Co-operation and Unilateral Commitment in the Presence of Global Environmental Problems*

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Abstract

This paper focuses on the link between group co-operation and unilateral commitment of some countries in the presence of global environmental problems. We show that in case of a failure of negotiation, some countries can decide to commit unilaterally and reduce their emissions. we call this behaviour precautionary commitment. Absence of international agreement does not mean global defection from the environmental issue. we also show that the emergence of a non-co-ordinated global co-operation can result from a strategic action from the members of the coalition. The insiders of the coalition create an incentive for the non-members to reduce without co-ordinating their emissions.

Key words : global environmental problems, coalition, unilateral commitment, precautionary commitment.

JEL classification: D74, Q28

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1 Introduction

This paper deals with the question of cooperation in the presence of global environmental problems such as emissions of greenhouse gases, the protection of the ozone layer. 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 change, ice melting and desertification. As Barrett (1991, 1992, 1994), Carraro and Siniscalco (1992, 1993) or Chander and Tulkens (1992) have pointed out, such environmental problems cannot be tackled effectively in isolation by any country, they require international coordination of environmental policies. This leads to international conferences aiming at signing agreements concerning the reduction of emissions such 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 always imply global cooperation. Cooperation can be only partial and not global.

The prisoner's dilemma (PD hereafter) is often used to describe transboundary environmental problems (Snidal 1985, Ostrom 1990). As we know, the issue of this game leads to a stable non-cooperative solution which is suboptimal according to Pareto. This solution is dominated by a cooperative solution which unfortunately cannot be reached spontaneously. According to the PD, an agreement will not be signed by all countries. If a country were sure of the commitment of the other countries on a cooperative solution, it would be tempted to desert the agreement and, as a consequence, obtain part of benefits resulting from the cooperative behaviour of the other countries without paying any costs. However, practice shows that it does not always apply since some agreements effectively are reached.

It is possible to explain cooperation in PD by consideration the PD supergame which is the (infinite) repetition of the basic PD-game for which the Folk Theorem shows that mutual cooperation is an equilibrium outcome. Güth *et al* (1991) show however that this theorem is inconsistent with stronger rationality requirements. Axelrod (1984) proposes the Tit-for-Tat strategy for the repeated PD. A player choosing Tit-for-Tat begins with the cooperative strategy and repeats the last choice of his opponent in later periods. This strategy does not loose against a defective player but wins a lot when confronted with a cooperative player. Cooperation in a repeated PD will be global and not partial. This result remains unsatisfactorily since international environmental agreements involve few countries.

Strategic bargaining models seem an attractive theoretical framework to

analyse the coordination of environmental policies (Chen 1997, Rotillon and Tazdaït 1996, Rotillon *et al* 1996), but this theory depends on a crucial assumption. Concerning the axiomatic and related players strategic environment, it is commonly envisioned that agents negotiate assuming that in case of a setting failure, the prevailing situation is as if negotiation had never taken place: the status-quo in which all countries defect the environmental cause. Hence, countries should have no other choice than cooperate since the non-cooperative outcome is shown as being the worse of the alternative. Nevertheless, because of the public good status of environmental items, the so called "Tragedy" of the commons property good (Hardin, 1968) -characterized by the domination of defection behaviour- will pertain, negotiation being then perceived as exerting a neutral influence on countries' behaviour. Grasping negotiation on that angle is not relevant. Countries organize indeed negotiation in order to improve their welfare. Negotiation is an attempt to resolve potential irreversibility environmental degradations could lead to. There is thus a will for cooperation and even in the eventuality of disagreement, there is no interest for countries to remain on that state. It is pertinent to assume that countries, in the absence of coordination, firm up their cooperation will by adopting a unilateral environmental policy. As firstly mentioned by Kaitala *et al* (1992a, b), countries can also start to reduce emissions unilaterally as the result of the influence of a border country. Absence of international agreement does not mean global defection to the environmental issue. In other words, absence of coordination does not mean absence of cooperation, countries can opt for a unilateral commitment.

The aim of this paper is to characterize the reasons of partial cooperation and the conditions under which countries are willing to reduce emissions unilaterally without coordination. Particularly, we focus on the link between group cooperation and unilateral commitment behaviour of some countries. The cooperation behaviour can occur inside a coalition when an agreement is reached or outside in case of a failure in the international bargaining process. We associate this last behaviour with a precautionary 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 that an international agreement always involves a sub-group of countries. This result is derived from the concept of coalition stability introduced by D'Aspremont et al (1983) 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 non-members 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 are public goods for all the involved countries

and not only for the cooperating ones. We also show that although this precautionary commitment has less impact than global cooperation, it has also a lower cost for the involved countries and it leads to less defection. The gains made by coordination of environmental policies are so important that it creates an incentive to defection, while the benefits created by a unilateral commitment movement are less important.

