Coalition dynamics in environmental problem solving

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Abstract

The present paper aims at examining the dynamics of coalitions that form under the pressure of environmental problems. Coalitions form as soon as a minimal set of players find it is either convenient or necessary to join a coalition, last for some more or less long periods of time and then may either widen or shrink so that a coalition becomes an empty shell and lose its reason of being. Keeping a coalition active for long periods of time requires both the use of resources to keep the members convinced that the coalition is useful and the continuous presence of the problem that caused the rising of the coalition. Such resources are necessary for the communication among the members and the sharing of resources, benefits and costs under the form of side payments. A hidden assumption is that members interact repeatedly with time so that their past knowledge of past interactive attitudes can be used in current interactions so to favour either co-operative or competitive attitudes.

1 Aim of the paper

The present paper aims at examining the dynamics of coalitions that form under the pressure of environmental problems. Usually coalitions are seen as static entities that form and share costs and benefits among the composing members. In real cases coalitions form, upward crossing a threshold, as soon as a minimal set of players find it is either convenient or necessary to join some coalition, last for some more or less long periods of time and then may both widen and shrink until the downward crossing of the threshold occurs so that a coalition becomes an empty shell and loses its reason of being. One

of the guesses we make in the present paper (without a deep justification) is that keeping a coalition active for long periods of time requires both the use of resources to keep the members convinced that the coalition is useful and the continuous presence of the problem that caused the forming of the coalition. Such resources are necessary for the communication among the members and the sharing of resources, benefits and costs under the form of side payments. A hidden assumption is that members interact repeatedly with time so that their past knowledge of past interactive attitudes can be used in current interactions so to favour either co-operative or competitive attitudes.
Owing to space constraints in the present paper we are going to examine many of the aforesaid topics only briefly and informally, forthcoming papers will be devoted to their deeper scrutiny and formalization.

2 The main topics

The main topics of this paper are **environmental problems**, **coalitions** and **coalition dynamics**.
Environmental problems concern critical situations involving the environment with a wide range of space and time scopes: such problems can indeed (space) range from very localized to global problems involving the whole planet and (time) from short time latitude problems to problems that span over several up to thousand years (involving several future generations)[1]. The space parameter allows the definition of the area within which stakeholders reside whereas the time parameter has a twofold meaning. We can indeed use it to point out:

1. how long it needs for a problem to be solved and its effects undone so to come back to a more or less ex-ante situation;
2. how long the effects of a problem will last in the future if no action is undertaken.

From all this it is easy to understand how environmental problems have the characteristic of **unescapability**. With this term we mean that no player

[1] Examples include: the localization of power or chemical plants, incinerators, solid waste disposal sites up to nuclear waste disposal sites; local, wide area or global leakages of pollutants; localization of big infrastructures (railways, ports and airports). The biggest and hardest problems are those involving the whole planet such as global warming, depletion of the ozone layer; depletion of both renewable (such as fertile land) and non renewable resources (such as oil). For a brief survey of the use of Game Theory for environmental problems we refer to [Cio06] (available as *pdf* file at *http://www.di.unipi.it/ lcioni/papers/2006/PresentazioneTdG.pdf*).

can escape from suffering environmental damages if within the space and time scope of an environmental problem. Maybe he can reduce his costs by not adhering to a common effort and trying to act as a free-rider but if such effort fails or is not sufficient he cannot escape from paying his ex-post environmental dues. We can easily understand, therefore, how environmental problems suffer from this two-faced aspect: from one side every actor has an incentive to act as a free-rider (see further on) so to let the others take care of solving the problem, from the other side every actor is (or should be) well aware of the fact that if all the other actors'effort is not enough to solve the problem all the actors have to suffer a damage and pay some costs.
The other side of the coin is that the benefits deriving form environmental problem solving are **non-exclusive** and are enjoyed by those that actively solve a problem as well as by those that do not contribute to the solution and behave as usual[2]. We will see in the following sections how such attitudes fall under the label of **free-rider**. Free-riders can be of two types: **inner free-rider**s and **outer free-rider**s. Those of the former type seemingly join the effort of problem solving but actually boycott any real attempt of solution whereas those of the latter type do not join such effort and wait for enjoining the benefits deriving from any strategy of solution.
Coalitions involve the interactions among groups of actors. Actors belong to the subset A of the set of stakeholders S. We note indeed that every actor is a stakeholder but the opposite is not true since only stakeholders that have the real power to undertake decisions can be defined to be actors. In this way we define $A \subseteq S$ as a set of actors or empowered stakeholders and, consequently, we define $\hat{S} = S \setminus A$ as the singly dummy actors.
The simplest scenario occurs whenever the members of A form a single coalition[3] (the grand coalition). In this case the members of $\hat{S}$ can be partitioned in three subsets[4]:

1. supporters of A, $\hat{S}_1$;
2. opponents of A, $\hat{S}_2$;
3. neutrals $\hat{S}_3 = \hat{S} \setminus (\hat{S}_1 \cup \hat{S}_2)$.

