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An Evolutionary Approach to the Climate Change Negotiation Game

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NOTA DI LAVORO 81.2001

OCTOBER 2001

ETA – Economic Theory and Applications

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SUMMARY

We describe in this paper an evolutionary game theoretic model aiming at representing the climate change negotiation. The model is used to examine the outcome of climate change negotiations in a framework which seeks to closely represent negotiation patterns. Evolutionary setting allows us to consider a decision making structure characterised by agents with bounded knowledge practising mimics and learning from past events and strategies. We show on that framework that a third significant alternative to the binary coordination-defection strategies needs to be considered: a unilateral commitment as precautionary strategy. As a means to widen cooperation, we examine the influence of linking environmental and trade policies via the implementation of a trade penalty on non cooperative behaviours.

Keywords: Environmental negotiation, coalition, precautionary unilateral commitment, evolutionary process

JEL: D74, Q28

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July 19, 2001

Abstract

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1 Introduction

Each country is both victim of and responsible for global environmental problems. As shown by Barrett (1991), Carraro and Siniscalco (1992, 1993) or Chander and Tulkens (1992, 1995, 1997), high levels of interdependencies between countries

*We would like to thank Ferenc Forgo, U. Gergely, Guillaume Hollard, Sylvie Lupton, Gilles Rotillon, Henry Tulkens and Thomas Vallée for their helpful comments on previous versions of this paper.

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make coordination of national environmental policies necessary for these problems to be resolved. To understand the process of international coordination, negotiation theory (Rotillon and Tazdaït, 1996; Rotillon *et al.*, 1996; Chen, 1997) is certainly the best tool to deal with. Indeed, it permits to draw the framework of the decision making environment and to highlight the potential outcomes of the negotiation game. Two main limits related to the current development of this theory call however for further scrutinising.

Regarding first the axiomatic and related players' strategic environment, it is implicitly envisioned that agents negotiate assuming that in case of coordination failure, the prevailing situation is as if negotiations had never taken place. It corresponds thus to a status quo in which all countries defect the environmental cause. Grasping negotiations on that angle is not relevant. Countries organize indeed negotiations in order to improve or at least maintain their welfare. Negotiations are an attempt to resolve potential irreversible environmental degradations. There is thus a will for cooperation and even in the eventuality of disagreement, there is no interest for all countries to defect the environmental cause. It is pertinent to assume that ecologically conscious countries, in the absence of coordination, firm up their cooperation will by adopting a unilateral environmental policy (Rotillon and Tazdaït, 1999). Countries could also start to reduce emissions unilaterally as the result of the influence of a border country (Kaitala *et al.*, 1992a, 1992b).

As a consequence absence of international agreement does not signify global defection to the environmental issue. In other words, absence of coordination does not mean absence of cooperation: countries can opt for unilateral commitment. Moreover, such unilateral strategy could be robust to environmental agreement. A coordination on an agreement could be intertwined with the unilateral commitment of a range of countries - for instance because they do not conceive the agreement as satisfactory. We propose to assimilate unilateral strategies to precautionary behaviours[1]. It remains indeed difficult to estimate with certainty responsibilities of, and degradations bear by each country, making significant cooperation difficult to instigate. Countries can however take unilateral measures at an acceptable cost as a mean to prevent an irreversible degradation of the environment. A precautionary behaviour is thus conceived here as a mean to both reverse irreversibilities and make an environmental policy effective by giving the example as an ultimate attempt to reach sufficient abatements.

Second, negotiation theory is usually grounded on a standard game theory framework, making the economic rationality assumption the driver of decision

[1]Several definitions of precautionary behavior have been formulated in the literature (see Godard 1997). They range from a recommendation concept to an obligation concept. Precaution is here used in the sense defined by the Barnier Law (1995) on the reinforcement of environmental protection in France

making. Optimization behaviour and common knowledge are questionable assumptions regarding environmental negotiations processes. Environmental issues and climate change in particular are indeed largely characterized by uncertainties. Countries cannot easily grasp the environmental consequences of their choices. In this context, countries' decisions appear to be different than the outcome corresponding to a pure optimization procedure with perfect information. Case studies on two "successful" previous negotiations which have led to regime building and development - the "acid rain" and the "ozone" cases - highlight the importance of instrumental and directional leadership influences (mimics and deterrents) in the cooperation process. In both cases, significant coordination and cooperation have been indeed preempted by the unilateral commitment of a country, immediately followed by a spreading out effect on other countries' strategy. As a consequence, we have chosen an evolutionary game theory setting to develop our argumentation[2]. We consider thus that countries are not able to choose the best strategy but have the skills to "achieve better" in particular via a learning process.

Using this construct, the concept of evolutionary stable strategy (ESS) allows us to draw the outcome of the negotiation process. We show in particular that incentives to cooperate can be strong but insufficient to instigate coordination of cooperative behaviour. Alternatively, since the global non cooperative outcome is very harmful in terms of payoff, precautionary behaviour can prevail under specific conditions. This behaviour is shown to have lower impacts than coordinated policies but is also less costly and instigates less defective behaviours than the coordination outcome since global payoff from unilateral commitment are lower. Introduction of trade linkage permits to grasp the effect of deterrent behaviour. It highlights the conditions which favor one strategy upon another and more generally the characteristics of the equilibrium subsequent to the allowance of trade penalties.

