COOPERATION vs. FREE RIDING IN INTERNATIONAL ENVIRONMENTAL AFFAIRS: TWO APPROACHES[1]

Henry TULKENS
CORE, Université Catholique de Louvain
Louvain-la-Neuve, Belgium

This version: December 1996

Outline

---

[1] Invited keynote speech at the Sixth Meeting of the European Association of Environmental and Resource Economists, Umeå, Sweden, June 22, 1995. The research reported here was part of the activities carried out under support of the European Union, within the project "Environmental Policy, International Agreements and International Trade" coordinated by Professor Alistair Ulph as well as within the HCM Network "Designing economic policy for management of natural resources and the environment" (CHRX CT93-0228) coordinated by Professor Anastasios Xepapadeas. It originated much earlier, however, during stimulating and valuable discussions with Carlo Carraro and Domenico Siniscalco that started at the Cambridge 1991 meeting of the European Economic Association and were pursued at several other occasions, in particular at the Harvard 1994 congress of the International Institute of Public Finance and at the CORE-FEEM workshop "Coalitions in environmental games and other economic applications" held in Louvain-la-Neuve in March 1995. For the completion of this paper the author also benefitted from the hospitality and support of the Fondazione ENI Enrico Mattei (FEEM), which he gratefully acknowledges.

COOPERATION vs. FREE RIDING IN INTERNATIONAL ENVIRONMENTAL AFFAIRS: TWO APPROACHES

Henry TULKENS

I. Introduction

This paper is about a controversy on the feasibility, and as a consequence the likelihood, of cooperation among countries on issues of transfrontier pollution. I want to contrast two theses, a pessimistic one and an optimistic one. Both of them are based on concepts rooted in economic analysis, and both of them are claiming additional support from game theory. Nevertheless they reach opposing conclusions. It is thus a challenging task to try to disentangle the arguments used on each side, in order to see whether the two theses can be reconciled or are intrinsically antagonistic.

The structure of the paper is as follows. Before entering into the dispute, I think it is justified to remind the reader, in the next Section II, of how economic analysis shows that cooperation raises a severe problem in international environmental affairs, and what the logical structure of that problem is. Section III then contains a summary presentation of the two theses. Section IV (which is the hart of the paper) is devoted to a systematic comparison of their respective characteristics, and to a search for a conceptual framework for reconciling the two approaches. Section V concludes with considerations on two basically different notions of "stability" for coalitions that are at stake.

II. The underlying economic-ecological model and the questions raised

I briefly[2] remind the reader of the structure of the economic model, which is common to the two theses. A set N of countries, indexed by i = 1, 2,...,n, share a common environmental resource. For each country, the function $u_i(x_i,z)$ describes national preferences over the consumption of some private good (x_i ³ 0) and of some environmental good (z ² 0)[3]. The function is assumed to be of the quasi linear form $u_i(.) = x_i + v_i(z)$, with v_i concave and increasing. Define ¹$_i$ = (_u_i/_z/_u_i/_x_i) ³ 0 as country i's marginal willingness to pay (in commodity x) for the environmental good. Let furthermore y_i = $g_i(p_i)$ be country i's production function, linking[4] its output y_i ³ 0 of the private good with its emissions p_i ³ 0 of pollutant in the environment, and assume $g_i = dy_i/dp_i$ > 0 up to some maximum value p_i^0. The derivative g_i is then naturally interpreted, when taken to the left, as the country's marginal cost (in y_i) of abating its emissions.

The "transfer function" z = _ p_i specifies how the pollutant emissions of all countries are diffused and transformed by ecological processes into the ambient quantity z. And finally, the private good is assumed to be transferable[5] between the countries, in amounts denoted as T_i (< 0 if given away by country i , > 0 if received by it).

---

[2] More detailed presentations, with some discussion of the main assumptions can be found in Section 2 of CHANDER and TULKENS 1992.