[2]Examples of this rewarding attitude are the non adhesion to international environmental agreements or, at a smaller scale, the non adhesion to cleaning programs of lakes, rivers and to the reforestation of burnt areas, to name only few cases.

[3]Formally speaking in the jargon of Game Theory a coalition is any non empty subset of players.

[4]We use an almost classical definition of partition so that a set is partitioned if it can be seen as the union of a certain number of disjoint sets some of which (but not all) can, at times, be empty.

Members of $\hat{S}_1$ favour the action of A, members of $\hat{S}_2$ hinder A' action whereas members of $\hat{S}_3$ act as a "game preserve" of the other groups.
In this case $\hat{S}_1$ can be seen as a **dummy member**[5] of A whereas $\hat{S}_2$ can be seen as a single opposing coalition[6] whereas members of $\hat{S}_3$ waver among the two other sets. We can say that $\hat{S}_1$ represents the legitimation of A whereas $\hat{S}_2$ its delegitimation. In this case we can define the ratios:

$$s = \frac{|\hat{S}_1|}{|\hat{S}|} \tag{1}$$

and

$$o = \frac{|\hat{S}_2|}{|\hat{S}|} \tag{2}$$

so that[7] $s > o$ means that the actions of A are more supported that opposed, the vice versa if $s < o$. We can use such indexes to model the interactions between the members of a coalition and the actors that do not belong to it and that can join more easily the more a coalition is legitimated.
Another interesting scenario occurs whenever we have two opposing disjoint coalitions A_1 and A_2 so that $A = A_1 \cup A_2$. In this way $\hat{S}$ contains the supporters and opponents of either coalitions and the set on neutral stakeholders. In this case we can justly suppose that the supporters of the first coalition are the opponents of the second and vice versa[8] so that:

$$s_1 = \frac{|\hat{S}_1^1|}{|\hat{S}|} = \frac{|\hat{S}_2^2|}{|\hat{S}|} \tag{3}$$

is a measure of the influence of A_1 whereas:

$$s_2 = \frac{|\hat{S}_1^2|}{|\hat{S}|} = \frac{|\hat{S}_2^1|}{|\hat{S}|} \tag{4}$$

is a measure of the influence of A_2[9]. The use of such indexes is similar to that of indexes s and o though extended to a pair of competing coalitions.

[5] A dummy member can be defined similarly to a dummy player in co-operative Game Theory as a member that joining a coalition simply brings his own dowry to that coalition.

[6] In this simple case we imagine $\hat{S}_2$ as having a flat and uniform structure. In real cases set such as $\hat{S}_2$ are characterized by a complex inner structure. The treatment of this case is out of the scopes of the present paper.

[7] We consider the case $s = o$ as occurring with 0 probability or as equivalent to the impossible event.

[8] In this case we use the exponent 1 or 2 to denote the coalition and the index 1 to denote the supporters and 2 to denote the opponents.

[9] The case of two opposing coalitions is quite common in real cases such as the building of a bridge on a strait or of a railway line in a valley or of an incinerator near a natural preserve and the like.

More complex cases involve the presence of k disjoint coalitions A_i. In these cases however coalitions tend to gather in two competing (or opposing) non flat [super]coalitions[10] with an inner dynamics. The presence of inner dynamics is an important factor of differentiation whose analysis will not carried on in this paper.
Last but not least, **coalition dynamics** represent a tool for the description of the steps through which coalitions form, evolve, expand or shrink, each split in two or more coalitions and even dissolve. To describe such dynamics we need tools that allow us to describe how a coalition forms, grows, reaches a maximum size and/or weight and then declines until when it reaches a minimum size and/or weight and the may grow again. In this way we want to describe a cyclical behaviour but also the fact that at any instant a coalition may collapse and dissolve.

3 Players and coalitions

From section 2 it is easily understood how actors are players whereas dummy stakeholders can be seen as actors only if they join in groups. Under this perspective, given a "population" of stakeholders, some of them being actors, we can characterize a set $N = \{1, \dots, n\}$ of n players.
The shift from actors to players is an abstraction step with the following outcomes ([Rap89] and [Pat06]):

1. players are seen as endowed with full rationality and intelligence;
2. players are seen as endowed with a bounded rationality;
3. players are seen as endowed with a minimal rationality.

In the first case players base their strategies on future expectations as determined by the structure of the game they are involved in.
In the second case players base their actions mainly (even if not exclusively) on their expected future outcomes and on the past actions of the other players.
In the third case players are only guided by the past actions of the other players and tend to act reactively so that the range of effective strategies[11] at disposal of each player is reduced at a minimum.

[10] We say that a coalition is flat if all the members are equivalent within it otherwise it is termed non flat.
[11] With **effective strategies** we denote the strategies that each player sees as feasible given his psychological state.