The remainder of the paper is organized as follows. Section 2 presents a negotiation model in a standard form taking into account the precautionary unilateral commitment strategy, main results raised in the related literature are discussed. Section 3 is devoted to highlighting the evolutionary dimension of such precautionary behaviour. Best response and ESS strategies are comparatively analyzed. Section 4 proposes to widen the model framework in order to grasp a possible dragging effect. A setting in which the effect of one strategy upon another is implemented considering that the starting point is the formation of a small coalition. Finally, section 5 introduces the study of deterrent behaviours. The outcome of the game is evaluated when a loose form of issue linkages is implemented. We assume that cooperating countries adopt a deterrent behaviour consisting in applying a trade penalty which aims at baring imports of environmentally harmful products.

[2]Van Damme (1994) gives a clear presentation of evolutionary game theory and its relevance regarding economic analysis.

2 Model Framework

In this section, we formalize negotiation in an environment in which players can alternatively choose between the cooperative or the non cooperative strategy[3]. Countries can cooperate according to two distinct behaviours: coordination or precautionary unilateral commitment. Consider $N = \{1, ..., n\}$ the set of identical countries interacting in a common environment threatened by the emission of a gas they all produce. Welfare of each country relies positively on its own emission reductions x_i and on emission reductions from other countries x_{-i}, with x_{-i} the vector $(x_1, x_2, ..., x_{i-1}, x_{i+1}, ..., x_n)$. Benefit and cost functions are represented in the payoff function $\pi_i(x) = B_i(x_i, x_{-i}) - C_i(x_i)$, with $B_i(x_i, x_{-i})$ the benefits from global abatement,and, $C_i(x_i)$ the reduction cost from country i with, $x = (x_1, ..., x_n)$ the emission reduction vector of all countries.

Countries negotiate in order to coordinate their environmental policy and thus to reduce efficiently and effectively the level of emissions. Let $\pi_i^c(j)$ be the welfare obtained by country i when it participates to a coalition made of j countries, $2 \leq j \leq n$, and $\pi_{-i}^c(j-1)$ its welfare when it does not join the coalition made of $j-1$ countries. In case of a negotiation failure, $\pi_i^a(k)$ is the welfare of country i when k countries (including i) commit unilaterally to a precautionary policy, whereas country's i welfare is denoted $\pi_{-i}^a(k-1)$ if it does not cooperate while $k-1$ countries commit unilaterally. Finally, we normalize the π_i function such as $\pi_{-i}^a(0) = 0$.

The game described is constructed according to the following structure. In a first stage, the n countries meet to negotiate the building of an environmental agreement, the game consists of a binary choice : to join or not a coalition. The second stage relies on the outcome of the first stage. In case an agreement is signed in between j countries ($2 \leq j \leq n$), the participants of the coalition commit to reduce their emissions while others countries defect. Alternatively if no agreement is reached, countries have again a binary choice: to embark into emission reductions in the absence of coordination (and thus adopt a precautionary behaviour) or to defect and thus not to reduce their emissions[4]. We deduce that the strategy space for each player i consists in adopting an environmental policy (E_F) or not (T).

In that construct, if an agreement is signed, each country knows the number of signatories. However, we assume that in case of a negotiation failure, countries are unable to predict other countries' behaviour and unilateral strategies cannot

[3]Results found in this section are in line with those developped by Péreau and Tazdaït (2000, 2001) using the welfare function from Barrett (1991).

[4]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 strategy in our analysis, it becomes possible to determine its relevance.

be predicted. We consider indeed that countries need in this case to wait for the post negotiation period to observe behaviours of their counterparts. We assume also that the time interval in between negotiation failure and the observation of effective environmental policies is short enough to not involve supplementary costs.

Let us denote by φ_i^k, the probability that k countries commit unilaterally knowing that country i adopts this strategy and by, β_i^{k-1} the probability that $k-1$ countries commit unilaterally knowing that country i do not cooperate. Thus:

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

where K assigns the set of the k countries, $2 \leq k \leq n$, which commit unilaterally if an agreement is not reached. We denote by J the set of members' country constituting the j-coalition.

Considering these assumptions, the following table sums up the behaviour of the i country, $i \in N$:

$i/.$	Coalition	No-Coalition
E_F	$\pi_i^c(j)$	$\pi_i^a(k,1)$
T	$\pi_{-i}^c(j-1)$	$\pi_{-i}^a(k-1,0)$

with:

$$\pi_i^a(k,1) = \varphi_i^k \pi_i^a(k) + \varphi_i^1 \pi_i^a(1), \quad (1)$$

$$\pi_{-i}^a(k-1,0) = \beta_i^{k-1} \pi_{-i}^a(k-1) + \beta_i^{k-1} \pi_{-i}^a(0) = \beta_i^{k-1} \pi_{-i}^a(k-1). \quad (2)$$

The significance of these equations (1) and (2) is the following. In case of a disagreement, if country i decides to cooperate, either it reduces unilaterally its emissions like the $k-1$ other countries with the probability φ_i^k, or it reduces its emissions unilaterally with the probability φ_i^1 while others countries defect. According to equation (2), if country i decides to not intend any reductions unilaterally and thus to defect, either it benefits from the $k-1$ countries reducing their emissions with the probability β_i^{k-1} or all countries defect the environmental cause.

