{nc} > 0 \tag{10}$$

It means that when the number of cooperative countries is the same, the incentive for a country i to join the coalition is greater than commit unilaterally. The global abatement is greater in the f i rst case than in the second one.

2.2 Results

Proposition 1 An international agreement consists of at least two, but never more than three signatories. More precisely, the cooperation strategy is a Nash Equilibrium if and only if :

- $j = 2$ for $n \geq b/2c \geq 2$
- $j = 3$ for $n \geq 16b/c$

Proof. The cooperation strategy is a NE if and only if :

$$\Pi_i^c(j) - \Pi_{-i}^c(j-1) \geq 0 \tag{11}$$

with

$$\Pi_{-i}^c(j-1) = \frac{a^2b^2(j-1)^2n(b(j-1)^2 + 2cn)}{2(b(j-1)^2 + cn)^2} \tag{12}$$

This gives the polynomial equation in j :

$$P(j) = -bj^4 + 4bj^3 - (6b + cn)j^2 + 4(b + cn)j - b - 2cn \geq 0 \tag{13}$$

If $n \geq b/2c$, the inequality (13) is fulølled for $j = 2$ and if $n \geq 16b/c$, (13) is fulfilled for $j = 3$ ■

Eq(11) represents the internal stability condition, a country i would not wish to withdraw from the coalition. We can also determine the external stability condition. A country l would not wish to join a size-j coalition since its payof f f is greater when it defects. Formally we have for a country $i \notin J$:

$$\Pi_{-i}^c(j) - \Pi_i^c(j+1) > 0 \tag{14}$$

(14) is verified for $n \leq 16b/c$. It means that a third country has no incentive to join a coalition formed by two countries when n is small. However, for large n, the size of the coalition is equal to 3.

The conditions (11) and (14) ensure that a coalition is internally and externally stable. This definition used by Carraro and Siniscalco [7] has been introduced by D'Aspremont et al [12], Donsimoni et al [13]). This proposition means that the number of countries involved in an agreement does not exceed 3[3]. The stability plays here a crucial role. Its introduction allows in fact to

[3]Note that $\forall$ values of b, c and n, $P(J = 4) < 0$. Contrary to the numerical simulations of Barrett's model (1991), the size of the coalition does not rise according the values of b and c. We explain this difference by the fact that in Barrett's model, the only choice for a country is to act cooperatively or non-cooperatively while in this paper each country decides whether or not to adopt an environmental policy.

make an agreement feasible from itself. First, we see that global cooperation cannot be reached because the incentive for a country to free-ride rises with the size of the coalition. As each country expects the same attitude, none will agree to sign the agreement. Partial cooperation is more the rule than an exception. If a signatory goes back on its decision, it is urged not to reduce its pollutant emissions. As a consequence, it does not bear any costs. However, a notable compensation exists. This desertion of the agreed country entails a reduction of the number of cooperating countries, which weakens the original agreement : remaining countries are indeed brought about to reduce their emissions' level. In fact, a signatory will attempt to withdraw only if the saving in abatement costs compensates the profit loss that results from. And vice-versa, any country that wishes to accede to the agreement decides to reduce its emissions and consents in the same time to bear the costs associated with the abatement demanded by the agreement. The membership of an additional country nevertheless reinforces the agreement, the other member countries of the coalition are urged to increase their reduction level. Let's underline that this support is possible only if the profit increase collected by the new signatory exceed the cost rise it follows. There is a private cost for a country to belong to a coalition while the coalition's benefits appear as public goods for all the involved countries and not only for the cooperating ones. To resume, a coalition of size 2 or 3 allows a coordination of environmental policies without incentive to defection.

The self-carrying out is all the more significant since it does not exist any organization sufficiently influential to make sure that the treaty should be respected. Of course, international institutions exist but any of them do not have the power or the duty to impose to one or several nations the behaviour to adopt. This accordingly requires an agreement between the diœerent parties involved.