This classification is really useful within $NCGT$[12] since within CGT we typically consider that coalitions have formed and have attained an outcome that must be shared among their members according one of the possible solution (i. e. distribution) rules.
At an earlier stage that CGT we may describe ([Spa03]) the process of the formation of coalitions among players. Coalitions are seen as temporary alliances for the attainment of a common goal or the engagement in a joint activity.
Such coalitions usually form under the pressure of some problem but tend to loosen and shrink (if not dissolve) as the problem is being solved and is perceived as less urgent and serious. This slackening of the attention can in turn cause a new worsening of the problem thus allowing the declining coalition to be felt as again necessary.
This should suggest by itself the dynamic nature of the life cycles of coalitions.
The cases we are interested in are essentially:

1. all the players join the **grand coalition**;
2. some of the players join a coalition $M \subset N$ whereas those of $N \setminus M$ act as single member coalitions[13];
3. some players join a coalition $M_1 \subset N$ whereas some others join another coalition[14] $M_2 \subset N$ and those left out, if any, act as single member coalitions.

In the last two cases we must examine how the singletons behave. We suppose that they are attracted by a coalition if they are better off by joining it or they act as singletons if they are better off by doing so.
In the first of the aforesaid cases all the players are theoretically involved in the grand coalition so to share its costs according to some generally accepted rule. In this case we can have the so called **inner free-riders** as those players that are within the coalition but do not obey its rules. This can occur

[12]In this paper we use the acronym CGT to denote co-operative Game Theory (CGT) where players can sign binding agreements and the acronym $NCGT$ to denote non co-operative Game Theory where there is no such possibility. We moreover use the acronym TU as **Transferable Utility** to describe games where all the players of a coalition share a common value of the game according to some solution rule whereas, if such possibility does not exist, we speak of **Non Transferable Utility** or NTU.

[13]We denote such coalitions as **singletons** so that when speaking of coalitions we always refer to sets of cardinality strictly greater that one.

[14]In all the cases we speak of two or more coalitions we suppose they correspond to disjoint subsets of the set of players N. Though in some cases we may have players that belong to more than one coalition we disregard this possibility.

since in environmental problems controls are hard to execute, individual responsibilities cannot be easily ascertained and, in many cases, there is no authority that has the power to give penalties to such players.
In the last two of the aforesaid cases we can have again inner free-riders and, moreover, **single member coalitions** act as **outer free-riders** since they benefit at no costs of the efforts made by the players involved in one or two coalitions[15]. This can occur since the participation to a coalition is a voluntary decision that can be encouraged and favoured through some economical concessions but cannot be forced at all. Players, indeed, tend to join a coalition only if they find it economically convenient.
As to *NCGT* we can use it in the following cases:

1. we model the interactions among the players in absence of any coalition;

2. we use it to model interactions among coalitions.

In the first case we have a set N of players, each acting according to his own strategies and trying to get the best possible outcome, depending on the actions of the other players.
In the other case we can devise the following pattern (that assume repeated stateless[16] interactions among the players):

```
initial_set_up
while(problem_exists)
do
   coalitions_interaction;  \\NCGT
   coalitions_dynamics;     \\CGT
end
```

The boolean condition assures an a priori random duration of the whole game form. Obviously the two steps we described in that succession can occur [partly] in parallel. The initialization phase allows the definition of one or more initial coalitions but also that at the very start we can have n singletons that face a problem individually.

[15] Obviously the same holds also for the members of M_1 with regard to those of M_2 and vice versa.

[16] In this way we impose the impossibility of a discount factor and the the impossibility for each player to play knowing that he will play again so to flatten all the repetitions at the time of the first interaction. In other words each player knows everything about past repetitions of a game (such as behaviours of the other players and profitability of past strategies) but almost nothing about future repetitions, more about this in section 6.

4 Environmental problem solving: costs and benefits

With the term "problem solving" we denote an abstract model that describe the solution of an environmental problem in terms of costs and benefits[17].

Costs, monetary or "environmental" [18], represent the perception of a problem and are caused by the problem itself, if it is not solved, and by the steps necessary for its solution.

Given a set of stakeholders[19] S, the costs of the first type (problem related costs, C_p) are usually borne by the subset of stakeholders S_p that are in the scope of the problem whereas those of the second type (solution related costs[20], C_s) are borne by the subset of stakeholders S_s (that are actors) that engage in planning and implementing a solution of that problem.

We can have the following cases:

1. $S_s \cap S_p = \emptyset$ but $S = S_p \cup S_s$;
2. $S_s \cap S_p \neq \emptyset$ but $S_s \setminus S_p \neq \emptyset$ and $S = S_p \cup S_s$;
3. $S_s \subset S_p$ so that $S = S_p$.

In the first case the members of S_p act as free-riders whereas in the other two cases we define as free-riders the members of $S_p \setminus S_s$. These scenarios

[17] Obviously we do not mean the real solution of an environmental problem. If we face the problem of the pollution of a lake, from our perspective its solution is the definition of a strategy among the players for the sharing of cleaning costs and not the definition of the best technology to be used given the actual pollutants of the lake nor other physical parameters.