We state that commitment strategy is the best reply to the defection strategy of non signatory countries if and only if:

$$\pi_i^c(j) - \pi_{-i}^c(j-1) \geq 0. \quad (3)$$

This equation relates formally the internal stability condition defined by d'Aspremont *et Al.* (1983) according to which a signatory country to an agreement cannot

be better off by defecting in order to form a singleton. To guarantee the stability of a coalition, the external stability is also compelling. Outsider countries cannot be better off by joining the coalition : $\pi_i^c(j+1) - \pi_{-i}^c(j) < 0$. Notice that as demonstrated by Donsimoni *et Al* (1986) the internal stability condition is sufficient to ensure the global stability of the coalition if the coalition benefit is an increasing function of its size.

Stability is a key concept since it ensures the agreement to be self enforceable. Indeed, a coalition insider (resp. outsider) decides to leave (resp. to join) the coalition in case it is profitable to do so. This relies on the costs and benefits to leave (resp. to join) the coalition. A country leaving a coalition benefits from a lowering of its abatement costs but its departure weakens the coalition and is followed by an overall decrease in the abatement level making benefits from avoided damages lower. Respectively, a country joining a coalition bears an abatement cost but its adhesion comforts other members of the coalition into the abating effort and, as a consequence, the benefit from avoided damage is higher[5].

Self enforcement is an important criterion since international agreements lack an institution in charge of enforcement. International institutions are numerous but national sovereignty hinders their competence to impose to country the "right" behaviour to adopt. Profitability is thus a prerequisite to coordination. The means to achieve a profitable coalition as wide as possible need to be studied.

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 a utility transfer is conceivable first, if at the most its amount equals the benefit perceived by the j countries from the widening of the coalition and second, if its amount is at least equal to the cost for the $j+1th$ country to join the coalition. Formally:

$$\pi_i^c(j+1) - \pi_i^c(j) \geq V > \pi_{-i}^c(j) - \pi_i^c(j+1).$$

The existence of V would signify that the coalition can be enlarged by a self-financed policy. This result is however clouded by the external stability condition which says 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. Carraro and Siniscalco (1993), to bypass the stability restriction to coalition enlargement propose new "rules of the game" specifying that some countries are more environmentally conscious than others and participate in any case to the coalition[6].

[5]For an extensive literature review on cost and benefit of further abatement levels, see Hourcade *et al.* (2000).

[6]Such assumption is ad hoc since nothing justifies the fact that some country can be more environmentally conscious than others.

Likewise, we state that non commitment strategy is a best reply strategy if and only if:

$$\pi^a_{-i}(k-1,0) - \pi^a_i(k,1) \geq 0 \tag{4}$$

By using the Bayes rule, conditional probabilities $\varphi_i^k, \varphi_i^1, \beta_i^{k-1}$, can be constructed as functions of $p(k)$, $k = 1, .., n$, the probability that exactly k countries commit unilaterally:

$$\varphi_i^k = \frac{p(i/k).p(k)}{p(i)} = \frac{p(i/k).p(k)}{\sum_{r=1}^n p(i/r)/p(r)}$$

Since country i is willing to sign an agreement as the $k-1$ other countries among n would, we have:

$$\begin{aligned} p(i/k) &= \frac{k}{n} \quad , \quad \varphi_i^k = \frac{p(k)}{\sum_{r=1}^n p(r)r} \quad , \quad \varphi_i^1 = \frac{p(1)}{\sum_{r=1}^n p(r)r} \\ \beta_i^{k-1} &= \frac{(n-k+1)p(k-1)}{n - \sum_{r=1}^n p(r)r} \end{aligned}$$

By substitution into (4), we deduce:

$$p(k-1) \geq \frac{[p(k)\pi_i^a(k) + p(1)\pi_i^a(1)]\,[n - \sum_{r=1}^n p(r)r]}{(n-k+1)p(k-1)} \tag{5}$$

These results lead us to the following propositions.

Proposition 1 (D'Aspremont et al. 1983) *For a i country, $i \in N$, commitment strategy is a best reply strategy to the defection behaviour of non signatory countries if and only if j is small relatively to n.*

Proposition 2 *Non commitment strategy is a best reply strategy if and only if:*

$$p(k-1) \geq \frac{[p(k)\pi_i^a(k) + p(1)\pi_i^a(1)]\,[n - \sum_{r=1}^n p(r)r]}{(n-k+1)p(k-1)}$$

Proposition (1) recalls the main result pointed out in Carraro and Siniscalco (1993) and Barrett (1994) according to whom coalition formation relies on the number of countries involved by the environmental issue. Coalition is however shown to be constituted of a small amount of countries even if the number of participants to negotiation is large.[7] The reason is the following. The larger the coalition is, the higher is the incentive to free ride in order to benefit from emissions abatement without bearing any cost. Anticipating this, countries are not induced to sign the agreement. In fact, we can consider that there is a

[7] For a good literature review on these analysis refer to Tulkens (1998).

personal cost to be part of a coalition while benefits are public goods for all countries. The maximum amount of countries forming a coalition is thus the right number of countries allowing the coordination to be sustainable. According to proposition (2), a country will not commit unilaterally if its beliefs concerning other countries' unilateral commitment are high. Thus, if a country i believes that numerous other countries will commit unilaterally, it will not commit in order to benefit from emissions reductions at no cost. We deduce from these propositions that a country participates to a coalition according to the sustainability of this coalition while it decides to commit unilaterally according to its beliefs about other countries' unilateral commitment.