Proposition 2 In the event of failure of international bargaining, some countries can decide to act unilaterally while the other ones defect. The number of these countries depends on the believes about the other countries. Formally, the non-commitment strategy is a Nash Equilibrium if and only if :

$$p(k-1) \geq \frac{[F(kp(k)+p(1))+M(p(1)-kp(k))+QM^{1/2}kp(k)](n-U)T}{(n-k+1)RSU} \tag{15}$$

Proof. The non-unilateral commitment strategy is a NE if and only if :

$$\Pi_{-i}^{nc}(k-1,0)-\Pi_{i}^{nc}(k,1)\geq 0 \tag{16}$$

with

$$\Pi_i^{nc}(k,1) = \frac{a^2b^2n}{2R}[F(\Phi_i^k+\Phi_i^1)+M(\Phi_i^1-\Phi_i^k)+QM^{1/2}\Phi_i^k] \quad (17)$$

$$\Pi_{-i}^{nc}(k-1,0) = \frac{a^2b^2n\theta_i^{k-1}S}{2T} \quad (18)$$

where $F=b^2k^2+2bckn$, $M=c^2n^2$, $Q=bk^2+2ckn-b$, $R=(b+cn)(bk+cn)^2$, $S=bk^2+2ckn-2bk+b-2cn$, $T=[b(k-1)+cn]^2$. It is the case when the incentive to defection is greater than or equal to zero :

$$\Theta_i^{k-1} \geq \frac{T}{RS}[F(\Phi_i^k+\Phi_i^1)+M(\Phi_i^1-\Phi_i^k)+Qcn\Phi_i^k] \quad (19)$$

Using Bayes formula, we express the conditional probabilities Φ_i^k, Φ_i^1 and Θ_i^{k-1} as functions of $p(k)$, $k=1,...,n$, the probability that exactly k countries commit unilaterally. We have :

$$\Phi_i^k = \frac{p(i/k)p(k)}{p(i)} = \frac{p(i/k)p(k)}{\sum_{r=1}^n p(i/r)p(r)} \quad (20)$$

When the country i has decided to sign the agreement with the other $(k-1)$ ones among the n bargainers, we have :

$$p(i/k) = \frac{k}{n} \quad , \quad \Phi_i^k = \frac{kp(k)}{\sum_{r=1}^n p(r)r} \quad , \quad \Phi_i^1 = \frac{p(1)}{\sum_{r=1}^n p(r)r}$$

$$\Theta_i^{k-1} = \frac{(n-k+1)p(k-1)}{n-\sum_{r=1}^n p(r)r}$$

By substitution in (19), we have (15) with $U=\sum_{r=1}^n p(r)r$. ■

In the event of failure of international bargaining, this proposition shows that some countries can decide to act unilaterally while the other ones defect. In particular, a country will not commit unilaterally if its believes about the unilateral behaviour of the other countries are strong (see 19). When a country expects a large unilateral commitment movement, its incentive to defect rises. Our results show that although this precautious commitment has less impact than the global cooperation, it has also a lower cost for the involved countries and it leads to reduce defection. Defection is the main problem. When countries decide to sign an agreement, they have to support the defection of the other countries. So, when bargaining failed, it might be more interesting for us to adopt a precautious behavior. Their individual contributions are lower and it appears less costly for countries which commit to support the defection of the other countries. The gains made by coordination of environmental policies are so important that it creates an incentive to defection while those made by a unilateral commitment movement are less important than the preceding.

3 Training Eœect and Non-Coordinate Global Cooperation

In the previous section, we consider a symmetric configuration. International bargaining can succeed or not. In the second case, some countries can decide to commit unilaterally. Now we suppose that when an agreement emerges, the outsiders have the choice between unilateral commitment and defection. This new framework allows us to have both partial cooperation and unilateral commitment in the same static game and as a consequence two levels of reduction. By adding a new strategy in the model of Barrett, we show that the emergence of a small coalition creates an incentive for all the non-members to reduce unilaterally their emissions. Cooperation is then global and non-coordinate.