[3] The absence of subscipt attached to this variable reflects its public good character; and with the convention of measuring the ambient characteristic in non positive amounts, our assumption _u_i/_z ³0 implies that z is felt by the consumers as a public bad. Notice also that z is treated in this paper as a flow only. Extensions to stock pollutants have been made recently for the SGC thesis (expounded below) in GERMAIN, TOINT and TULKENS 1995 as well as in GERMAIN, TULKENS and de ZEEUW 1996. Another limitation of all models discussed here is that they deal with scalar-measured pollutants only.

[4] Labor, capital and the other inputs are taken as constant and subsumed in the functional symbol g.

[5] With some abuse of language, these transfers will often be called "financial" in the sequel.

For the *economic-ecological system*, so described,

Definition 1: A *feasible state* is a vector

$$(x, y, p, z, T) \equiv (x_1,\dots,x_n;\, y_1,\dots,y_n;\, p_1,\dots,p_n;\, z\,;T_1,\dots,T_n)$$

such that:

$$\forall i, \qquad x_i = y_i + T_i$$

$$y_i = g_i(p_i)$$

$$\_x_i = \_y_i + \_T_i\ ,$$

$$z = \_\,p_i\ .$$

Notice that the first three constraints imply $\_T_i = 0$.

Definition 2: A *non-cooperative equilibrium* in the sense of Nash is a feasible state $(\bar{x}, \bar{y}, \bar{p}, \bar{z}, \overline{T})$ such that:

$$\forall i,\ (\bar{x}_i, \bar{p}_i) \text{ maximises } x_i + v_i(z)$$

$$s.t. \qquad y_i = g_i(p_i)$$

$$p_i + (z) = \sum_{j \neq i} \bar{p}_j.$$

Notice that here, one has $T_i = 0\ \forall i$.

Definition 3: An *internationally efficient state* (or, for short, an *international optimum*) is a feasible state $(x^*, y^*, p^*, z^*, T^*)$ that maximises

$$\sum_{i \in N} [x_i + v_i(z)].$$

The well known fact — readily established from first order conditions — that the non-cooperative equilibrium is not an international optimum suggests that environmental efficiency at the world level can only be achieved through some form of cooperation among the countries involved. This is the source of the economists' motivation for interpreting and/or designing international treaties as instruments towards world efficiency.

But what contents for such a treaty? and which signatories? If all countries are convinced to cooperate, an "efficient" treaty would naturally specify the joint abatement policy corresponding to the internationally optimal emissions vector ($p_1^*, ..., p_n^*$) derived above[6]. For some countries however, the emission policy p_i^* may be so costly that it makes them worse off at the optimum compared with the non cooperative equilibrium (*i.e.* the situation prevailing without treaty). To keep such countries convinced to cooperate the treaty might in addition provide for private good transfers compensating for that cost. It is by now well known[7] that such transfers can be designed, and conceivably managed by an international agency[8], ensuring that the condition $x_i^* + v_i(z^*) \geq \bar{x}_i + v_i(\bar{z})$ be met for each potential signatory, taken individually.

Subgroups of countries — henceforth called "coalitions" — should also be considered, because for various reasons they may wish to act on their own instead of in cooperation with the full set N of the countries involved in the transfrontier problem. But acting on their own would mean designing treaties for themselves, involving abatement policies most likely different from ($p_1^*, ..., p_n^*$)): thus sub optimal at the world level. Is this inevitable, or can it be avoided? This is exactly the point on which the controversy arises that is to be discussed presently.

Two theses are opposing each other: on the one hand there is what I call the "small stable coalitions" (SSC) thesis, according to which only small subsets of the n countries can ever emerge and sign a treaty; there is on the other hand the "grand stable coalition" (GSC) thesis, presenting the contents of a feasible

---

[6]Close analysis of the economic model reveals that, just as in reality, there are many optima in general — optima that may differ either in terms of the emissions vector ($p_1^*, ..., p_n^*$), or in terms of the consumption levels ($x_1^*, ..., x_n^*$), or both. The quasi-linearity assumption simplifies the reasoning in this respect because it implies that the emissions vector ($p_1^*, ..., p_n^*$) is the same at all international optima (for a proof, see Proposition 1 in CHANDER and TULKENS 1995b).