[18] Such costs may be completely independent. We can imagine the drilling of a tunnel that causes the draining of a certain number of springs and wells. The costs for the tunnel are charged to the company that drills the tunnel but the other costs are charged to those who live in the affected territory. Even in presence of monetary compensations it can happen that they cover only short time effects without any real effect on the long run. In many cases compensations are in monetary terms so that they cannot really repair the real damages.

[19] Such a set is composed by those who are within the time and/or space scope of a problem and usually belongs to a wider set that includes also the out-of-the-scope individuals. In this way we dynamically define a universe U as partitioned in a set of stakeholders S and a set of stakelackers $\tilde{S}$ but concentrate only on S. A stakelaker is the opposite of a stakeholder.

[20] Such costs are directly paid by the members of S_s and indirectly by either the members of S or by the members of some superset of S. The sharing of the costs is a hard issue since, case by case, it is not always clear who has to pay what and how much. In this paper we suppose that costs are only directly paid by the members of S_s.

hold under the assumption that we have a winning coalition $A = S_s$ that has devised a solution that is being implemented.
Benefits can be thought as being of different types:

1. direct monetary,
2. indirect monetary,
3. non monetary[21].

Benefits of the first type are due exclusively to members of S_s, benefits of the second type can be enjoyed by all members of S whereas those of the last type are due essentially to all the members of S_p.
It should be clear that members of S_s are the players whose problem related behaviours we want to study and model.

5 Basics on coalition dynamics

5.1 Coalitions as dynamic processes

Coalitions ([Ray92]) are neither static nor isolated entities since they evolve with time and are immersed in the set S.
Given the set N of players the starting point is **coalition building** ([Spa03] and [For97]).
In an ideal initial setting we suppose to have n singletons each facing ordinary environmental problems and acting according to isolated patterns. In this case however we are even outside the realm of Game Theory. If singletons act according to strategic but selfish patterns we fall within $NCGT$. If we want to move within the framework of CGT we must turn to coalitions[22]
In the light of a major problem P, two or more players can indeed decide to form a coalition. Such initial coalition M^0 can form if players together can obtain more that they can obtain as singletons. What does this mean? The right ambit is based on at least two criteria: the costs and the benefits. Problem[23] P has associated costs and benefits that span over the time and

[21] We denote in this way all the benefits that involve the quality of the environment or the quality of life and the like.

[22] Though we assign to such a term a simple meaning from set theory it is worth noting that ([Ray92]) we can identify a set of players with a plurality of names such as alliance, pact, bloc or cartel, each with its own nuance of meaning.

[23] Simple small scale examples are the disposal of solid or special wastes, the cleaning of the industrial pollutants leakages in a river or in a lake, the cleaning of the smoke of industrial plants and so on.

the space. Let us assume that for M^0 they are respectively C_P^0 and B_P^0. The members of M^0 try to:

1. maximize B_P^0 so to maximize their individual share $B_{P_i}^0$,
2. minimize C_P^0 so to minimize their individual share $C_{P_i}^0$.

(with $i \in [1, |M^0|]$). The first target is generally compatible with smaller coalition sizes whereas the second with bigger coalition sizes[24].
Within this framework members of M^0 try to enlist other members so to form a bigger coalition M^1 such that:

1. $B_{P_i}^1 \geq B_{P_i}^0$
2. $C_{P_i}^1 \leq C_{P_i}^0$

for the players $i \in [1, |M^0|]$ whereas the new incumbents[25] $M_1 \setminus M^0$ are at least better off that they were acting as singletons. In this way coalition tends to grow up so that we have the succession:

$$M^0 \subseteq M^1 \cdots \subseteq M^i \ldots \tag{5}$$

The growth continues till conditions 1. and 2. above are satisfied. Obviously the biggest coalition that can form is the grand coalition where all the players are involved. If this can really occur or not depends both on the nature of the problem and on the behaviour of the incumbents at each stage of the interaction.
Behaviour described by relation (5) is one of the possible behaviours and is based on conditions 1. and 2. If such conditions are false at step i-th (one or both) this does not necessarily imply that coalition formation stops or that coalition collapses and dissolves. This is mainly due to the fact that the reasons for coalition formation and upkeep are both exogenous and endogenous to the coalition itself.
The main exogenous reason is the environmental problem that convinced the initial set of players to join in M^0 and whose continuing presence and pressure may be a sufficient reason for coalition survival and extension in other

[24]There are significant exceptions to this rule of thumb. The main exceptions are those regarding global environmental problems (*GEP*s) whose solution gives benefits to all the members (and non members too) of a coalition whereas costs may be lower the greater is a coalition. In these cases it may be sufficient for the players to minimize the cost shares and, as a side effect, maximize the benefit shares. In the agreements for the solution *GEP*s however players tend to fix individual effort levels and try to minimize their costs shares given such levels.