Remark 2

If eq (28) is fulfilled, then it is profitable for the $k = n - j$ countries to commit unilaterally.

Proof. Now consider the case where the members of the coalition expect that k countries will decide to reduce their emissions. We have to solve simultaneously the following maximization programs :

$$\max_{q_1,...,q_j} bj[a(Q_{+k} + Q_{+j}) - \frac{1}{2n}(Q_{+k} + Q_{+j})^2] - \frac{c}{2}\sum_{i=1}^{j} q_i^2 \tag{21}$$

and

$$\max_{q_i} b[a(q_i + Q_{-(k-1)} + Q_{+j}) - \frac{1}{2n}(q_i + Q_{-(k-1)} + Q_{+j})^2] - \frac{c}{2}q_i^2 \tag{22}$$

This leads to :

$$Q^c(j/k) = \frac{abj^2n}{bj^2 + cn + bk} \text{ and } q_i^c(j/k) = \frac{abjn}{bj^2 + cn + bk} \tag{23}$$

$$Q^{nc}(k/j) = \frac{abkn}{bj^2 + cn + bk} \text{ and } q_i^{nc}(k/j) = \frac{abn}{bj^2 + cn + bk} \tag{24}$$

where $Q^c(j/k)$ is the global abatement of the j-size coalition knowing that k countries will decide to commit unilaterally and $Q^{nc}(k/j)$ the global abatement of the k commitment movement knowing that j countries cooperate within the coalition and coordinate their policies. If we compare the global abatement of the j-size coalition (5) with (23), we have for $k \geq 1$: $Q^c > Q^c(j/k)$: when the insiders of the coalition expect no reduction for

the remaining countries, their global and individual abatements are greater. The net benefit of one member of the coalition which expect a k-movement of unilateral commitment is :

$$\Pi_i^c(j/k) = \frac{a^2b^2n(2kbj^2 + bk^2 + 2cnk + bj^4 + cnj^2)}{2(bj^2 + cn + bk)^2} \tag{25}$$

Let $\Pi_i^{nc}(k/j)$ the payoff of a country i which adopts a unilateral strategy when a coalition of j-size appears, knowing that $k-1$ countries adopt the same behaviour and the members of the coalition have expected a such unilateral movement.

$$\Pi_i^{nc}(k/j) = \frac{a^2b^2n(2kbj^2 + bk^2 + 2cnk + bj^4 + 2cnj^2 - cn)}{2(bj^2 + cn + bk)^2} \tag{26}$$

We must check that :

$$\Pi_i^{nc}(k/j) - \Pi_{-i}^c(j) \geq 0 \tag{27}$$

this gives :

$$P(k) = bcnk^2 + 2cn(bj^2 + cb)k - b^2j^4 - 2bcnj^2 - c^2n^2 \geq 0 \tag{28}$$

This condition is checked for $k = n - j$. ■

Futhermore, it does not mean that all the nonmembers of the coalition will decide to commit unilaterally. This movement will be effective only if its stability is guaranteed, that is to say when a country belonging to the k-movement does not wish to withdraw, this leads to the following proposition.

Proposition 3 The emergence of a small coalition of size 2 creates an incentive for all the non-signatories countries to commit unilaterally.

Proof. A country will not decide to withdraw from the unilateral commitment movement if and only if :

$$\Pi_i^{nc}(k/j) - \Pi_{-i}^{nc}(k-1/j) \geq 0 \tag{29}$$

this gives :

$$P(j) = -b^2j^4 - 2b^2(k-1)j^2 + bcn + c^2n^2 - b^2(k-1)^2 \geq 0 \tag{30}$$

In order to determine the value of k, we have to find out the size of the coalition. We must analyse two cases according that a country which withdraws

from the coalition decides to adopt an unilateral commitment or a defection behaviour. This leads to (31) and (33) conditions :

$$\Pi_i^c(j/k) - \Pi_i^{nc}(k+1/j-1) \geq 0 \tag{31}$$

We obtain :