[7] As amply elaborated upon in CHANDER and TULKENS 1991 and 1992.

[8] as suggested in TULKENS 1979, p. 206.

treaty which is shown to be in the interest not only of all members individually but also of all subgroups of N,. These two views are now developed in the next Section.

III. The two theses: a summary presentation

III.1 The "Small Stable Coalitions" (SSC) thesis

This thesis has been formulated prominently by CARRARO and SINISCALCO 1993 and BARRETT 1994. It is based on a concept of coalitions stability (due to d'ASPREMONT and GABSZEWICZ 1986) borrowed from the industrial organization literature on cartels. I follow here — and limit myself to — the first authors' presentation in CARRARO and SINISCALCO 1995 (hereafter CS).

Let $S \subseteq N$ be a "coalition", *i.e.* a set of countries that are willing to cooperate and to sign among themselves a treaty to that end. Using in this subsection the authors' notation, let $P_i(S)$ denote the utility of country i if i is a member of S, and $Q_i(S)$ denote the utility[9] of i if i is *not* a member of S.

Definition 4: The coalition $S \subset N$ is called *stable* if it satisfies the following two conditions:

(i) internal stability: $\forall i \in S, \quad P_i(S) \geq Q_i(S \setminus \{i\})$

and

(i) external stability: $\forall j \notin S, \quad P_j(S \cup \{j\}) \leq Q_j(S)$.

For the coalition $S = N$, only internal stability applies.

[9] These utilities could also be written in the notation of the previous section, but I shall turn to that later.

For the proponents of the SSC thesis, treaties are only likely to be signed by subsets of countries that meet these two conditions. As to the likelihood of worldwide environmental treaties on worldwide pollution problems (typically climate change, where *N* is the set of all countries in the world), these authors are led to pessimism because of the following result (henceforth, I denote by *S** a stable coalition):

Proposition CS:

If all countries are assumed to be identical,

(a) the existence of stable coalitions can be established;

(b) the size of stable coalitions is always small, in the sense that $\forall S^*,\ |S^*| << |N|$*;*

(c) Introducing private good transfers between countries does not increase the size of stable coalitions.

A second result[10], due to (BOTTEON and CARRARO 1995 BC hereafter), mitigates the pessimism of the one just quoted. It is also based on the more realistic premise of non identical countries. But it rests on a numerical example only:

Proposition BC :

When countries are not identical, a numerical example with five countries shows:

(a) the existence of stable coalitions;

(b) that without transfers, stable coalitions are always small;

(c) that private good transfers can be found that increase the size of stable coalitions, all the way to making stable even the grand coalition N.

---

[10] I shall leave aside the otherwise interesting results of CS concerning the implications of possible *commitments* to cooperate, because the issue here is only the explanation of cooperation.

As to transfers, it should be pointed out that those considered by these authors are not linked with the countries' emissions: they are all formulated as lump sum transfers.

III.2 The "Grand Stable Coalition" (GSC) thesis

This thesis has been formulated and defended in the two papers CHANDER and TULKENS 1995a, b (CT hereafter; we use here mainly the model of the latter). It is based on the cooperative game theoretic concept of the γ-core[11], and can be summarized in the following two steps:

Assumption "γ": If a coalition $S \subset N$ forms, the highest aggregate utility it can achieve for its members is given by the function

$$w^{g}(S) = \underset{\{(x_i, p_i)_{i \in S}\}}{\text{Max}} \sum_{i \in S} \left[x_i + v_i(z)\right]$$

$$\text{subject to } \sum_{i \in S} x_i \le \sum_{i \in S} g_i(p_i)$$

$$\text{and } \sum_{i \in S} p_i + z = - \sum_{j \in N \setminus S} p_j ,$$

where $\forall j \in N \setminus S$, (x_j, p_j) maximizes $x_j + v_j(z)$

$$\text{subject to } x_j \le g_j(p_j)$$

$$\text{and } p_j + z = - \sum_{\substack{i \in N \\ i \neq j}} p_i .$$

If coalition N forms, the highest aggregate utility it can achieve for its members is given by

$$w^{g}(N) = \sum_{i \in N} [x_i^* + v_i(z^*)],$$

where x^*, z^* are values given by an international optimum $(x^*, y^*, p^*, z^*, T^*)$.