[25]Incumbents are the players that belong to a coalition whereas applicants are those who ask for or are asked for joining a coalition.

directions (i. e. with other players). Other exogenous reasons may be the legitimation of supporters and the actions of the singletons.
The main endogenous reason is that at least up to a certain coalition dimension conditions 1. and 2. above are satisfied and that that dimension is generally a downward stability point of the coalition. With this we mean that the non adhesion or the withdrawal of one player leaves the coalition in a state where such conditions are satisfied. That state is termed downward stable since we do not want to prevent the possibility that the coalition can grow up with the adhesion of other players but only that a small shrinking of a coalition is sufficient for its fall.
There is really no termination condition but the stable solution of the coalescing problem so that, even if the grand coalition M_G forms, this is not the end of the story. As we have already noted, it can happen that the perception of the problem slacken so that some players abandon M_G that shrinks to a smaller coalition. But their abandonments can cause a worsening of the problem and this may be enough to convince some of those players to re-join the coalition. This can obviously occur at any stage of coalition formation and can depend also from the interactions among coalition members and singletons (see the $NCGT$ phase of the pseudo-code we gave in section 3). In this way we cover the first two situations we described in section 3. We note that hardly ever M_G exists from the very beginning and that the starting point is almost always a coalition $M^0 \subset M_G$.
Things become more complex in presence of two competing coalitions M_1 and M_2 that embody two [radically] distinct ways to define, face and solve an environmental problem[26] and a set of singletons that form the set $N \setminus (M_1 \cup M_2)$. In this case the following cases can occur:

1. one coalition forms before the other, both in a reactive way,

2. both coalitions form at the same time in a proactive way.

In the first case without loss of generality we can suppose that coalition M_1^0 forms as a reaction to P and that, as a reaction to M_1^0, coalition M_2^0 forms after a more or less short lapse of time[27]. At set level we have the following succession of events:

1. in the initial state we have n singletons,

2. M_1^0 forms with m_1^0 members and $n - m_1^0$ singletons,

[26] For instance in the case of solid waste treatment those who are in favour of incinerators versus those who are in favour of dumps.

[27] Time parameter is really not meaningful since we are in an event driven world so what is important for us is which event occurs but not the very instant when it occurs.

3. when M_2^0 forms it can get its members either among the singletons or among the members of M_1^0 or among both.

Independently from how and where the second coalition recruits its members, at "time" 0 we have the two coalitions (M_1^0 and M_2^0) and a residual set of singletons $\{\{i\}|i \in N \setminus (M_1^0 \cup M_2^0)\}$.
In the second case as a reaction to a problem P two coalitions form (M_1^0 and M_2^0), each as an opponent/competitor of the other. In many cases each coalition tries to recruit the most of the singletons (so to gain weight with respect to the other) compatibly with maximizing individual benefits and minimizing individual costs and the inertia/resistance of the singletons.
Again at "time" 0 we have the two coalitions (M_1^0 and M_2^0) and a residual set of singletons $\{\{i\}|i \in N \setminus (M_1^0 \cup M_2^0)\}$.
In the next section we examine how a coalition can behave to reach optimal stable conditions or conditions in which it is dynamically stable with optimal benefits and costs.

5.2 The behavioural possibilities of a coalition

At this point we are going to examine only the following situations:

1. a single coalition M with m players and $n - m$ singletons that can evolve up to the grand coalition;

2. a pair of coalitions M_1 (with m_1 players), M_2 (with m_2 players) and $n - m_1 - m_2$ singletons.

In the latter case it may happen that one of the two coalitions either collapses in a set of singletons or joins to the other: in both cases we fall in the former case.
In both cases we are interested in interactions among coalitions and within coalitions. Such interactions (see the pseudo-code of section 3) occur at distinct stages and can be described with distinct tools (that is either $NCGT$ or CGT).
The basic consideration is that joining or belonging to a coalition has some costs but must give some benefits so that players wish to join or stay in. In each $NCGT$ phase players try to get their best payoff, depending on the strategies of the others, and (in each CGT phase) share it among the members of non singleton coalitions. Such dynamics of gaining and sharing can either attract new members in a coalition or convince the incumbents to remain incumbents or to leave a coalition and act either as a singleton or join the other coalition, if it is present.

The two situations we have listed above however are not equivalent since the presence of a second coalition introduces strategic interactions that are absent in the case of only one coalition.
In the first situation the incumbents are interested in widening the coalition M so to share costs and efforts among a wider number of players without dilute too much benefits. Applicants, on the other side, may agree to join in exchange for side payments. Such side payments may be in the form of technological transfers or monetary aids or trade benefits and the like.
In this case, coalition M ([Lav05]) can try to act either as an **aggregator** or as a **sticker**. In the former case M adapt its policy so to try to meet at the most the demands of the singletons and convince them to join the coalition. In this case there are more rewards that sanctions and in kind transfers and side payments can be used. In the latter case M never changes its policy and uses mainly sanctions[28] against singletons to force their adhesion. We note how a sticker attitude may favour the forming of a competing coalition that can act both as a predator or an aggregator.
If two coalitions are present we can face essentially two cases:

1. they are of comparable sizes,
2. one is bigger that the other.