$$P(j) = a_6 j^6 + a_5 j^5 + a_4 j^4 + a_3 j^3 + a_2 j^2 + a_1 j + a_0 \geq 0 \tag{32}$$

with the coefficient $a_6 = -b^2$, $a_5 = 4b^2$, $a_4 = -(7b^2 + 2bcn + 2b^2k)$, $a_3 = 8bcn + 8b^2 + 4b^2k$, $a_2 = -10bcn - 4b^2 - c^2n^2 - b^2k^2 - 2b^2k - 2bkcn$, $a_1 = 8bcn + 4c^2n^2 + 4bcnk$ and $a_0 = b^2k^2 - 3c^2n^2 - 2bkcn - 4bcn$.
and

$$\Pi_i^c(j/k) - \Pi_{-i}^{nc}(k/j-1) \geq 0 \tag{33}$$

this yields :

$$P(j) = a_6 j^6 + a_5 j^5 + a_4 j^4 + a_3 j^3 + a_2 j^2 + a_1 j + a_0 \geq 0 \tag{34}$$

$a_6 = -b^2$, $a_5 = 4b^2$, $a_4 = -(6b^2 + 2bcn + 2b^2k)$, $a_3 = 4b^2 + 8bcn + 4b^2k$, $a_2 = -(b^2k^2 + 8bcn + b^2 + 2bkcn + c^2n^2 + 2b^2k$, $a_1 = 4bcn + 4c^2n^2 + 4bcnk$ and $a_0 = -(bcn + 2bkcn + 2c^2n^2)$. ■

Eqs (32) and (34) are simultaneously checked for $j = 2$ under the respective conditions[4] :

$$n \geq A = \frac{b}{c}(k - 2 + 2\sqrt{1 + k + k^2}) \tag{35}$$

and

$$n \geq B = \frac{b}{4c}(2k - 7 + 3\sqrt{9 + 4k + 4k^2}) \tag{36}$$

For $n \geq \max(A, B)$, the emergence of a coalition of size-two will be followed by a $k = n - j$ unilateral commitment movement[5].

Contrary to the previous section where an unilateral commitment movement occurs only in the case of a failure in the international bargaining, this

[4]When countries play Nash strategies, the size of the coalition cannot exceed two. However, if we suppose, like Barrett 1994's model, that the signatories play as a leader of Stackelberg, the size of the coalition can rise according the values of the parameters (Barrett [5]).

[5]To see this, substitute A and B in (30).

new framework allows us to have cooperation within the coalition and also outside by a unilateral commitment form. Since the pollutant reduction of the coalition are lower than the previous case ($Q^c(j = 2/k = n-2)$), the signatories of the agreement create an incentive for the nonmembers to adopt an environmental policy. The main characteristic of the coalition is to be incentive. The insiders force the outsiders to reduce their emissions. The benefits made by the coalition are so low that the other countries prefer to commit rather than free-ride. This unilateral movement both improve the welfare of the insiders and the outsiders. This strategy leads to a greater global abatement compared with the case where it does not exist a such unilateral movement. Formally we have :

$$Q^c(j = 2/k = n-2) + Q^{nc}(k = n-2/j = 2) > Q^c(j = 2/k = 0) \qquad (37)$$

In such context, the emergence of a small coalition implies a training effect which leads to a non-coordinate global cooperation. So, it is necessary that a coalition emerges in order to enforce a reduction of the nonmembers.

Let's denote that when $n < \max(A, B)$, an incentive coalition of size-two cannot appear. When the global environmental problem involves a few number of countries, the expected global reductions made by a coalition are so low that the nonmembers prefer to act as free-rider rather than adopt a environmental policy.