The next step of the analysis conciliates these two forms 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-signatory countries have the choice between unilateral commitment and defection. In this case, we show that the main characteristic of the coalition is the incentive it creates for all the non-members to commit unilaterally. The benefits made by the initial coalition of size two are so low that the outsiders prefer to reduce their emissions without coordination rather than free-ride in order to improve their welfare. This training effect leads to non-coordinated global cooperation. The global emissions reduction will be higher than the previous one without training effect.

The paper is organized as follows. In section 2, the model is introduced and the partial cooperation and precautionary unilateral commitment strategies are defined. Section 3 analyses how the training effect due to the emergence of a small coalition can lead to non-coordinated global cooperation. Finally, the last section concludes.

2 Partial Cooperation and precautionary Unilateral Commitment

2.1 The model

Assume negotiation 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 emissions. This is a necessary assumption to the extent to its corresponds to the reality. More precisely, the change we observe is based on two trends[1]. Firstly, any agreement to be signed is only signed by a restricted number of countries. Secondly, any

[1]Truly speaking, this change relies on three trends. We remark that, after its formation, the initial coalition has been enlarged with the entry of additional countries. However, it did not lead to a convergence towards the participation of all countries to the agreement.

environmental policy is not adopted by a non-signatory country. Then, when a coalition is emerging, cooperation remains the result of the only countries that are members of the coalition. We should also add that the threat of "no action" is regularly considered by developing countries in the course of climate change negotiations. By introducing this alternative in our analysis, it becomes possible to determine its relevance.

Turning to notation, let $\Pi_i(j)$ be the payoff of a country i belonging to a j-size coalition and $\Pi_{-i}(j-1)$ 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 in the international bargaining process, 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 precautionary 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 adopt a precautionary behaviour. Let $\Pi_i(k)$ denote the payoff of i when k countries (i included) adopt a unilaterally commitment strategy and $\Pi_{-i}(k-1)$ 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 $\Pi_{-i}(0) = 0$.

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

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

where K is the set of the countries, $2 \leq k \leq n$, which adopt a precautionary behaviour in the event of failure in international negotiation. We denote J the set of the members of the coalition of size j.

The payoffs of country i, $i \in N$ for the different strategy combinations are listed in the matrix:

$i/.$	Coalition	No-Coalition
Cooperation	$\Pi_i(j)$	$\Pi_i(k,1)$
Defection	$\Pi_{-i}(j-1)$	$\Pi_{-i}(k-1,0)$

with:

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

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

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}(eq 2)[2].

As in Barrett (1991), the ith country's payoff function can be written:

$$\Pi_i = b[aQ_n - \frac{1}{2n}Q_n^2] - \frac{c}{2}q_i^2 \tag{3}$$

where a, b and $c > 0$ are positive parameters, $Q_n = \sum q_i$ is global abatement and q_i the abatement of the country i. Each country benefits from global reductions of pollution. The gross benefit function is concave and increases in Q_n. The abatement costs faced by each country depends only on its own abatement. The cost function is convex and increases in q_i. Eq (3) thus defines 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. 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:

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

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

[2]We assume that the sum of the probabilities is equal to one : $\Phi_i^k + \Phi_i^1 + \Theta_i^{k-1} + \Theta_i^0 = 1$.

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 net benefits for country i to join the coalition are greater than its benefits from committing unilaterally. Global abatement is greater in the first case than in the second one.

Remark 2
$\forall$ j and k such that:

$$j^2 \leq \frac{bk^2 + cn(2k-1)}{b + cn} \tag{11}$$

we have

$$\Pi_i^c(j) - \Pi_i^{nc}(k) \leq 0 \tag{12}$$

Consequently, for some values of k and j, it is more interesting for a country i to adopt a precautionary behaviour rather than to join a coalition of size $(j-1)$. This appears when j is small relatively to n.