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 program. 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 commitment 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.

This formal setting is appealing, it is however based on an idealized picture of countries' rationality in which high intellectual capabilities are attributed. Furthermore, uncertainties about consequences of strategies on the environment make decision making a difficult task and countries have recourse to a learning process which might not lead to the optimal outcome planned by the non cooperative game theory construct[8]. For the rest of the paper, we will consider that equations (3) and (4) are not true.

$$\pi^c_{-i}(j-1) - \pi^c_i(j) \geq 0 \text{ and } \pi^a_i(k,1) - \pi^a_{-i}(k-1,0) \geq 0. \tag{6}$$

[8]Refer to Mailath (1998) and Weibull (1996) for an extensive evolutionary game theory approach to the concept of "as if".

We now need to assess the equilibrium conditions in a mixed strategy framework.

Lets x (resp. $1-x$), $0 < x < 1$, be the probability that no coalition (resp. a coalition) emerges. x^* is a mixed strategy equilibrium for country i if and only if both pure strategies E_F and T have the same expected payoff. Hence, if country i plays E_F, its expected payoff is:

$$\Pi E_F = x.\pi_i^a(k,1) + (1-x).\pi_i^c(j). \tag{7}$$

while by playing T, its expected payoff is:

$$\Pi T = x.\pi_{-i}^a(k-1,0) + (1-x).\pi_{-i}^c(j-1), \tag{8}$$

x^* is hence an equilibrium strategy if:

$$x^* = \frac{\pi_{-i}^c(j-1) - \pi_i^c(j)}{\pi_i^a(k,1) - \pi_{-i}^a(k-1,0) + \pi_{-i}^c(j-1) - \pi_i^c(j)}. \tag{9}$$

This equation states that x^* is the best strategy against itself. Note that the expression at the numerator corresponds to the incentive to cooperate, the denominator to the sum of the incentive to cooperate and to defect. We can thus conclude that x^* is an equilibrium in a mixed strategy framework if and only if it equals the frequency of the incentive to cooperate. Let us now focus on the evolutionary process of the negotiation game.

3 Evolutionary Process

In the setting developed in the previous section, unilateral commitment probabilities φ and β are exogenous. In order that the representation of international negotiation is more realistic, a major improvement consists in associating these probabilities to agent's strategies such as for each country i, $i \in N$:

$$\varphi_i^k = \varphi_i^k(x),\ \varphi_i^1 = \varphi_i^1(x) \text{ and } \beta_i^{k-1} = \beta_i^{k-1}(x). \tag{10}$$

By considering φ and β determined by x, probabilities become endogenous to the model.

In this new framework, a country i playing E_F gets a payoff:

$$\Pi E_F(x) = x.[\varphi_i^k(x).\pi_i^a(k) + \varphi_i^1(x).\pi_i^a(1)] + (1-x).\pi_i^c(j). \tag{11}$$

while playing T, it gets:

$$\Pi T(x) = x.\beta_i^{k-1}(x).\pi_{-i}^a(k-1) + (1-x).\pi_{-i}^c(j-1). \tag{12}$$

We assume that the population of players are x-monomorphic, meaning that the tendency to defect the coalition in the pre-negotiation period is equal to x for

all players. The equilibrium concept allowing to determine the outcome of this evolutionary negotiation game is the ESS (Maynard-Smith and Price (1973)). The formal definition we use is based on Lessard (1990)[9].

Definition : x^* is an evolutionary stable strategy with $0 \leq x \leq 1$, if it exists $\varepsilon > 0$ such that:

$$\begin{aligned} \Pi E_F(x) &> \Pi T(x) \text{ for } x^* - \varepsilon < x < x^*, \\ \Pi E_F(x) &< \Pi T(x) \text{ for } x^* < x < x^* + \varepsilon. \end{aligned}$$

Literally, it signifies that x^* is an ESS : (a) if against x^*, no strategy y is better off than x^* or, (b) when x^* is not better off than y against x^*, if x^* is better off than y against y herself.