In the former case both ([Lav05]) can act as aggregators but also as **hunters**. Acting as a hunter a coalition, following an unsatisfactory outcome, changes its policy (for instance from co-operative to non co-operative) before engaging in a new strategic interaction. In this way a match[29] losing coalition tries to mimic the behaviour of the other so to attract, at least, some singletons.
In the latter case the bigger coalitions can again act either as an aggregator or an an hunter but the smaller may be better off by behaving ([Lav05]) as a **predator**. Acting as a predator a coalition tries to mimics the other by adopting its rewards scheme without adopting its penalties/sanctions scheme (or adopting a lighter version of it). In this way the smaller coalition tries both to attract singletons and convince incumbents of the bigger coalition to abandon it.

5.3 Practical cases of environmental coalitions

One of the most quoted applications of *CGT* and coalitions dynamics, at least in a recent past, is **Kyoto Protocol** (see for instance [Fin00], [FR01]

[28]Such sanctions ([TLvdZ00]) can range from denying another player the access to some technologies to withholding some other player's technologies.

[29]We use this term to denote a single repetition of a *NCGT* phase of our repeatedly quoted pseudo-code.

and [CMO03]). Kyoto Protocol ([Wik07]) is characterized by a set of subscribers that form a main coalition M_{KP}. Such a coalition is however not flat since within it we can detect at least two subcoalitions, one of the so called developed countries and another of the so called developing countries. Within the first subcoalition it is possible to find clusters of countries joined to form the so called "bubbles" but also subcoalitions of local governments. It is easy to see how the whole structure is complex and dynamic. The inner functioning of the coalition is based on the global target of the reduction of the overall emissions of six greenhouse gases[30] with a timing and obligations, penalties and possibilities of trading among members. Currently the main coalition gathers 172 countries and other governmental entities (such as states, regions and cities) but 132 of them have ratified the protocol without having no obligation beyond monitoring and reporting emissions ([Wik07]). Stability of M_{KP} depends mainly on the trading of emissions among its members and technology transfers between developed and developing countries. Beyond this coalition there are at least two other coalitions:

1. **Regional Greenhouse Gas Initiative**, M_{RGGI};
2. **Asia Pacific Partnership on Clean Development and Climate**, M_{CDC}.

The former ([Wik07]) involves eight north-eastern US states that act outside Kyoto Protocol to reduce and trade emission levels and exert pressure on US Federal Government. The latter involves six Asia-Pacific nations (Australia, China, India, Japan, South Chorea and United States) and has the goal of reducing greenhouse gases emissions without any enforcement mechanisms. The three coalitions interaction level is low so that they can behave as each was the only coalition present. Members of M_{KP} are indeed planning meeting and strategies for new and better agreements though there have been pressures from M_{CDC} to induce some country (for instance Russia), during the ratification phase, not to sign the Kyoto Protocol so to prevent its coming into force. This stability is mainly due to political reasons that goes beyond the methods of CGT and $NCGT$. In the case we can only note how M_{CDC} tends to act as a predator whereas M_{KP} as an attractor (owing to the presence of a threshold level below which the protocol loses any effect).
Other examples of coalitions at the international scale ([FR01]) are those associated to the **Oslo Protocol** or to the **Montreal Protocol**. In all these cases the main feature is the lack of any supranational authority that can

[30] They are: carbon dioxide, methane, nitrous oxide, sulphur hexafluoride, HFCs and PFCs.

force the adhesion or the compliance of the treaties that, therefore, must be self-enforcingly designed so to minimize both inner and outer free-riding.
Within our framework we are interested also at the formation of coalitions on small scale problems. In the closing part of this section we therefore give some hints about two such problems. Both are local problems with medium or small space scope and from medium to long time scope. The problems[31] are:

1. the **Val di Susa** affair;
2. the **incinerator of San Donnino** affair.

The former case (case A) concerns the solution of a transportation problem between two points at a medium distance (between 300 and 500 km) through a site already heavily charged of infrastructures of various types and with a harsh topography.
The latter case (case B) concerns the solution of a solid waste treatment problem in an area cluttered of small or medium settlements at small distances one from the others with heavily polluting industrial areas and big infrastructures (airports, highways and railway lines).

1. Case A.
   In this case[32] at a high political level (maybe involving relations between bordering nations) a transportation problem P is identified and time and financial constraints are fixed[33]. At this point a coalition M_1^0 may form that proposes a solution S_1^0 and gathers a set of supporters so to gain a more or less wide legitimation. As a reaction another coalition M_2^0 forms whereas there are a set of seemingly neutral singletons that stay waiting to see which coalition will prevail on the other. Also the new coalition has its supporters and has a certain level of legitimation. The main difference between the two coalitions is that M_1^0 has a core of members at high institutional and industrial levels and its supporters are spread over a wider area than the one on which insists S_1^0 whereas M_2^0 has a core of members at low institutional and industrial levels and its supporters are concentrated in the area on which insists S_1^0.

[31] We use also the terms affair or case.

[32] We are purposely depicting an idealized scenario since it is not in the scope of this paper to examine real Italian courses of events. We moreover disregard the timings of the decision processes as well as the institutional levels of jurisdiction and the necessary steps proposed solutions must pass through before they can reach any deliberative phase. In practice we are in the full realm of toy models.

