Environmental Agreement and Coalitional Games: Alternative Theoretical Methods

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Abstract

In this paper we investigate how the cooperation for an efficient international environmental agreement can be encouraged. Until now all the types of the Environmental Treaties have been based on multilateral agreements easily formalized using classic contract theory models that emphasize the role of the compatibility with simple incentives for each countries. Assuming the superadditivity in the coalition we know that once the coalition has formed the cooperation within that coalition is unrestricted. Introducing the externality schemes and convexity we show how the grand coalition is efficient.

1 Introduction

The environmental regulation represents a fundamental tool able to reduce the pollution and the climate changes. It is well known that the Kyoto Protocol was signed in the 1997 but did not become effective until 2005. All the Countries that ratified it committed themselves to reduce their emission before the end of 2012. The average target was to decrease the emission of 5% respect to level of 1990. In spite of this environmental agreement the CO_2 emissions are still growing, there are many reasons behind this result and after the deadline of the 2012 there is no new unanimous environmental agreement. The Achilles heel of Kyoto Protocol was mainly the lacking ratification of the agreement from the USA and the decision to not apply any kind of restriction to some developing countries as China and India. This two situations determine a delay in the concrete implementation of the agreement since there were necessary at least two conditions in order to enter into force it. The first condition was that at least 55 nations should be ratified the agreement and the second fundamental condition was that these countries should be those who produced the 55% of the total world carbon emissions. These conditions became real only in the 2004 when the Russia ratified the agreement. In the 2011 Canada decide to exit from the agreement and actually several countries have signed a new agreement but they correspond only to the 15% of the world greenhouse gas emissions. It is our intention to underline that there can be others reasons that can have influenced negatively the implementation of the Kyoto agreement. Mainly we stress that the three mechanisms who constitute the Kyoto Protocol can be change in order to reinforce the working principle of the international agreement. Basically there are three mechanisms that operate on the aim to support the developed countries to attain their Kyoto emission reduction targets by lowering the costs of reduction. In that way the designer of agreement have tried to make more convenient the subscription of the agreement for the developed countries. This framework it seems to be a typical contract theory model with incentives able to induce the agents to respect their commitment. The three instrument are the following: the Emission trading, the Join Implementation and the Clean Development Mechanism. The first mechanism is the most used instrument by the developed countries. In our opinion is a mechanism that make inefficient the Kyoto Agreement. The mechanism works in the following way: for every country involved in the agreement there is a definite amount of emissions units, this is the target of emissions accepted from the country when it has ratified the Kyoto Protocol. In case the country reaches a level of emissions lower than the target fixed by Kyoto Agreement it can trade the excess emissions units in the form of licences to another country that has not successfully attained its assigned target. In that way each country can remedy the unsuccessful performance in the emissions reduction buying the licences in order to reduce the gap between its own emission reduction assigned target and its real emissions level. The licenses are sold to the highest bidder on the international market. As is clear this kind of mechanism determines two types of inefficiency: in case of big amount of emissions units on the market the price is very low respect to the real “punishment cost”that have to suffer the country that damages the environment more than the others; secondly this possibility becomes an incentive to purchase emissions units instead to make investment to reduce the emissions of the country. The second mechanism is named Joint Implementation, using this mechanism a developed country can financing and executing a reducing emissions project in another developed country on the aim to credit the resulting emissions reductions as reduction units of its emissions target, on the other hand the beneficiary country cannot obtain any reduction units. Also in that mechanism it is totally cancelled the possibility of joint project excluding from beginning technologies exchanges and the possibility to perform project characterized by economies of scale and of the scope. The third mechanism is so-called Clean Development Mechanism differently from the Joint Implementation Mechanism the developed countries can finance and carry out reducing emission project in a developing country without a reduction commitment, in that way the developed country can earn emissions reductions units. This mechanism try to reduce the CO_2 and at same time to assist the developing countries transferring technologies able to make these countries less harmful to the environment. Unfortunately in that case mainly the developing countries has no incentives to be available to joint project given that they have no commitment to reduce their emissions. It comes to light that each country has an own aim that not necessarily corresponds to the target determined by the international environmental agreement. As we have described before, the Kyoto Mechanism have tried to determine incentives for each countries but sometimes an international agreement with incentive compatible mechanism can be inefficient in case there can be the possibility to deviate. In this paper we develop a model using a cooperative game theory approach on the aim to propose an alternative mechanism to build up a new kind of international environmental agreement that can substitute the Kyoto Protocol improving the results reached until the 2012.