Suppose x is not an ESS, then it exists a strategy $y \neq x$ which eventually spreads over the x-monomorphic population. In such a case, we have necessarily:

$$\Pi E_F(x) \neq \Pi T(x). \tag{13}$$

Indeed, consider $\Pi E_F(x) < \Pi T(x)$. Consider also that a strategy y is slightly better off than strategy x and is thus preferred by some countries. y-countries have necessarily a higher tendency to play T than x-countries and get as a consequence higher payoffs. The selection process eventually leads x-countries to play y which at end will become the unique outcome of the game. In the same manner, if we consider $\Pi E_F(x) > \Pi T(x)$, we can assume that a strategy y slightly worse off than strategy x will invade the game. As a consequence, all members of the x-monomorphic population will play x as soon as $\Pi E_F(x) = \Pi T(x)$, with $0 < x < 1$. We deduce then the following proposition:

Proposition 3 *Given a x^*-monomorphic population, x^* is an evolutionary stable mixed strategy if and only if:*

$$\Pi E_F(x^*) = \Pi T(x^*) \text{ with } 0 < x^* < 1$$

Let us now focus on the limit cases, $x^* = 0$ and $x^* = 1$.

When the probability that no coalition emerges is null (i.e. $x^* = 0$), expected payoff of country i, $i \in N$ is:

$$\Pi E_F(0) = \pi_i^c(j) \text{ and } \Pi T(0) = \pi_{-i}^c(j-1) \tag{14}$$

[9]ESS is a refinement of Nash equilibrium. Precisely, an ESS is a Nash equilibrium strategy of a symmetric bimatrix game which satisfies the additional stability requirement that it cannot be beaten by any rare alternative strategy. As a consequence, any Nash equilibrium can be an ESS making the following propositions particularly relevant.

and it exists j such as:

$$\Pi E_F(0) \geq \Pi T(0) \tag{15}$$

This corresponds to a positive incentive to cooperate.

Respectively, if the probability that no coalition emerges is certain (i.e. $x^* = 1$), it exists j such as:

$$\Pi E_F(1) \leq \Pi T(1) \tag{16}$$

which corresponds to a positive incentive to defect.

Relations (15) and (16) define the conditions for x^* to be a pure evolutionary stable strategy. Hence, we have established for any cases ($0 \leq x^* \leq 1$) the conditions for x^* to be a Nash equilibrium.

Proposition 4 *In this evolutionary negotiation setting, if x^* is an ESS then x^* is a Nash equilibrium.*

We can conclude at that point that countries' behaviour within negotiations is determined by the additional payoff of one strategy upon another. A positive additional payoff is an incentive to cooperate, while a negative one is an incentive to defect. It emerges thus from the negotiation process a j-coalition if the additional payoff of joining is positive for the j countries. Alternatively, no coalition emerges if the incentive to defect is positive. A third stable outcome is the situation where countries cooperate in the absence of coordination, via a precautionary unilateral commitment. Such behaviour is available in case of a coordination failure. It exists indeed a probability distribution for countries to be neutral regarding their preference to adopt or not an environmental policy. Then, some countries will decide to cooperate by adopting a precautionary behaviour in case of a negotiation failure, while others defect.

A global picture of decision making within negotiations can be drawn. Since coordination is weakened by large movements of defection, it can be more viable for countries to commit unilaterally. This indeed is less constrictive than the coordination outcome for a twofold reason. First, countries adopt then policies which are not as ambitious as in the coordination case. Second, the defection behaviour of other countries is then not as costly. As a consequence, the precautionary behaviour seems to be the most sustainable one against defection behaviours. Countries not willing to cooperate, in the absence of a significant welfare gain from other countries' abatement efforts, have no other choice than committing as well. Precautionary unilateral commitment can initiate a dragging effect.

4 Framework Widening

Behaviours in a symmetric setting were analyzed in the previous section : the outcome of negotiations was conceived as the emergence either of an agreement or, in case of a coordination failure, of precautionary unilateral commitments. To take into account a situation where both an agreement and precautionary unilateral commitments coexist is a further step toward the achievement of a more realistic framework. If a coalition of countries signs an agreement, the outsiders have the choice between precautionary unilateral commitment or defection. In other words, precautionary unilateral commitment is made available whether an agreement is signed or not.

In this setting, two cooperative behaviours are simultaneously made available to countries. They can choose to cooperate only as a member of a coalition (strategy denoted by E_f), or alternatively be willing to adopt a precautionary behaviour in case they do not participate to the coalition (strategy denoted by E_F). For country i, $i \in N$, this new setting can be described by the following table:

$i/.$	Coalition	Cooperation	Non-Coalition
E_F	$\pi_i^c(j)$	$\alpha.\pi_i^c(j, m-1)$ $+(1-\alpha)\pi_{-i}^c(j-1, m)$	$\pi_i^a(k, 1)$
E_f	$\pi_i^c(j)$	$\pi_i^c(j, m-1)$	$\pi_{-i}^a(k-1, 0)$
T	$\pi_{-i}^c(j-1)$	$\pi_{-i}^c(j-1, m-1)$	$\pi_{-i}^a(k-1, 0)$

Let us focus on the situation where both coalition and precautionary unilateral commitment coexist. A country i playing strategy E_F can either participate to the coalition with a probability α getting $\pi_i^c(j, m-1)$ or, commit unilaterally with a probability $(1-\alpha)$ getting $\pi_{-i}^c(j-1, m)$. In such a case, the choice in between joining the coalition and committing unilaterally relies on the size of the coalition. Indeed, if the coalition is already stable, country i will commit unilaterally; reciprocally it will join the coalition if its participation is required for the agreement to be stable.