[33] This problem may be inserted in wider plans or not. What is important is that the problem has got through the stage of hypothesis so that it can claim for a solution.

Of course neither of the coalitions has a flat structure. Moreover coalition M_2^0 focus point is the opposition to S_1^0 but within it we usually can find at least two subcoalitions each favouring an alternative solution when not the preservation of the status quo.
In this case[34] M_1^i can adopt a plain strategy of **aggregator** ([Lav05]) or the more aggressive strategy of **hunter** ([Lav05]) so to continuously change strategy so to upset the other coalition.
On the other hand if M_2^i stays on the defensive by only saying "no" (behaving like **sticker**) it can easily lose members and legitimation so its best strategy is to act ([Lav05]) as a **predator** until when it gains sufficient weight to switch to an **aggregator** with a valid alternative solution S_2^i.
Of course this dynamics must end, before or later, and this can occur in three ways:

(a) the status quo prevails,

(b) it is adopted the possibly refined and modified solution S_1^i,

(c) it is adopted the possibly refined and modified solution S_2^i.

2. Case B.
In this case the situation may be somewhat different since the problem is well known and evident from its effects on the territory so that the two opposing coalitions M_1^0 (in favour of an incinerator S_1^0) and M_2^0 (in favour of a dump and a parallel differentiated garbage collection S_2^0) raise almost at the same time. In this case both coalitions try to gather members at higher institutional levels and gain both local and wide legitimation (see they both behave mainly as attractors). The evolution is quite similar to the preceding but for the pressure of the problem that grows with time and, reaching an emergency level, can force the adoption of a solution that can be that favoured by the losing coalition (since the final decision is taken elsewhere).

6 The interaction continuum

In the last sections of the paper we try to frame what we have said so far within the approaches of $NCGT$ and CGT. The basic idea is the definition, following [For97], of a continuum of interaction types among players.
For modelling purposes we define two ends: at one end we have independence

[34] We use the apex i to denote that coalitions vary in size and composition and that solutions evolve and are modified as time passes.

among players whereas at the other end we have the formation of coalitions. All this is showed by the following scheme:

$$independence \rightarrow cooperation \rightarrow coordination \rightarrow collaboration \rightarrow coalition \quad (6)$$

In this way we can associate the first three cases to $NCGT$ and the last two to CGT. This should be seen as a dynamic classification in a context where players are engaged in multi stage (repeated) games. Contrary to what happens usually in Game Theory ([Mye91] and [Pat06]) we can have four types of repeated games[35]:

1. repetition of the same game form or of the same game without having specified preferences for the strategies (i. e. the payoffs of the players);
2. repetition of the same game;
3. repetition of distinct game forms;
4. repetition of distinct games.

We note that players are either coalitions or singletons that stay in the $NCGT$ portion during the **coalition_interaction** phase and in the CGT portion during the **coalition_dynamics** phase. Moreover players when in the interaction phase suffer from bounded rationality so that they hardly ever can succeed in maximizing a form of expected utility but more often mainly react to past attitudes of the other players. Similar considerations hold also whenever players are in the dynamic phase where they should share the gain of any coalition among its members. In these cases they hardly ever are able to use classic solution concepts (such as the core, the stable sets or the Shapley value) but tend too distribute such gain under the blackmail of the more unstable or empowered members of a coalition.

7 The left side of the continuum: non cooperative approaches

As we have seen $NCGT$ can be used, in our framework, either to describe the initial interactions among singletons or the successive interactions among a coalition and the remaining singletons or between two coalitions and the remaining singletons.

[35]The difference is that in case of game forms payoffs must be specified case by case whereas for games payoffs are specified once for all.

Such interactions can be characterized by variable degrees of consent. At the lowest degree we have pure **independence** among the players that act according their own strategies so to maximize their expected utility (or minimizing their cost in case of a cost game). In this case, solutions of a game are represented by Nash Equilibria (NE, [Mye91] and [Ray00]) and their refinements (perfect, proper and sub game perfect). NE represent strategy profiles of the players and are such that no player has an incentive to deviate unilaterally from these profiles. Given a game we have no guarantee that it has an unique NE (in pure or mixed strategies). Traditionally this has been seen as a pitfall and has represented a strong incentive for the refinement of such kind of equilibrium. This is not necessarily so, at least within the framework of repeated games we sketched in section 6. The lack of unicity within single stage games may give to the players a bargaining space that allows the obtaining of more fair distributions of utilities on the long run. This can be seen even in a typical two players battle of the sexes game where the presence of three NE (two pure NE and one mixed) can allow, with more repetitions, a more fair distribution of the gains among the players. This is true also in other elementary games where the multiplicity of NE, in presence of even a limited amount of communications among the players, allows the attainment of better solutions.
Though in a $NCGT$ approach players cannot sign binding agreements and form coalitions they can ([Mye91] and [Ray00]) behave less selfishly so to either **cooperate** or **coordinate**. In the former case they can attain a cooperation through **correlated equilibria** whereas in the latter they can coordinate through **coalition proof correlated equilibria**.
To get better outcomes even in cases of social traps (like the one that occurs in Prisoner's Dilemma game) players ([Mye91]) can communicate and coordinate their moves with or without agreements. Classical theory gives the following possibilities for the players:

1. coordinate their strategies with the help of a mediator or of an arbitrator;

2. coordinate their strategies with a common randomizing device (such as a coin toss or a dice cast).