---

[11] As distinct from those of α- and β-cores. The greek letters used refer to alternative specifications of the assumption just about to be stated. The references cited contain a discussion of these alternative assumptions

Proposition CT:

Given the vector of optimal emissions (p_1, ..., p_n*), private good transfers of the form*

$$T_i^* = -\left(g_i(p_i^*) - g_i(\overline{p}_i)\right) + \frac{\mathrm{p}_i}{\mathrm{p}_N}\left(\sum_{i \in N} g_i(p_i^*) - \sum_{i \in N} g_i(\overline{p}_i)\right), \quad i \in N, \qquad (1)$$

induce a feasible state $(x^*, y^*, p^*, z^*, T^*)$ of the economic-ecological system which is such that, for every coalition $S \subset N$,

$$\sum_{i \in S}\left[x_i^* + v_i(z^*)\right] > w^{\mathrm{g}}(S).$$

The proposition asserts that with transfers defined as in (1), the feasible state $(x^*, y^*, p^*, z^*, T^*)$ cannot be improved upon to the benefit of its members by any coalition $S \subset N$. Technically, the feasible state $(x^*, y^*, p^*, z^*, T^*)$ is a strategy that belongs to the core of a cooperative game associated with the economic-ecological system, $w^{\mathrm{g}}(S)$ being the characteristic function of that game.

The assumption yielding the function $w^{\mathrm{g}}(S)$, on which the proposition's statement rests, specifies that if S forms, its members choose the actions that are the most beneficial for themselves, while the other players (countries) act to the best of their individual interests, "playing Nash" against S. The outcome of these behaviors is a state of the economic-ecological system that the authors call a "Partial Agreement Nash Equilibrium with respect to S" (denoted henceforth as P.A.N.E. w.r.t.(S)). The core property of the state $(x^*, y^*, p^*, z^*, T^*)$ is thus that if a treaty is proposed to N that induces this state, no subset S of countries can hope to gain from inducing instead a P.A.N.E. w.r.t. itself. Therefore the "grand treaty" should be signed by all, without regret.

The structure of the transfers formula (1) has been amply commented upon on pp. 289-91 of CHANDER and TULKENS 1995a. Only important for our present purposes is to note that they are linked with the emissions — actually to their abatement cost.

IV. Differences and similarities

As the preceding summary already makes clear, a theory of stable coalitions is here opposed to the theory of the core of a cooperative game. We consider here four aspects of this opposition.

A. On coalitions, coalition formation, and the final outcome of the games

Let us remind ourselves first that the theory of the core of a cooperative game, on which the GSC thesis rests, is basically *not* a theory of the formation of coalitions. Its scope is in fact more limited. It does indeed focus on arguments to support the view that only the so called "grand coalition"[12] of all players will form, and that the other coalitions will not form.

By contrast to this, the SSC approach claims to be able to identify some specific subsets of N for which it asserts that they will form as "coalitions" because they are stable (in the specific SSC sense), and other subsets that will not form in this way. The justification for the assertions of stability — is provided by comparing, for each conceivable subset, the payoffs of each individual player when he belongs to the coalition and when he stays out.

---

[12] As will appear below, it may be expositionally convenient to keep the term of "coalition" for *proper* subsets of players only and avoid using it for denoting the full players set. As an additional justification for this terminological convention, one may remember that a coalition is usually conceived of as a group opposing itself *against* some other people. Clearly there are no such other people when the "coalition" is the full players set.

It thus appears that the term "coalition" is not used in the same way by the two groups of authors. In the language of the SSC view held by the second group, a coalition denotes a set of "good" guys, who do cooperate among themselves[13], and intend to sign a treaty together — while those who stay outside of the coalition are the "bad" guys, who act in isolation. Note that, in this parlance, any coalition must comprise at least two players (here, countries): singletons are meaningless as "coalitions".