Denote by x, the probability that no coalition emerges while precautionary unilateral commitment is conceivable, y the probability that a coalition and a unilateral commitment movement coexist and, $1-x-y$ the probability that only a coalition emerges with $0 < x, y < 1$. Expected payoffs of country i related to

each strategy are :

$$\begin{aligned}
\Pi E_F(x) &= x.[\pi_i^a(k,1) - \pi_i^c(j)] + y.[\alpha.\pi_i^c(j,m-1) \\
&\quad +(1-\alpha).\pi_{-i}^c(j-1,m) - \pi_i^c(j)] + \pi_i^c(j) \\
\Pi E_f(x) &= x.[\pi_{-i}^a(k-1,0) - \pi_i^c(j)] \\
&\quad +y.[\pi_i^c(j,m-1) - \pi_i^c(j)] + \pi_i^c(j) \\
\Pi T(x) &= x.[\pi_{-i}^a(k-1,0) - \pi_{-i}^c(j-1)] \\
&\quad +y.[\pi_{-i}^c(j-1,m-1) - \pi_{-i}^c(j-1)] + \pi_{-i}^c(j-1)
\end{aligned}$$

Assume:

$$\begin{aligned}
A &= \pi_i^a(k,1) - \pi_i^c(j) \\
B &= \alpha.\pi_i^c(j,m-1) + (1-\alpha).\pi_{-i}^c(j-1,m) - \pi_i^c(j) \\
C &= \pi_i^c(j) \\
D &= \pi_{-i}^a(k-1,0) - \pi_i^c(j) \\
E &= \pi_i^c(j,m-1) - \pi_i^c(j) \\
F &= \pi_{-i}^a(k-1,0) - \pi_{-i}^c(j-1) \\
G &= \pi_{-i}^c(j-1,m-1) - \pi_{-i}^c(j-1) \\
H &= \pi_{-i}^c(j-1)
\end{aligned}$$

Then, x^{**} is an ESS if:

$$\begin{aligned}
x^{**} &= \frac{(E-B).(H-C)}{[(A-F).(E-B)-(A-D).(G-B)]} \\
y^{**} &= \frac{(A-D).(H-C)}{[(A-F).(E-B)-(A-D).(G-B)]} \\
1-x^{**}-y^{**} &= \frac{[(E-B).(A-F-H+C)-(A-D).(G-B+H-C)]}{[(A-F).(E-B)-(A-D).(G-B)]}
\end{aligned}$$

with the following conditions:

$$\begin{aligned}
\pi_{-i}^c(j-1) - \pi_i^c(j) &\geq 0 \\
\pi_i^a(k,1) - \pi_{-i}^a(k-1,0) &\geq 0 \\
\pi_i^c(j,m-1) - \alpha.\pi_i^c(j,m-1) - (1-\alpha).\pi_{-i}^c(j-1,m) &\geq 0 \\
\pi_{-i}^c(j-1,m-1) - \alpha.\pi_i^c(j,m-1) - (1-\alpha).\pi_{-i}^c(j-1,m) &\geq 0
\end{aligned}$$

Note that from $x^* = (H-C)/(A-F)$, we deduce that $x^* > x^{**}$ if $(A-D).(H-C).(G-B) < 0$. Since $A-D > 0$ and $H-C > 0$, this inequality is true for $G-B < 0$, this implies:

$$\alpha\pi_i^c(j,m-1) + (1-\alpha)\pi_{-i}^c(j-1,m) - \pi_{-i}^c(j-1,m-1) > -\pi_i^c(j) + \pi_{-i}^c(j-1) \tag{17}$$

Beside, if $G-B > F-A$, it involves $1-x^* > 1-x^{**}-y^{**}$, which means $y^{**} > 0$.

Proposition 5 *if* $F - A < G - B < 0$ *then:*

$$x^* > x^{**},\ y^{**} > 0 \quad \textit{and} \quad 1 - x^* > 1 - x^{**} - y^{**}$$

In other words, when the incentive to adopt strategy E_F is higher than the incentive to adopt E_f (i.e. $F - A < 0$ and $G - B < 0$), the likelihood of cooperation to be exclusively the result of unilateral commitment is lower than in the symmetric decision making case. Likewise, the frequency to be part of a coalition is lower. This last statement is true only if $G - B$ is minored by $F - A$, which happens to be always true. If it was not the case, no country would have interest to build a coalition and strategy choices would be restricted to E_F and T, meaning that cooperation is exclusively formed by a restricted unilateral commitment movement. Under the condition $F - A < G - B < 0$, the framework in which unilateral and cooperative strategies intertwin is conceivable. In such case, precautionary unilateral commitment is underlying the coalition construct: the formation of a j-coalition favours the emergence of a large bulk of unilateral commitments reinforcing the coalition achievements. This result is nevertheless a paradox since it is independent of probabilities $\pi_i^a(k, 1)$ and $\pi_{-i}^a(k-1, 0)$. This is in fact as if the existence of a smaller group of countries E_f stimulated some countries playing T to prefer strategy E_F. More accurately, it suffices that the proportion of countries capable of playing E_f decreases at the advantage of strategy E_F for cooperation to grow. When an agreement is signed, countries playing E_F as well as some countries playing T commit unilaterally ; In other words, the rise of a stable coalition provokes a dragging effect.