The paper is organized in the following way: in the next section we describe the literature on the construction of efficient international environmental agreements; in the third section we present a model of NTU cooperative game in partition function form; in the forth section we introduce externality schemes and in the section 6 we show the results.

2 Literature

The formation of international environmental agreements it has been initially formalized using a classic contract theory models that emphasize the role of the compatibility with incentives for each countries on the aim to determine a stable and efficient agreement able to reduce the greenhouse emissions. In case of treaty based on the contract theory approach it is very important to consider the existence of huge negotiating costs mainly because it is difficult for many agents to reach a mutually satisfactory agreement, in addition it is necessary to take into account the costs of monitoring the agreement (Barrett, 1990). It has been utilized non cooperative games theory in order to design a self-enforcement agreement, more in details comparing two different approaches it has been showed that self-enforcing international environmental agreements, which establish rules for managing shared environmental resources, may not be able to improve substantially upon the no cooperative outcome (Barrett, 1994). It is also considered that the structure of some interactions imply that the full cooperative and non-cooperative outcomes are not very far apart (Barrett, 1997), but also in this assertion the notion of cooperation is related to the outcomes of the game theoretic model not to the structure of it. From the same perspective it has been demonstrated that using a linear version of the N-player prisoner's dilemma game it is possible to provide a formal proof of Olson's conjecture that only a 'small'number of countries can sustain full cooperation by means of a self-enforcing agreement (Barrett, 1999). Lastly it has become clear that the global and international dimension of the environmental problems requires multiple and heterogeneous methods of analysis appropriate to the several implications of the environmental policies (Carraro and Siniscalco, 2009). The problems related to the greenhouse emissions can be also be engaged considering that environmental externalities are international, multilateral and embody public good characteristics. In this circumstance the game-theoretic core concept provides optimal outcomes that have interesting properties against free riding (Chander and Tulkens, 1997 and 1995). Finus gives an overall view of the literature which has approached the problem of international pollution control from a game theoretical perspective (Finus, 2001). Actually the open question strictly connected with the regulation of the greenhouse emission is which kind of agreement can be reached after that Kyoto Protocol is expired. Also the international coordination on climate policies is a crucial point in order to make efficient the feasible greenhouse emission regulation (Finus et al., 2013). In spite of everything agreements based on individual incentive compatible the mechanisms could be subject to failures when there are coalitional incentive to deviate as a group. Thus it can be interesting investigate how the cooperation for an efficient international environmental agreement can be encouraged. In this viewpoint it is analysed the stability of self-enforcing climate agreements, considering a sequential coalition formation process of heterogeneous and farsighted players (Finus et al., 2014).

3 Preliminaries and technical assumptions

Two or more countries are considered to form a coalition if they sign a multilateral environmental agreement.

Three types of coalition scenarios may result. If all parties concerned sign the agreement the situation is denoted as full cooperation, and a grand coalition is said to be formed. If some countries stay outside the agreement the situation is denoted as partial cooperation and outsiders may act as free riders. Finally, in the case of non cooperation there are no agreements between the countries, and each is only interested in maximizing individual utility. In our framework NTU game is appropriate for all international issues. Based on the three possible outcomes described above we defined a coalition structure to be a partition. This means that each individual writes agreements with the coalition to which he belongs. If he does not write any agreements, he forms a singleton coalition, which is certainly allowed for by the partitional restriction. What is not allowed for is the possibility that coalitions may overlap, so that some individuals write two (or more) different agreements with different groups. We will assume superadditivity in coalition, that is once a coalition has formed, cooperation within that coalition is unrestricted. Moreover, we will introduce externalities. With externalities, the group must also attempt to predict he coalition structure that arises elsewhere. Externalities are present, if there is at least a merger of coalitions that changes the payoff of a player belonging to a coalition not involved in the merger. If the merger increases (decreases) the payoff of the player, the externality is considered as positive (negative).

3.1 The model

Let $N = \{1, ..., n\}$ be a finite the set of players. A coalition is a nonempty subset of N, generically denoted by S or T.