4 Coordinate Global Cooperation

The next step of this analysis of cooperation is to introduce a environmental tax prescribed by the cooperating countries to the non-cooperating ones. We assume that countries which decide to reduce their pollutant emissions are those where the production is conform to ecological norms. In order to not penalize home firms which undertake the necessary investment, those countries decide to impose a tax on foreign's goods that are liable not to be conformed to ecological norms. It is in the interest of the firms which invest in proper technology to claim its standardization in order to eliminate the rival foreign firms. This leads the firms of the cooperating countries to put pressure on their governments to adopt such tax against products which are not conform to ecological standards. A such configuration require that the origin of the pollution come from the consumption of a tradeable good between all the countries which are by assumption identical.

We suppose that the global amount of tax received by the cooperating countries is used to reduce their abatement costs of an amount equal to t.

The payof f function when the cooperating countries decide to tax the non-cooperating ones is :

$$\Pi_i^t = b\left[aQ_{+n} - \frac{1}{2n}Q_{+n}^2\right] - \frac{(c-t)}{2}q_i^2 \tag{38}$$

A country belonging to the coalition will receive $\frac{t}{2}q_i^2$. This global amount of tax will be taken on the $n-j$ countries which are outside the coalition. Each of one will then pay $\frac{t}{2(n-j)}q_i^2$ for one country in the coalition. The payoff of a country which decides not to join the coalition is :

$$\Pi_{-i}^t(j-1) = b\left[aQ_{+(j-1)} - \frac{1}{2n}Q_{+(j-1)}^2\right] - \frac{(j-1)t}{2(n-j+1)}q_i^2 \tag{39}$$

The j-size cooperative solution is given by the following program :

$$\max_{q_1,\ldots,q_j} \Pi_i^t(j) = bj\left[aQ_{+j} - \frac{1}{2n}Q_{+j}^2\right] - \frac{(c-t)}{2}\sum_{i=1}^{j} q_i^2 \tag{40}$$

The first-order conditions give :

$$Q^t = \frac{abj^2n}{bj^2+(c-t)n} \text{and } q_i^t = \frac{abjn}{bj^2+(c-t)n} \tag{41}$$

The payoff of a country belonging to the j-size coalition is then :

$$\Pi_i^t(j) = \frac{a^2b^2j^2n}{2(bj^2+(c-t)n)} \tag{42}$$

The incentive for a country i to cooperate is given by the following condition :

$$\Pi_i^t(j) - \Pi_{-i}^t(j-1) \geq 0 \tag{43}$$

where $\Pi_{-i}^t(j-1)$ is the payoff of the country i when it does not join the j-size coalition given by :

$$\Pi_{-i}^t(j-1) = \frac{a^2b^2(j-1)^2n\left[(n-j+1)\left(b(j-1)^2+2(c-t)n\right)-nt(j-1)\right]}{2\left(n-j+1\right)\left(b(j-1)^2+(c-t)n\right)^2}$$

The condition (43) gives the polynomial equation in j :

$$P(j) = a_5j^5 - a_4j^4 + a_3j^3 - a_2j^2 + a_1j - a_0 \geq 0 \tag{44}$$

with the coefficients

$$\begin{aligned}
a_5 &= bc \\
a_4 &= b(c-t)(n+5)+3bt \\
a_3 &= (c-t)(cn+4bn+10b)+3bt \\
a_2 &= (c-t)\left[(c-t)^2+(6b+5c-2t)\,n+10b\right]+bt \\
a_1 &= (c-t)\left[4(c-t)n^2+(4b+6c-3t)n+5b\right] \\
a_0 &= (c-t)\left[2(c-t)n^2+(b+2c-t)n+b\right]
\end{aligned}$$

In order to show that a coalition can involve all the countries, we determine under which conditions the inequality (44) is checked[6]. For $j=n$, (44) can be rewritten in a second-order equation in t :

$$P(t)=b_2t^2+b_1t-b_0\geq 0 \tag{45}$$

with

$$\begin{aligned}
b_2 &= -n^4+2n^3+n^2-n \\
b_1 &= bn^5+(c-2b)n^4-(b+c)n^3+5(b-c)n^2+(3c-4b)n+b \\
b_0 &= -bcn^4+c(4b-c)n^3+2c(2c-3b)n^2+2c(b-c)n-bc
\end{aligned}$$

Hence, for some values of t such that $0<\overline{t}<t<c$ with $\overline{t}$ the smallest eigenvalues of (45), cooperation will be global. This leads to the proposition :

Proposition 4 When the members of a coalition of size-j prescribe side payments in the form of an environmental tax to the nonmembers, an international agreement can lead to a global cooperation for a global amount of tax equal to t such that $0<\overline{t}<t<c$.