In case equation (17) is reversed then, $x^* < x^{**}$ and $1 - x^* > 1 - x^{**} - y^{**}$. For x^{**}, y^{**} and $1 - x^{**} - y^{**}$ to be meaningful, it is necessary that $(A - F)(E - B)/(A - D) > (G - B)$ meaning that $y^{**} > 0$.

Proposition 6 *If*

$$\frac{(A - F)(E - B)}{(A - D)} > (G - B) > 0$$

then: $x^* < x^{**}$, $y^{**} > 0$ *and* $1 - x^* > 1 - x^{**} - y^{**}$

If the incentive to adopt E_f is higher than the incentive to play E_F, the potentiality of cooperative behaviour to be under the form of unilateral commitment gets higher. This does not mean however that it is worse off for the coalition, contrarywise. The probability of a stable j-coalition overlapped by unilateral commitment is indeed also higher than in the previous case (y^{**} grows with $(G - B)$). One can also notice that $1 - x^{**} - y^{**}$ is decreasing with $G - B$ and it follows:

$$(1 - x^{**} - y^{**})(G - B < 0) > (1 - x^{**} - y^{**})(G - B > 0)$$

We can deduce that the emergence of a stable j-coalition will be followed by a weak unilateral commitment.

Propositions (5) and (6) insure potential enlargements of the cooperation around the j-coalition. Hence the coordination is followed by an intertwined unilateral commitment of some countries. The amount of countries playing this precautionary behaviour can be significant (proposition (5)) or relatively weak (proposition (6)). In both cases however, the process described is conceivable. What differentiates both cases is the amount of countries playing E_f relatively to E_F. In case countries playing E_f are numerous, cooperation cannot be large. Indeed as seen in the previous section, the stability condition implies that a coalition contains j members at the most. When the coalition forms, countries playing initially E_f which will not play E_F will play T. Alternatively if countries playing E_F are numerous, unilateral commitment will be significant since those not joining the coalition will opt for a precautionary behaviour. In order to be as large as possible, cooperation must set up according to the following process : the j-coalition must be constituted of countries playing initially E_f for countries playing E_F to make unilateral commitment effective. Thus to avoid countries playing initially E_f to switch to strategy T, countries playing initially E_F must not be part of the coalition.

5 Trade Linkage : Impact of a trade penalty on non cooperative behaviours

An increasing awareness of the high degree of interdependence between trade and environment calls for cross issue coordination through joint negotiations. For example, the policy debate has led recently to the suggestion that global environmental and competition policies should be intertwined policies included into future WTO rounds of negotiations[10]. Tying in multiple issues in international talks can indeed facilitate multilateral cooperation. It also allows to balance the disadvantage bear by firms from cooperative countries. In a loose form, such linkage was part of both the "acid rain" and the "ozone" negotiation games. Recall indeed that within the process of those negotiations, leading countries resorted to threaten non cooperating countries to bar imports of non ecological products[11]. These threats are determinant for cooperation and it is thus necessary to study the effect such an ecological norm can play on countries' behaviour.

[10]The underlying idea is that the WTO could act as an international "policing" organism which could enforce compliance upon unwilling governments even for issues that do not strictly pertain to trade policy narrowly defined (Conconi and Perroni, 2000).

[11]After having adopted a unilateral policy (GFAV) to reduce acidic pollution in 1983, the West German government used Article 36 of the Treaty of Rome to ban imports of non clean cars in 1985 (Courtois 1998); The U.S within the Montreal Protocol negotiation threatened countries to ban import of non CFC free products (Oberthuer 2000).

Formally, tied up negotiations are a relatively recent topic study and few works were achieved[12]. Furthermore, no formal legislative attempts were conducted within negotiation process to implement issue linkage yet. For that reason, we propose in this paper to focus on a loose linkage form such as the one used by leader' countries within the acid rain and the ozone negotiations : an ecological norm which can be assimilated to a trade penalty exerted on non cooperative behaviours. We assume hence that in order to limit the drawback of cooperation, a pecuniary sanction on non cooperating countries is imposed. For the sake of simplicity we bound the reasoning here to uniform penalties meaning that countries cooperating via a unilateral commitment is entitled to benefit by the proceeds from the penalty in the same way than a country intending to a coalition. The payoff matrix of country i, $i \in N$, is then the following:

$i/.$	Coalition	Cooperation	Non-Coalition
E_F	$\pi_i^c(j) + t_{n-j}$	$\alpha.\pi_i^c(j, m-1)$ $+(1-\alpha).\pi_{-i}^c(j-1, m)$ $+t_{n-j-m+1}$	$\pi_i^a(k, 1, t_{n-k}, t_{n-1})$
E_f	$\pi_i^c(j) + t_{n-j}$	$\pi_i^c(j, m-1) + t_{n-j-m+1}$	$\pi_{-i}^a(k-1, 0, t_{k-1})$
T	$\pi_{-i}^c(j-1) - t_{j-1}$	$\pi_{-i}^c(j-1, m-1)$ $-t_{j+m-2}$	$\pi_{-i}^a(k-1, 0, t_{k-1})$

Note that the magnitude of the sanction is positive (resp. negative) when country i cooperates (resp. defects). The index on the tax level denotes the number of countries paying the tax to country i (resp. the amount of countries to be paid by country i if it plays the non cooperative outcome).