In the GSC (core-theoretic) way of reasoning, things are reversed: the strategy in the core (that is, the contents of a treaty for *N*), is supposed to be first proposed to all players; and then the term coalition is used to denote people who might possibly object to it. Coalitions are thus here a set of "bad guys", who put in question the fact of cooperating within *N*, and refuse to sign the grand treaty proposed to them; they instead consider doing something else: specifically, achieving what is specified as a P.A.N.E. w.r.t.(*S*). Note that here a singleton *is* meaningful as a "coalition": because the essence of a coalition is not the fact that its members cooperate, as is the case above; it is instead the fact that the coalition does (or envisages to do) something different from what is being proposed to *N*.

With this clarification of the vocabulary in mind, as well as of the behaviors this vocabulary is intended to describe, one can perhaps better see the central difference between the two theses, which lies in the final outcome of the transfrontier pollution game that they each envisage:

— For the SSC literature, the final outcome is a two-fold situation consisting of, on the one hand, the formation of some small coalition of countries whose members do sign an abatement treaty and, on the other hand, the other

[13] In both theories, "to cooperate" means the same thing, namely: for any set of players whose cardinal number is at least two, to do together something different from what each of the cooperating players would do alone.

countries who decline to join signing (and enjoy a free ride from the signatories' cleanup: more on this below). Note that this outcome in fact exactly what CT have dubbed a P.A.N.E. with respect to some coalition.

— In the GSC literature, the final outcome is a joint strategy for all players — the grand treaty, which is better for any coalition *S* than the P.A.N.E. this *S* might achieve.

In terms of the cooperative game theoretic literature on "stable coalitions structures"[14] where a coalition structure is defined as a partition of the all-players set, one can restate the above as follows: the SSC literature predicts an outcome with a coalition structure of the form $\{S, \{j\}_{j \in N \setminus S}\}$, where the sets {*j*} are singletons, whereas the GSC literature predicts an outcome with a coalition structure of the form {*N* }, with no singletons. None of the two views at study here refers to the concept of stable coalitions structures, nor is it used by d'ASPREMONT and GABSZEWICZ 1986 who had inspired the SSC view. But it obviously applies very well to what we are dealing with.

B. On free riding and threats

Just as with "coalition" the words of "free riding" are also used with different meanings in the two strands of literature under review.

In the SSC approach, the free riding that is dealt with is one that occurs when — in the words of its authors — "a country lets other countries sign a cooperative agreement, and thereby enjoys a cleaner environment at no cost" (CARRARO and SINISCALCO 1995, pp. 264-5). This prompts two remarks:

(i) It is referred to *individual* free riding only. Of course, one may rephrase the definition and speak of countries instead of just one. This is indeed the case

---

[14] A concept used and studied by AUMANN and DREZE 1974, as well as HART and KURZ 1983. Recent work of DEMANGE is also relevant.

with the SSC final outcome I just recalled. But the set of such free riders then amounts to a collection of singletons, not a set of cooperating players.

(ii) Suppose a (*e.g.* upstream) country is a major polluter, but does not care at all for the quality of the (downstream) environment, for objective reasons. As it pollutes a lot, it should be brought into the treaty, since its actions are determinant ones for achieving a full international optimum. If it stays out nevertheless, is it to be considered as a free rider? In fact, the above definition of free riding does not apply very well to such case.

Turning to the GSC view, I first see two elements emanating from the core concept that are relevant for free riding:

(i) Free riding is considered for *any* subset S of N, that is, for singletons but also for larger subsets of N. We have thus explicitly the possibility of *coalitional* free riding.

(ii) It is supposed that free riders do cooperate among themselves: they indeed are assumed to achieve $w^g(S)$, as defined in Assumption γ.

Much more importantly, however, the GSC view adds another ingredient in describing free riding behavior, namely a reaction of the other, non free riding countries. This reaction is not to punish the free riders in an irrational way: it is simply not to form as a coalition, and to just play Nash against the free riding coalition S. This is a threat element, that I like to call an individually reasonable threat.