Let $\Pi(N)$ be the set of all partitions of N. For any partition $\pi \in \Pi(N)$, let $\pi(i)$ denote the (unique) block of π that contains player i. A partition is a collection $\pi = \left\{S^1, S^2, ..., S^m\right\}$ of coalitions such that $S^k \bigcap S^j = \emptyset$ for all $k \neq j$ and $\bigcup_{k=1}^m S^k = N$. An embedded coalition is a pair (S, π) such that $S \in P(N) \cup \{\emptyset\}$, where $P(N)$ is the set of nonempty subsets of N, $\pi \in \Pi(N)$ and $S \in \pi$ (by convention, $\emptyset \in \pi$ for any $\pi \in \Pi(N)$). The set of all embedded coalitions is $\mathcal{C}(N)$. Let $\Pi_S(N)$ be the set of partitions containing coalition S.

The choices that a coalition C can make may depend on the coalition structure formed by the players in $N \setminus C$. Such scenarios are modeled by partition function games for NTU.

Definition 1 *A partition function game is a map V which assigns to each embedded coalition (S, π) a nonempty, closed, convex subset $V(S, \pi) \subseteq \Re^S$ such that*

1. *$V(S, \pi)$ is comprehensive: that is, for $x \in V(S, \pi)$ and $y \leq x$ we have $y \in V(S, \pi)$,*
2. *the set $\{x \in V(S, \pi) : x \geq x*\}$ is bounded for each $x \in V(S, \pi)$.*

Feasibility takes into account not only the coalition but also the rest of the society choices.

Definition 2 *Given a Partition Function Game,* (N, π)*, a feasible allocation is a vector* $x = (x_1, x_1, ..., x_n)$ *such that* $x \in V(N, N)$*. For any embedded coalition* (S, π)*, if* $x \in V(S, \pi)$ *we say that* x *is feasible for* (S, π)*. We call a game non-levelled if for all* (S, π) *and all* $x \in \partial V(S, \pi)$ *we have* $y > x$ *only if* $y \notin V(S, \pi)$*.*

Individual rationality (IR) requires every cooperating agent to be able to gain no less than the utility that he can obtain by not cooperating. That is, no agent is to be worse off by cooperating, than not cooperating and forming its own singleton coalition.

Definition 3 *An allocation* $x \in V(N, N)$ *is Individually Rational,* ***IR****, if and only if for every* $i \in N$ *and for all* $\pi \in \Pi$

$$x >_i y$$

for every $y \in V(\{i\}, \pi)$*.*

As pointed out by Barrett, an IEA needs also *Collective Rationality* (CR). With this assumption negotiation become a collective action and requires that it not be possible for agents to gain collectively by changing their treaty. The treat must be credible, countries can decide their strategy in order to construct the treaty incorporating different instruments, such as technology standards or emission limits, or minimum participation clause, financial transfer, etc. That is, no countries have an incentive to renegotiate the agreement.

Collective Rationality contracts the set of feasible outcomes that can be sustained by a self-enforcing treaty. The possibility of renegotiation makes cooperation harder to strengthen.

Collective Rationality is a property of a treaty implying not only efficiency for the group of signatories, but also free riding deterrence. Collective Rationality has two important implications: first, when countries decide to sign an agreement, there cannot exist an alternative, feasible agreement that all countries prefer; second, the agreement cannot be renegotiate when a country decide to deviate. In our framework, we define CR after introducing Externalities schemes, in order to capture the group effect.

Imputations and blocking embedded coalition can be defined unambiguously as follows.

Definition 4 *An imputation of the partition function game* V *is a vector* $(x_1, ..., x_n)$ *such that* $x \in V(N, N)$ *and* x *is individually rational. An embedded coalition* (S, π) *blocks an imputation* x *if there exists* $x' = (x_i)_{i \in S}$ *such that* $x' \in V(S, \pi)$ *and* $x' \gg_S x$*.*

In cooperative games, the core describes usually the set of imputations that cannot be blocked by any coalition S. In partition function games such a definition is not precise enough as one needs to account for the expectations of the blocking coalition with respect to the partition that possibly forms. Hence in that context a natural definition of the core is merely unseizable. Chandler and Tulkens 2005 define a new core concept for International Environmental Agreement in a TU game setting, the γ-core . The γ-core consists of all allocations that specify:

- a profile emissions for each party, that are Pareto efficient at the world level;
- transfers amongst the parties.

The resulting set of core allocations is that any individual or group of parties considers deviating from it, the best it can do is less attractive than what it gets in the allocation.

The core allocations in our NTU game, will specify also a profile emissions for each party, taking into account not only Pareto efficiency, but also Individuay and Collective Rationality without any transfers.