2.2 Results

Proposition 1 *An international agreement consists of at least two, but never more than three signatories. More precisely, for a country i, the cooperation strategy is the best reply to the desertion behaviour of non-signatory countries:*

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

Proof. The cooperation strategy is the best reply to the desertion behaviour if and only if $\forall i \in J$:

$$\Pi_i^c(j) - \Pi_{-i}^c(j-1) \geq 0 \tag{13}$$

with

$$\Pi_{-i}^c(j-1) = \frac{a^2b^2(j-1)^2n(b(j-1)^2 + 2cn)}{2(b(j-1)^2 + cn)^2} \tag{14}$$

This gives the polynomial equation in j

$$P(j) = -bj^4 + 4bj^3 - (6b + cn)j^2 + 4(b + cn)j - b - 2cn \geq 0 \tag{15}$$

If $n \geq b/2c$, the inequality (15) is verified for $j = 2$ and if $n \geq 16b/c$, (15) is verified for $j = 3$. ■

Eq(13) represents the internal stability condition, such that a country i would not wish to withdraw from the coalition. We can also determine the external stability condition. A country i would not wish to join a size-j coalition since its payoff is greater when it defects. Formally we have for a country $i \notin J$:

$$\Pi^c_{-i}(j) - \Pi^c_i(j+1) \geq 0 \tag{16}$$

Eq (16) 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 (13) and (16) ensure that a coalition is internally and externally stable. This definition, used by Carraro and Siniscalco (1993), is due to D'Aspremont et al (1983), Donsimoni et al (1986). The proposition means that the number[3] of countries involved in an agreement does not exceed 3. Stability plays a crucial role here. Its introduction allows for a self-enforcing agreement. First, we note 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 sign the agreement. Partial cooperation is more the rule than an exception. If a signatory goes back on its decision, it will not reduce its emissions. As a consequence, it does not bear any costs. However, a notable compensation exists. The desertion of the country from the agreement 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 consequent profit loss. And vice-versa, any country that wishes to accede to the agreement decides to reduce its emissions and consents at 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, since the other member countries of the coalition are urged to increase their reduction level. Let's underline that this result is possible only if the profit increase collected by the new signatory exceeds the cost

[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 to 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.

increase 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.

Self-enforcement is all the more significant since there 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 a behaviour onto one or several nations. This accordingly requires an agreement between the different parties involved.

Now, consider a stable j-coalition. One can ask if the j countries can enlarge the coalition size by implementing utility transfers to countries lacking incentives to join. Note that an utility transfer T is conceivable first, if at the most its amount equals the benefit perceived by the j countries from the widening of the coalition : $T > \Pi^c_{-i}(j) - \Pi^c_i(j+1)$, and second, if its amount is at least equal to cost for the $j+1$th country to join the coalition: $T \leq \Pi^c_i(j+1) - \Pi^c_i(j)$. These two conditions yield

$$\Pi^c_{-i}(j) - \Pi^c_i(j+1) < T \leq \Pi^c_i(j+1) - \Pi^c_i(j)$$

The existence of T would signify that the coalition can be enlarged by a self-financed policy. This result is however clouded by the external stability condition which states that the j countries constituting the stable j-coalition will tend to leave the coalition as soon as another country joins. We can conclude that if a j-coalition is stable, utility transfers won't enlarge the coalition.

We should also observe that the comparison of our results to Barrett's ones (1991) leads to the following remarks : playing $q_i = 0$ is not an individually rational strategy for non-signatory countries. As soon as a stable coalition is emerging, it is a better choice for non-signatory countries to envisage a reduction of their GHG emissions. Nevertheless, the effort to be achieved by a non-signatory country will be less important than the effort of signatory country. It results from this that the threat of non-signatory countries to collectively deviate from the Nash equilibrium (as defined by Barrett, 1991) is not at all credible. Consequently, whatever the behaviour of non-signatory parties, the interest of the coalition members is to keep to their cooperative behaviour. This is the reason why, in our model, as in Barrett's one (but also Carraro and Siniscalco, 1993), the coalition of cooperating countries reaches the same size.

Proposition 2 *In the event of failure of international negotiation, some countries can decide to adopt a precautionary behaviour while the other ones defect. The number of these countries depends on the beliefs about the other countries. Formally, the non-commitment strategy is the best rply strategy if and only if:*

$$p(k-1) \geq \frac{[F(kp(k)+p(1))+M(p(1)-kp(k))+QM^{1/2}kp(k)](n-U)T}{(n-k+1)RSU} \tag{17}$$