Threats against free riders[15] are absent from the SSC analysis; but the constructive results yielded by the GSC analysis, using some form of threat, make one wonder whether this is not precisely an important source of its difficulty in finding grounds for cooperative agreements.

[15] Threats are of course not to be confused with the "reaction functions" analyzed with much detail in section 3.2 of CS. On reaction functions, however, it is interesting to note that while stability in the SSC sense is shown by CS to be weakened by non orthogonal functions, the P.A.N.E.(S) on which stability of N in the GSC sense is established do imply non orthogonal reaction functions (see assertion *(iii)* in Proposition 4 of CHANDER and TULKENS 1995b).

C. Characteristic functions: A common tool for further analysis

We have observed above the fact that the final outcome of the SSC approach is nothing else than a P.A.N.E. w.r.t.(S) where some S is found to be stable. On the other hand, that same concept is used by the GSC approach to formulate the characteristic function $w^{g}(S)$ whereby a coalitionally stable strategy is claimed to be found for N.

This rapprochement suggests that while the SSC thesis does use the tool of characteristic function, one could nevertheless ask whether there is not some characteristic function underlying, or hidden within the SSC approach. I want to argue here that this is indeed the case, after having made two preliminary remarks on the characteristic function $w^{g}(S)$.

(i) Let me observe first that with the characteristic function $w^{g}(S)$, in the special case where S ={i} is a singleton, the resulting P.A.N.E. w.r.t. ({i}) is nothing else than the Nash equilibrium of the problem. Any individual free riding, in the GCS framework of thought, entails absence of any cooperation at all. This is the extreme form of the threat I described above.

*(ii)*There is also something to be learned from considering, still with the characteristic function $w^{g}(S)$, the other extreme case where S = N\{i}, and the final outcome is the P.A.N.E. w.r.t. (N\{i}). Here, N\{i} are cooperating, or "coalitional" free riders, and {i} is left alone, albeit willing to cooperate. Compared with the previous case, things are reversed here . The "free rider" expression is perhaps not too appropriate a vocabulary any more, since this outcome would be more naturally seen as the one occurring when the full players group N throws out a singleton {i}.

What do we learn from considering this case ? Essentially that the core strategy for N is to be understood as one that deters N\{i} to act that way. This is relevant for the case mentioned above, namely if i were a strong polluter, careless for the environment, and refusing to cooperate with N: the core strategy is one such that for the members of $N\backslash\{i\}$, it is not in their interest to leave $\{i\}$ out.

My main point in this subsection is a different one, however. In the definition of the characteristic function $w^{\mathrm{g}}(S)$, it is assumed that given S, the players not in S play Nash against this coalition, and $w^{\mathrm{g}}(S)$ then denotes the payoff for the members of S given that assumption.

Now, why not change this assumption, and consider what the SSC literature denotes (recall Section III.1) as the magnitude $Q_i(S)$, that is, the payoff of player i when he is not a member of S, *and S is formed.*[16] Let us, in particular, consider this magnitude for $S = N \setminus i$, that is, $Q_i(N \setminus i)$. Using now the variables of the underlying economic-ecological model, let us exhibit the strategies of all players that induce such a payoff. In the notation of Section III.2, we have[17]:

[16] This proviso was not mentioned explicitly in the exposition of section III.1; but it is unquestionably present, albeit implicitly, in the SSC theory.

[17] The superscript δ is used to point out to the once more different assumption made here on the behavior of players that do *not* belong to the coalition S under consideration. Writing this δ case in a more explicit way as $w^{\mathrm{d}}(\{i\} \mid N \setminus \{i\})$, one could also imagine still further cases suggested by the expression $w^{\mathrm{e}}(\{i\} \mid S, \{j\}_{j \neq i, j \notin S})$. Examining these is beyond the scope of this discussion.