Assume the following notation:

$$\begin{aligned}
A' &= A + \varphi_i^k.t_{n-k} + \varphi_i^1.t_{n-1} - t_{n-j} \\
B' &= B + t_{n-j-m+1} - t_{n-j} \\
C' &= C + t_{n-j} \\
D' &= D - \beta_i^{k-1}.t_{k-1} - t_{n-j} \\
E' &= E + t_{n-j-m+1} - t_{n-j} \\
F' &= F - \beta_i^{k-1}.t_{k-1} - t_{j-1} \\
G' &= G - t_{j+m-2} + t_{j-1} \\
H' &= H - t_{j-1}
\end{aligned}$$

Then, x^{***} is an ESS if:

$$x^{***} = \frac{(E' - B').(H' - C')}{[(A' - F').(E' - B') - (A' - D').(G' - B')]}$$

[12]Conconi and Perroni (2000) is a significant contribution to be mentioned.

Since any cooperative country perceives the same benefit from the penalty exerted on non cooperative countries, $t_v = vt$ We deduce that $x^{***} > x^{**}$ if,

$$\begin{aligned}[(n-k)\varphi_i^k + (n-1)\varphi_i^1].(H-C)(E-G) \;<\; & [(n-1)(A-D) \\ & +(k-1)\beta_i^{k-1}(H-C)](G-E)\end{aligned}$$

This is always true for $G - E > 0$ (and impossible for $G - E < 0$). Hence, if the incentive to defect, $\pi^c_{-i}(j-1, m-1) - \pi^c_i(j, m-1)$ is higher than the incentive to remain outside the coalition, $\pi^c_{-i}(j-1) - \pi^c_i(j)$, then the probability that negotiation fails is high. Accurately, in case of a uniform sanction framework, negotiation failure is more likely. The explanation is that it is not in the interest of countries to coordinate since precautionary unilateral commitment ensures cooperation. A uniform sanction thus instigates unilateral commitment to the detriment of coordination behaviour. As a consequence, cooperation relies then on the likelihood of countries to commit unilaterally.

6 Conclusion

To better represent negotiation patterns and specificities was the major stake of this paper. An additional strategy alternative to the coalition versus defection strategies was introduced - a so-called precautionary strategy - and dragging effects were studied by the way of an evolutionary setting allowing to grasp the learning processes.

Full cooperation is the most profitable outcome if mutually accepted. As shown in the literature however, the larger the coalition is, the most profitable becomes defection. Full cooperation is therefore non sustainable. We thus proposed to review alternatives to the coordination outcome since representation of negotiation as a binary strategy is unsatisfactory. The absence of agreement does not mean absence of cooperation. A precautionary behaviour consisting in playing environmentally friendly unilaterally is eventually the most relevant outcome in case of a coordination failure. It can be moreover assimilated to a cooperating behaviour although less efficient than full cooperation. This leads actually to one interesting finding of this paper. Since payoffs from unilateral commitments are much lower than payoffs from full cooperation, it does create a lower defection incentive. Another interesting finding is that stable coalitions constitute an incentive for some countries to admit a precautionary behaviour.

This leads us to the evolutionary setting we implemented. Recall that the use of evolutionary game theory leads us to consider that countries are not able to choose their best strategy in an ad hoc manner, but have the skills to "achieve better" in particular via a learning process. Within an evolutionary framework we showed that if an agreement is signed among few countries (few being little), precautionary behaviour proved to be a way to widen cooperation. In other

words, we highlighted the existence of a dragging effect on cooperative behaviour from playing unilaterally.

Another stake of this paper was to analyse cross-issue instruments as means to widen cooperation. To implement a trade sanction on non cooperating countries does not guarantee large cooperation. Precisely, it appeared that such penalty favoured precautionary behaviour rather than coalition widening. If the penalty is uniform, countries prefer to commit unilaterally which allows them to implement a rather loose environmental policy and to avoid the cost of the sanction. In fact, there appears to be no dragging effect from sanctions. Countries that do not want to cooperate will achieve as little as possible in order not to be sanctioned. The analysis of a differentiated tax could be very fruitful. Then, the country which commits unilaterally will be entitled to impose a penalty, but not as high as if it participates to an agreement. Such a policy might be more in favor of coordination behaviours.

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(xxxvii) This paper was presented at the Fourth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei, CORE of Louvain-la-Neuve and GREQAM of Marseille, Aix-en-Provence, January 8-9, 1999
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(xxxix) This paper was presented at the 3rd Toulouse Conference on Environment and Resource Economics, organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE on "Environment, Energy Uses and Climate Change", Toulouse, June 14-16, 1999
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(xli) This paper was presented at the Fifth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CODE, Universitat Autonoma de Barcelona, Barcelona January 21-22, 2000
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