Definition 5 *The core of a partition function game* (V, N) *is the set of imputations* x *that cannot be blocked by any embedded coalition* (S, π)*.*

We denote the core of the game (V, N) by C.

In words the above definition states that there is no coalition S with expectations π that can enforce payoffs $(y_1, ..., y_S)$ such that $y_i > x_i$, $i \in S$, and $y \in V(S, \pi)$. Note that the definition can be viewed as too restrictive since it requires no restriction on the possible embedded coalitions that possibly block an imputation.

Definition 6 *The mapping* V *is superadditive if for any* $S, T \subseteq N$ *and* $S \cap T = \emptyset$*, and any partition* π *of* $N \setminus (S \cup T)$*,* $V(S, \pi) \times V(T, \pi) \subseteq V(S \cup T, \pi)$*.*

In a game in PFF, superadditivity could be not enough for efficiency of the grand coalition (Hafalir **??**).

Convexity assumption, as introduced first by Shapley [**?**], captures a natural group effect:

Definition 7 *A characteristic function game is said to be convex if for any* $S, T \subset N$*, it holds that* $V(S \cup T) \times V(S \cap T) \supseteq V(S) \times V(T)$*.*

In words, the convexity property arises if the game displays increasing returns to scale in cooperation. Convex games satisfy interesting properties as one studies how the gains from cooperation are shared between players. Among others it holds that any convex game admits a nonempty core.

4 Externality schemes

A key point in the analysis of partition function games rely on the understanding of expectations on complementary coalitions as a new group of players forms. In the next definition, we capture the externality effect as presumed by coalition S given a state π that stems for the current distribution of groups.

Definition 8 *An externality scheme is a mapping* $f : P(N) \times \Pi(N) \to \Pi(N)$ *such that* $(S, f(S, \pi)) \in \mathcal{C}(N)$*.*

The partition $f(S)$ describes the externality effect as the coalitions S forms in the state π, or equivalently the expectations of the group S on the partition which results from the merge of these players as the state is π. We denote the set of externality schemes by $\mathsf{Ex}(N)$.

We will make use of the following general definition of core concept to go over the classical concepts of the literature.

Definition 9 *Given an externality scheme* $f \in \mathsf{Ex}(N)$*, the core with respect to scheme* f *(*f*-core for short) is the set of imputations* x *such that* $x \in V(S, f(S, \pi))$ *for each* $S \subset N$ *and each state* $\pi \in \Pi(N)$*.*

We denote the core with respect to f by $\mathsf{C}(f)$.

Note that the intrinsic interpretation of the concept does not differ from the one introduced in Definition 5 but one explicitly restricts the possibly blocking embedded coalitions through a fixed scheme f. To make precisely the link with Definition 5: the f-core of a partition function game (V, N) is the set of all feasible imputations x for each embedded coalition $(S, \pi) \in \mathcal{C}^f(N) := \{(S', f(S', \pi') \mid S' \subset N,\ \pi' \in \Pi(N)\}$.

With respect to convexity we introduce the following general definition.

Definition 10 *A game is convex with respect to the externality scheme* $f \in \mathsf{Ex}(N)$ *if for any* $S_1, S_2 \subset N$ *and every state* $\pi \in \Pi(N)$*:*

$$V(S_1 \cup S_2, f(S_1 \cup S_2, \pi)) \times V(S_1 \cap S_2, f(S_1 \cap S_2, \pi)) \supseteq V(S_1, f(S_1, \pi)) \times V(S_2, f(S_2, \pi))$$

A convex game with respect to f is said to be f-convex. In other words, the partition function game is f-convex if the induced characteristic form game with respect to f is convex.

Definition 11 *An allocation* $x \in V(S, f(S, \pi))$ *exhibit the Collective Ratinality (CR) property respect to the externality scheme* $f \in \mathsf{Ex}(N)$ *if there not exists an allocation* $y \in V(S \setminus \{i\}, f(S \setminus \{i\}, \pi))$ *such that, for all* $j \in S \setminus \{i\}$*,* $y >_j x$*.*

5 Results

Efficiency for a group of countries (S or N) is a joint policy of memebers of the group that maximizes the group's aggregate welfare W, in such manner. In an economic sense, because the public good is global, as in Samuelson 1954, efficiency can be reached only if all countries are involved in the process of resource allocation required to manage the externality. In that sense, efficiency has then necessity of cooperation. Moreover, an IEA may be viewed as outcomes of voluntary negotiations between generators and recipients of externalities (Coase 1961), that determines at an efficient outcome under appropriate conditions.