When no tax exists on products which are not conform to ecological norms edicted by the cooperating countries, the non signatories are in a better position than the former [7]. The non signatories have no incentive to join the coalition since their payoff will be worse. The solution to induce a larger cooperation consists either to put on a system of transfers from the signatories to the remaining ones (Chander and Tulkens [9], [10]), or either

[6] Eq (44) has five eigen-values, two complex and three real ones. The first real eigen value is between 0 and 1 since $P(j=0)<0$ and $P(j=1)=(c-t)^2n^2>0$. The inequality become positive for $j=2$ for n small or $j=3$ for n large (see proposition 1). As we are not able to determine the third real eigen value $\forall$ a, b, c, t and n, we shall restrict our analysis to $j=n$.

[7] We have $\Pi_{-i}(j)<\Pi_{-l}(j)$ for all $l\notin J$.

to suppose that countries adopt an environmental policy in an irreversible way (Carraro and Siniscalco [7]). Our framework develop a third approach. As soon as we introduce a tax on the products which are not conform to ecological norms, cooperation becomes global.

The cooperating countries have a wide range of instruments at their disposal to obtain the cooperation of the non cooperating ones. We may divide these instruments into two categories : positive inducement (as f i nancial or technological compensations) and the threat of sanctions (which may also take several forms) such as a boycott of goods coming from those countries that do not wish to join the international agreement. The authors who have studied this second category of instruments are inclined to conclude that they are not particularly helpful in sustaining environmental cooperation : The theory of international debt and our own experience suggest that sanctions are at best a most ineffective menace. We are led to conclude that the best method for stabilizing international agreements on greenhouse effect gas emissions is the carrot, i.e. the granting of f i nancial compensation to those countries inclined to avoid their obligations. Generally, the carrot is sufficient in itself (Mohr [20]).

In our analysis, this tax can be considered as a barrier to entry. The cost of the tax for the outsider countries rises with the number of countries belonging to the coalition. The only way for the non cooperating countries to avoid to pay it is to join the coalition. If they don't join the coalition, their payoff will be worse compared to the coalition's members. The tax can be considered as a negative incentive but not as a sanction. As the signatories countries are in a better position than the non cooperating ones, the tax creates also a positive incentive to cooperate. The purpose of the tax is not a deal between reduction and transfers, it is just a change in the competition's rules. Let us notice that the implement of this tax does not require the existence of an international agency. As soon as countries decide to adopt a such tax system, an agreement involving all the countries is self-enforcing.

5 Conclusion

In the spirit of Barrett's works, our analyse highlights the following results. Cooperation will be partial when countries are characterized by only two strategies : to sign an agreement or foresee no environmental policy. A self-enforcing environmental agreement consists of three countries when the number of countries involved by the transfrontier problem is large. In case

of a failure in bargaining, a precautious unilateral commitment can emerge when countries have to choose between unilateral commitment or defection. We also show that the emergence of a non-coordinate global cooperation can result from a strategic action from the members of the coalition. The latest will be create to urged the outsider countries to reduce without coordination their emissions. Finally, a coordinate global cooperation is feasible when we assume that cooperating countries decide to tax the non cooperating countries's products which are not conform to some ecological standards. To conclude, when we extend the scope of the countries strategies, we are able to emphasize different forms of cooperation. Extensions to improve this study must nonetheless be envisaged. In fact, throughout our formulation we have considered identical countries. We would have to relax this assumption and consider heterogeneous countries (Barrett [4]).

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