Proof. The desertion strategy is the best reply to a precautionary commitment movement if and only if:

$$\Pi_{-i}^{nc}(k-1,0)-\Pi_{i}^{nc}(k,1)\geq 0 \tag{18}$$

with

$$\Pi_{i}^{nc}(k,1) = \frac{a^2b^2n}{2R}[F(\Phi_i^k+\Phi_i^1)+M(\Phi_i^1-\Phi_i^k)+QM^{1/2}\Phi_i^k] \tag{19}$$

$$\Pi_{-i}^{nc}(k-1,0) = \frac{a^2b^2n\theta_i^{k-1}S}{2T} \tag{20}$$

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:

$$\Theta_i^{k-1}\geq\frac{T}{RS}[F(\Phi_i^k+\Phi_i^1)+M(\Phi_i^1-\Phi_i^k)+Qcn\Phi_i^k] \tag{21}$$

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 adopt a precautionary behaviour. We have

$$\Phi_i^k=\frac{p(i/k)p(k)}{p(i)}=\frac{p(i/k)p(k)}{\sum_{r=1}^{n}p(i/r)p(r)} \tag{22}$$

When 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 (21), we have (17) with $U = \sum_{r=1}^{n} p(r)r$. ■

In the event of failure in international negotiation, this proposition shows that some countries can decide to adopt a precautionary behaviour while the other ones defect. In particular, a country will not commit unilaterally if its beliefs about the unilateral behaviour of the other countries are strong (see 21). When a country expects a large unilateral commitment movement, its incentive to defect rises. Our results show that although this precautionary commitment has less impact than global cooperation, it has also a lower cost for the involved countries and it leads to less defection. Defection is the main problem. When countries decide to sign an agreement, they have to withstand the defection of other countries. So, when bargaining fails, it might be more interesting for countries to adopt a precautionary 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 they creates an incentive to defect while those made by a unilateral commitment movement are less important than the preceding.

Given this result, it is interesting to analyse the failure of the Conference of Parties on Climate Change, held in Buenos Aires in November 1998. The United States rejected the EU proposal to adopt a CO_2 emissions reduction programme. They were arguing that they would sign such an agreement only when developing countries would also join. Following this refusal, every country kept to its initial position; in other words, no environmental policy was decided. However, we learn from proposition (2) that the situation could have been radically different. Despite the failure of the negotiation, some countries could have envisaged to commit unilaterally. This commitment would have then led to induce a potentially large training effect. Even if such a commiment would not have the impact of a global agreement, it would have facilitated further negotiation. Just like the CFC example displayed it, it is easier to envisage a global agreement when some leading countries already engaged into a cooperation than when none country adopted a given environmental policy. Indeed, as soon as a link between chlorine release into the stratosphere by CFCs and the potential catalytic destruction of the ozone layer, the United States banned in 1978 the use of CFC 11 and 12 in aerosols. Scandinavian countries followed the policy initiated by the United States, thus confirming the idea of a training effect. Cooperation reached again a wider level with the signature of the Montreal Protocol in 1987 with much more countries involved.

3 Training Effect and Non-Coordinated Global Cooperation

In the previous section, we considered a symmetric configuration. International negotiation can succeed or not. If the negotiation fails, some countries can decide to commit unilaterally. Now we introduce two supplementary assumptions. Firstly, we suppose that when an agreement emerges, the non-signatories have the choice between individually rational commitment and defection. Secondly, the cooperative countries can determine precisely the number of countries which adopt an individually rational commitment. This new framework allows us to have both partial cooperation and unilateral commitment in the same static game. As in Barrett's model, we consider two levels of emissions reduction. In this context, we show that the emergence of a small coalition creates an incentive for all non-members to reduce their emissions unilaterally. Cooperation is then global and non-coordinated.

Remark 3

If eq (30) is fulfilled, then it is profitable for the $k = n - j$ countries to commit unilaterally.

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

$$\max_{q_1,\ldots,q_j} bj[a(Q_k + Q_j) - \frac{1}{2n}(Q_k + Q_j)^2] - \frac{c}{2}\sum_{i=1}^{j} q_i^2 \tag{23}$$

and

$$\max_{q_i} b[a(q_i + Q_{(k-1)} + Q_j) - \frac{1}{2n}(q_i + Q_{(k-1)} + Q_j)^2] - \frac{c}{2}q_i^2 \tag{24}$$