In this paper we show that efficiency can be obtained for the grand coalition:

Proposition 1 *Let f be a single externality scheme and consider any partition function game. Then the following assertions are equivalent:*

1. *the game is a f-convex game;*
2. *the game satisfies f-increasing returns with respect to the coalition size;*
3. *the core with respect to f is nonempty;*
4. *the core allocations exhibit Collective Rationality property.*

Proposition 2 *If a partition function game is f-convex, then for any partition $\pi \in \Pi(N)$,*

$$V(N, \{N\}) \supseteq \chi_{S \in \pi} V(S, \pi)$$

We show that convexity and positive externalities imply efficiency of the grand coalition. In other words, convexity implies that a coalition can achieve at least as much as what its part can achieve.

6 Conclusions

The IEA based on cooperation can be more efficient respect to the agreements founded on individual incentive compatible mechanism. The second type of agreement can be easily exposed to deviations. We show how can be plausible to build a cooperative mechanism to encourage an efficient IEA. Using a NTU game we describe a coalition structure to be a partition. The coalition has other characteristics as the superaddivity and the absence of the restriction for the possibility to cooperate within the coalition. In that context we introduce the externalities indicating how the externality effects generate the formation of a new or big group of players that cooperate to protect the environment. After this step we point out that the efficiency can be obtained for the grand coalition.

6.1 Example - Positive Ext. and Collective Rationality

Consider the followings symmetric 3-player PFG:

$N = \{1, 2, 3\}$

Coalition	Payoff
$\{123\}$	$V(\{123\}, N) = \{x^{\{123\}} \in \Re^{\{N\}} \| x^1 + x^2 + x^3 \leq 14\}$
$\{\{ij\}, \{k\}\}$	$V(\{ij\}, \pi = \{\{ij\}, \{k\}\}) = \{x^{\{ij\}} \in \Re^{\{ij\}} \| x^i + x^j \leq 9\}$
	$V(\{k\}, \pi = \{\{ij\}, \{k\}\}) = \{x^{\{k\}} \in \Re^{\{k\}} \| x^k \leq 1\}$
$\{\{1\}, \{2\}, \{3\}\}$	$V(\{i\}, \pi = \{\{1\}, \{2\}, \{3\}\}) = \{x^{\{i\}} \in \Re^{\{i\}} \| x^i \leq 4\}$
	for all i=1,2,3

Coalition	Payoff
$\{123\}$	$V(\{123\}, N) = \{x^{\{123\}} \in \Re^{\{N\}} \| x^1 + x^2 + x^3 \leq 15\}$
$\{\{12\}, \{3\}\}$	$V(\{12\}, \pi = \{\{12\}, \{3\}\}) = \{x^{\{12\}} \in \Re^{\{12\}} \| x^1 + x^2 \leq 11\}$
	$V(\{3\}, \pi = \{\{12\}, \{3\}\}) = \{x^{\{3\}} \in \Re^{\{3\}} \| x^3 \leq 2\}$
$\{\{13\}, \{2\}\}$	$V(\{13\}, \pi = \{\{13\}, \{2\}\}) = \{x^{\{13\}} \in \Re^{\{13\}} \| x^1 + x^3 \leq 10\}$
	$V(\{2\}, \pi = \{\{13\}, \{2\}\}) = \{x^{\{2\}} \in \Re^{\{2\}} \| x^2 \leq 2\}$
$\{\{23\}, \{1\}\}$	$V(\{23\}, \pi = \{\{23\}, \{1\}\}) = \{x^{\{23\}} \in \Re^{\{23\}} \| x^2 + x^3 \leq 12\}$
	$V(\{1\}, \pi = \{\{23\}, \{1\}\}) = \{x^{\{1\}} \in \Re^{\{1\}} \| x^1 \leq 2\}$
$\{\{1\}, \{2\}, \{3\}\}$	$V(\{i\}, \pi = \{\{1\}, \{2\}, \{3\}\}) = \{x^{\{i\}} \in \Re^{\{i\}} \| x^i \leq 4\}$
	for all i=1,2,3

These games are superadditive and exhibit positive externalities: the Core is non-empty. The second example has the Collective Rationality property.

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