$$
\begin{aligned}
Q_i(N \setminus i) \equiv \; & Max\, u_i = x_i + v_i(z) \\
& s.t.\; x_i \le g_i(p_i) \\
& \quad p_i + z = -\sum_{j \ne i} p_j
\end{aligned}
$$

where the vector $(p_j)_{j \in N \setminus i}$ maximizes $\sum_{j \in N \setminus i} u_j = \sum_{j \in N \setminus i} [x_j + v_j(z)]$

$$
\begin{aligned}
s.t.\; & \sum_{j \in N \setminus j} x_j \le \sum_{j \in N \setminus j} g_j(p_j) \\
& \sum_{j \in N \setminus j} p_j + z = -p_i.
\end{aligned}
$$

To harmonize notation, let me now substitute $w^{\mathrm{d}}(\{i\})$ for the value of $Q_i(N \setminus i)$ so defined. Let me further define this value $w^{\mathrm{d}}(\{i\})$ for all singletons of N, and write for N itself $w^{\mathrm{d}}(N) = w^{\mathrm{g}}(N)$ as defined in Assumption γ.

I thus define a function $w^{\mathrm{d}}(.)$ that associates with all singletons of N and N, itself a real number. In cooperative game theoretic parlance, this is of the nature of a characteristic function, with the peculiarity that its domain is restricted to only some subsets of N. Nevertheless, we have a cooperative game, defined by the pair [N, $w^{\mathrm{d}}(.)$].

If for this game a core imputation exists, then N is a stable coalition *in the SSC sense*, and we have a reconciliation of the two theses. If the core is empty, then N is not a stable coalition in that sense, in spite of Proposition CT: the two concepts cannot be reconciled, in general.

This is what Proposition CS establishes, using the case of identical players: the core of the game [N, $w^{\mathrm{d}}(.)$] is thus empty, in general. However, BOTTEON and CARRARO 1995 showed with an example that with non identical players and transfers, the core of that game may not be empty: reconciliation is thus not a hopeless task. It only remains to find out how large, and realistic can be the conditions under which it would hold. I have not done that work, but I am convinced that it would be a worth while one, if only because the economic-ecological world we are dealing with is essentially and immensely diversified, and transfers of resources across countries is evidently a tool of international economic policy.

With the construct just presented, I thus have attempted to reformulate the stable coalitions theory in terms of the theory of cooperative games. The scope of that attempt is of course limited to the issue of the stability of the grand coalition vis à vis *individual* [18] free riding, and its interest essentially rests in delineating the conditions of reconciliation[19] between the two theories.

D. On transfers and "side payments"

A final dissimilarity lies in the formulation of transfers. As pointed out in Section III, they are of the lump sum form in the SSC models, whereas in formula (1) of the GSC approach they appear as linked with the amounts of emissions abatement. While in the former case they are just "side payments" between countries, they can be given in the latter case an interpretation in terms of a formula[20] for sharing, between the countries, the aggregate abatement costs.

Introducing this second kind of transfers in the characteristic function apparatus I just outlined would definitely be relevant. While they would not change the negative result obtained by CS with identical countries, they might reinforce the positive result of Botteon and Carraro with non identical countries.

---

[18] Thus, not coalitional free riding.

[19] When the core is empty, one may consider as a substitute the nucleolus: LITTLECHILD's work on airplane landing fees may be relevant here, in which he uses games comparable to the one described here.

[20] The details of which are given in section 6 of CHANDER and TULKENS 1995a.

V. Conclusion

What is essentially at stake in this controversy is the stability of the grand coalition: are all countries likely to sign treaties in matters of worldwide transfrontier pollution problems? The above comparative exercise suggests an answer in the form of a further question: what kind of stability does one have in mind: (1) a *passive* stability *w.r.t. singletons only*, with "passive" meaning stability without threat against defecting singletons — this is the SSC view ; or (2) an *active* stability *w.r.t. all conceivable coalitions*, with "active" meaning stability with the threat of playing Nash against defecting coalitions — this is the GSC view.

From a positive economics point of view, both concepts are defensible, and it remains to the analyst to find out which one is more often observed, and therefore more realistic. From a normative point of view, in which I would include the discourse of policy advisors, I cannot help thinking that the active stability perspective has stronger merits because of two reasons: it embodies the reality of threats in a richer way, and it has shown to lend itself to formulating explicit emission and transfers policies that both implementable and computable.