In the former case it is necessary to modify the structure of the strategic form of the game whereas in the latter case of **correlated strategies** such a structure remains unchanged but a common probability distribution over any possible combination of pure strategies of the players is introduced. Correlated strategies are obviously associated to **correlated equilibria** that allow the players to attain better outcomes than acting according to classical NE.

If we extend such solution concept to subsets S of N (the so called coalitions) we can speak of **coalition proof correlated equilibria** ([Ray00]).
What is important is to understand the applicability of these theoretical tools to practical cases of environmental problems where, in many cases, authoritative entities lack, controls are hard to exert and the same holds also for penalties.
Since these solution concepts lack of a full normative power (since real players in real rewarded interactions do not fully obey the predictions of the theory, [Rap89]) we can only use them to describe real interactions where players give up from using dominating strategies (whenever they exist) and prefer to adopt strategies that allow each player to attain the social optimum.
This can be seen in classic Prisoner's Dilemma game (where a dominant strategy exists) as well as in other games where such dominating strategies are absent but where (even as a consequence of a somewhat blind repetitions structure) players prefer to adopt cooperative strategies.

8 The right side of the continuum: co-operative approaches

The co-operative approaches can be dealt with from a somewhat distinct perspective that than of the non co-operative approach. In this case, indeed, players can sign binding or enforceable agreements ([Rap89]) so to form coalitions. Even in presence of coalitions, however, players can behave according to two distinct paradigms: within a NTU game and within a TU game.
In the former case we have **collaboration** since players act within a coalition but a coalition attains a vector of gains whose single elements are due to the single members of the coalition. In this paper we do not examine this case any longer since we believe it is not well suited to describe the formation of coalitions within environmental problems.
In the latter case we really speak of **coalitions** since, for instance, the grand coalition N forms, gets a value $v(N)$ and shares that value among its members according to one of the available rules such as the **stable set** or the **core** or the **Shapley value**. The first two solutions again may "suffer" the "problem" of non unicity (what is worse is that the core may be empty): in such cases there is again a bargaining space among the players and such a bargaining space is an added value to the game, mainly in the case of repeated games we saw in section 6.
On the other hand the Shapley value gives always a univocal allocation of $v(N)$ among the members of the grand coalition N. In this case we can have,

at least theoretically, problems when the core is empty since this means that the allocation among the members of N is not stable and there are players $i \in N$ that can do better by leaving N and forming a coalition S.
All this theoretic apparatus is confusing in our cases where games we deal with are rarely super additive[36] so that what we need is the ability of describing coalitions smaller that N and understand how they share their value $v(S)$ among their members.
The lack of super additivity can be easily understood by looking at the cases we have introduced in section 5.3. If we have two opposing disjoint coalitions M_1 and M_2 it is usually not possible that $v(M_1 \cup M_2) \geq v(M_1) + v(M_2)$.
As to the smaller coalitions we can try, for instance, to scale down the definition of the core itself so to get:

$$core(v, S) = \{(x_i)_{i \in S}\ \Sigma_{i \in S} x_i = v(S)\ and\ \Sigma_{i \in S'} x_i \geq v(S')\ \forall S' \subseteq S\} \qquad (7)$$

for a given $S \subset N$ with $|S| > 1$. In this way any coalition can have a core and such a value has a role in the dynamics between coalitions. Similar considerations hold also for a solution concept such as Shapley value that we want to extend so to be applied to smaller coalitions that the grand coalition.
Beyond these theoretical extensions and refinements we are interested in understanding (and describing) how we can characterize coalitions as active entities that, in a certain sense, can create their own value $v(S)$ and then decide how to share it among their members.
This allows us to give different meanings to the concepts of internal and external stability and to better characterize coalitions dynamics.

9 Concluding remarks and future plans

The present paper presented an informal and partial examination of the dynamics of coalitions that form under the pressure of environmental problems. We tried to present a somewhat "heretical" approach, very far from that of classical *NCGT* and *CGT*, and based on the assumption of blind multiple repetitions of even different game forms with players endowed with minimal capabilities. Obviously this is a somewhat project paper since most of the issues we presented here urge deepest analysis and formalization. We only laid out the pathway with a small set of milestones to mark the route. Forthcoming papers will provide to fill up the details and paint accurately the whole drawing.

[36] A *TU* game is super additive if for each $S, T \subset N$ with $S \cap T = \emptyset$ we have $v(S \cup T) \geq v(S) + v(T)$ so that the best coalition that can form is the grand coalition N.

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