This leads to

$$Q^c(j/k) = \frac{abj^2n}{bj^2 + cn + bk} \text{ and } q_i^c(j/k) = \frac{abjn}{bj^2 + cn + bk} \tag{25}$$

$$Q^{nc}(k/j) = \frac{abkn}{bj^2 + cn + bk} \text{ and } q_i^{nc}(k/j) = \frac{abn}{bj^2 + cn + bk} \tag{26}$$

where $Q^c(j/k)$ is the global abatement of the j-size coalition knowing that k countries will decide to adopt an individually rational commitment 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 (25), we

have for $k \geq 1 : Q^c > Q^c(j/k)$. When the insiders of the coalition expect no emissions reduction by the remaining countries, their global and individual abatement levels are greater. The net benefit of one member of the coalition which expect a k-"movement" of unilateral commitment is

$$\Pi_i^c(j/k) = \frac{a^2b^2n(2kbj^2 + bk^2 + 2cnk + bj^4 + cnj^2)}{2(bj^2 + cn + bk)^2} \tag{27}$$

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

$$\Pi_i^{nc}(k/j) = \frac{a^2b^2n(2kbj^2 + bk^2 + 2cnk + bj^4 + 2cnj^2 - cn)}{2(bj^2 + cn + bk)^2} \tag{28}$$

We must check that

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

This gives

$$P(k) = bcnk^2 + 2cn(bj^2 + cn)k - b^2j^4 - 2bcnj^2 - c^2n^2 \geq 0 \tag{30}$$

This condition holds for $k = n - j$. ■

Furthermore, it does not mean that all the non-members of the coalition will decide to adopt an individually rational commitment. 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-signatory countries to commit unilaterally.*

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

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

this gives

$$P(j) = -b^2j^4 - 2b^2(k-1)j^2 + bcn + c^2n^2 - b^2(k-1)^2 \geq 0 \tag{32}$$

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

from the coalition decides to adopt an individually rational commitment or a defection behaviour. This leads to conditions (33) and (35):

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

We obtain

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

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

$$\Pi_i^c(j/k) - \Pi_{-i}^{nc}(k/j-1) \geq 0 \tag{35}$$

This yields

$$P(j) = a_6 j^6 + a_5 j^5 + a_4 j^4 + a_3 j^3 + a_2 j^2 + a_1 j + a_0 \geq 0 \tag{36}$$

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

Eqs (34) and (36) simultaneously hold for $j = 2$ under the respective conditions :

$$n \geq A = \frac{b}{c}(k - 2 + 2\sqrt{1 + k + k^2}) \tag{37}$$

and

$$n \geq B = \frac{b}{4c}(2k - 7 + 3\sqrt{9 + 4k + 4k^2}) \tag{38}$$

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[4].

Contrary to the previous section where a unilateral commitment movement occurs only in the case of a failure in the international bargaining, this new framework allows us to have cooperation within the coalition and also outside by unilateral commitment and as a consequence two levels of emissions reduction. Since the emission reduction of the coalition is lower than in the previous case ($Q^c(j = 2/k = n - 2)$), the signatories of the agreement create an incentive for the non-members to adopt an emission reduction. The main characteristic of the coalition is the creation of incentives for outsiders to reduce their emissions. The benefits made by the coalition are so low that

[4]To see this, substitute A and B in (32).

the other countries prefer to commit rather than free-ride. This unilateral movement improves the welfare both of insiders and outsiders. The strategy leads to greater global abatement compared with the case where such a unilateral movement does not exist. Formally we have :

$$Q^c(j = 2/k = n - 2) + Q^{nc}(k = n - 2/j = 2) > Q^c(j = 2/k = 0) \qquad (39)$$

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

Note that if $n < \max(A, B)$, the number of countries concerned by the environmental problem is then very low. In this context, a 2-coalition can not be organised to the extent to it could not incite non-signatory countries to adopt a given environmental policy. Indeed, for n very small, reductions envisaged by a 2-coalition would be sufficient for non-signatory countries to get substantial enough gains as to prefer defection, thus leading to the absence of training effect.

4 Conclusion

In this paper, we attempt to find out the link between group cooperation and unilateral commiment of some countries in the presence of environmental problems. Our analysis highlights the following results. Cooperation will be partial when countries are characterized by only two strategies : to sign an agreement or to implement 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 negotiation, a precautionary unilateral commitment can emerge when countries have to choose between unilateral commitment or defection. We also show that the emergence of non-coordinated global cooperation can result from a strategic action from the members of the coalition. The existence of the coalition will create incentives for the outsider countries to reduce emissions unilaterally. 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, 1997a). Another way of research would be to investigate interactions between trade and the environment (Folmer *et al,* 1993) and to analyse under which conditions global cooperation is feasible when the cooperating countries can imposed a

ecological tax on the non-cooperating countries (Barrett, 1997b; Péreau and Tazdaït, 2000).

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