Yet, there is of course a long way, a very long way indeed, between what our little models allow us to assert, and the immensely complex reality we are facing. But I cannot help being happy with theoretical thinking that gives some ground for optimism, because in this way it becomes possible that our intellectual and scientific activity contributes positively to the endeavors of negotiators and decision makers who are in charge of those matters. When theory can help them in a constructive way, I submit we do our job best.

References

AUMANN, R.J. and DREZE, J. 1974, "Cooperative games with coalition structures", *International Journal of Game Theory.* 3, 217-237.

BARRETT, S. 1994, "Self enforcing international environmental agreements, *Oxford Economic Papers* 46, 878-894.

BOTTEON and CARRARO, C. 1995, "Burden sharing and coalition stability in environmental negotiations with asymetric countries", paper presented at the 2nd meeting of the HCM network "Designing economic policy for management of natural resources and the environment", Venice, May 1995.*FEEM Nota di Lavoro* n°78.95 (November).

CARRARO, C. and SINISCALCO, D. 1993, "Strategies for the international protection of the environment", *Journal of Public Economics* 52, 309-328.

CARRARO, C. and SINISCALCO, D. 1995, "International coordination of environmental policies and stability of global environmental agreements", chapter 13 in Bovenberg, L. and Cnossen, S. (eds), *Public economics and the environment in an imperfect world*, Kluwer Academic Publishers, Boston, London, Dordrecht.

CHANDER, P. and TULKENS, H. 1991, "Strategically Stable Cost Sharing in an Economic-Ecological Negotiation Process", *CORE Discussion Paper n° 9135*, June 1991 (revised October 1992); to appear in Mäler, K.G. (ed.) *International Environmental Problems*, a volume sponsored by the European Science Foundation, Kluwer, Boston and Dordrecht.

CHANDER, P. and TULKENS, H. 1992, "Theoretical foundations of negotiations and cost sharing in transfrontier pollution problems", *European Economic Review*, 36 (2/3), 288-299 (April).

CHANDER, P. and TULKENS, H. 1995a, "A core-theoretic solution for the design of cooperative agreements on transfrontier pollution",*International Tax and Public Finance* 2 (2), 279-294.

CHANDER, P. and TULKENS, H. 1995b "The Core Of An Economy With Multilateral Environmental Externalities", *CORE Discussion Paper* n° 9550 (revised: August 1996); forthcoming in *International Journal of Game Theory* .

d'ASPREMONT, C. and JASKOLD GABSZEWICZ, J. 1986, "On the stability of collusion", chapter 8 (pp. 243-264) of J.E. Stiglitz and G.F. Mathewson (eds), *New developments in the analysis ofmarket structure,* Cambridge (Mass.), The MITPress.

GERMAIN, M., TOINT, P. and TULKENS,H. 1996, "Financial transfers to ensure cooperative international optimality in stock pollutant abatement", paper presented at the conference Ecology, Economy and Society, Université de Versailles at St Quentin en Yvelines, France (June); submited for publication in Duchin, F., Faucheux, S., Gowdy, J. and Nicolaï, I. eds, *Sustainability and Firms: Technological Change and the Changing Regulatory Environment*, Edward Elgar, London.

GERMAIN, TULKENS and de ZEEUW 1996, "Stabilité stratégique et pollution-stock transnationale : le cas linéaire", IRES Discussion Paper n° 9701, Université Catholique de Louvain, Louvain-la-Neuve, forthcoming in *Revue Economique.*

HART, S. and KURZ, M. 1983, "Endogenous formation of coalitions", *Econometrica* 51 (4), 1047-1065.

LITTLECHILD, S. 197?, "A simple expression for the nucleolus in a simple case", *International Journal of Game Theory .*

TULKENS, H. 1979, "An Economic Model of International Negotiations Relating to Transfrontier Pollution", chapitre 16 (pp. 199-212) in K. Krippendorff, (ed.) *Communication and Control in Society,* Gordon and Breach Science Publishers, New York.