A short note on joint welfare maximization assumption

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Abstract

Non-cooperative game theoretical models of international environmental agreements (IEAs) use the assumption that coalition of signatories maximizes their joint welfare. The joint maximization assumption is compared with different welfare sharing schemes such as Shapley value, Nash bargaining solution and Consensus Value. The results show that the joint welfare maximization assumption is similar with Nash Bargaining solution.

Keywords: game theory, coalition formation, joint welfare maximization, Shapley value, Nash bargaining solution, Consensus Value, international environmental agreements.

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1 Introduction

The formation and implementation of International Environmental Agreements (IEA) is the topic of a broad economic literature. A significant part of the literature uses game theory as a tool to understand the formation mechanism of IEAs. There are two main directions of literature on IEAs (for a review of current literature see Finus 2003; Carraro/Siniscalco 1998; Ioannidis/Papandreou/Sartzetakis 2000; Carraro/Eyckmans/Finus 2005). The first direction utilizes the concepts of cooperative game theory in order to model the formation of IEAs. This is a rather optimistic view and it shows that an IEA signed by all countries is stable provided that utility is transferable and side payments are adequate (Chander/Tulkens 1995, 1997). The second direction uses the concepts of non-cooperative game theory to model the formation of IEAs. At the first level, the link between the economic activity and the physical environment is established in order to generate the economical-ecological model. This link is established through a social welfare function. The social welfare function captures the difference between the profit from pollution and the environmental damage.

The Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model provides the social-welfare functions in our model.

Following this approach, countries play a two stage-game. In the first stage, each country decides to join the IEA, or to stay as non-member. In the second stage, every country decides on emissions. The main body of literature examining the formation of IEA within a two stage framework uses a certain set of assumptions. We mention below only the essential ones:

- Decisions are simultaneous in both stages.
- Countries are presented with single agreements.
- Stability of IEA's is based on the ideas developed for cartel stability (d'Aspremont et al. ((1983)) and requires so-called internal and external stability. Internal stability means that a country does not have an incentive to leave the coalition. External stability means that a country does not have an incentive to join the coalition. When defecting from coalition, a country assumes that all other countries remain in the coalition (this is a consequence of the employed stability concept of d'Aspremont et al that allows only singleton movements and myopia).

- Within the coalition, players players cooperatively and maximize their joint welfare, while the coalition and single countries compete in a non cooperative way.

Non-cooperative game theory draws a pessimistic picture of the prospect of successful cooperation between countries. It claims that a large coalition of signatories is hardly stable, and that the free-rider incentive is strong. The model explains the problems of international cooperation in the attendance of environmental spillovers, but cannot explain IEAs with high membership such as the Montreal Protocol. This calls for a modification of the standard assumptions. We mention in the following paragraphs some of the possible modifications.

Asheim et. al (2006), Carraro (2000) and Osmani & Tol (2006) allow more than one IEA to be formed. They reach the conclusion that two IEA's can perform better than one IEA in regional environmental problems.

Diamantoudi & Sartzetakis (2002), Eyckmans (2003) and Osmani & Tol (2007a,b) use the farsighted stability concept instead of D'Aspremont myopic stability. The farsighted stability is firstly introduced by Chwe (1994). The idea of farsightedness implies that one should check for multi-step stability by comparing the profits of a coalition member after a series of deviations has come to an end. Non-cooperative game theory predicts more optimistic results by employing farsighted stability.

The main contribution of the paper is the discussion on the assumption of *joint welfare maximization*. As the members of coalition *play cooperatively* we compare the joint welfare maximization with classical cooperative game theory value such as Shapley Value and Nash bargaining solution. We make use of farsightedly stable coalitions that comes form applying the *Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model* (see Osmani & Tol (2007a).

In section two, the FUND model is described. We continue with introducing our game-theoretic model, farsighted stability and coalitions that are going to be considered. In the next section, the different sharing schemes such as Shapley Value, Nash Bargaining and Consensus Value are presented. In fifth section section, our results are discussed. Section six concludes. In Appendix the results are introduced in eight different Tables.

2 FUND model

This paper uses version 2.8 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND). Version 2.8 of FUND corresponds to version 1.6, described and applied by Tol (1999a,b, 2001, 2002c), except for the impact module, which is described by Tol (2002a,b) and updated by Link and Tol (2004). A further difference is that the current version of the model distinguishes 16 instead of 9 regions. Finally, the model considers emission reduction of methane and nitrous oxide as well as carbon dioxide, as described by Tol (forthcoming^a).

Essentially, FUND consists of a set of exogenous scenarios and endogenous perturbations. The model distinguishes 16 major regions of the world, viz. the United States of America (USA), Canada (CAN), Western Europe (WEU), Japan and South Korea (JPK), Australia and New Zealand (ANZ), Central and Eastern Europe (EEU), the former Soviet Union (FSU), the Middle East (MDE), Central America (CAM), South America (LAM), South Asia (SAS), Southeast Asia (SEA), China (CHI), North Africa (NAF), Sub-Saharan Africa (SSA), and Small Island States (SIS). The model runs from 1950 to 2300 in time steps of one year. The prime reason for starting in 1950 is to initialize the climate change impact module. In FUND, the impacts of climate change are assumed to depend on the impact of the previous year, this way reflecting the process of adjustment to climate change. Because the initial values to be used for the year 1950 cannot be approximated very well, both physical and monetized impacts of climate change tend to be misrepresented in the first few decades of the model runs. The period of 1950-1990 is used for the calibration of the model, which is based on the IMAGE 100-year database (Batjes, Goldewijk, 1994). The period 1990-2000 is based on observations (WRI, 2000). The climate scenarios for the period 2010-2100 are based on the EMF14 Standardized Scenario, which lies somewhere in between IS92a and IS92f (Leggett et al., 1992). The 2000-2010 period is interpolated from the immediate past, and the period 2100-2300 extrapolated.

The scenarios are defined by the rates of population growth, economic growth, autonomous energy efficiency improvements as well as the rate of decarbonization of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide. The scenarios of economic and population growth are perturbed by the impact of climatic change. Population decreases with increasing climate change related deaths that result from changes in heat stress, cold stress,malaria, and tropical cyclones. Heat and cold stress are assumed to have an effect only on the elderly, non-reproductive population. In contrast, the other sources of mortality also affect the number of births. Heat stress only affects the urban population. The share of the urban population among the total population is based on the World Resources Databases (WRI, 2000). It is extrapolated based on the statistical relationship between urbanization and per-capita income, which are estimated from a cross-section of countries in 1995. Climate-induced migration between the regions of the world also causes the population sizes to change. Immigrants are assumed to assimilate immediately and completely with the respective host population.

The market impacts are dead-weight losses to the economy. Consumption and investment are reduced without changing the savings rate. As a result, climate change reduces long-term economic growth, although consumption is particularly affected in the short-term. Economic growth is also reduced by carbon dioxide abatement measures. The energy intensity of the economy and the carbon intensity of the energy supply autonomously decrease over time. This process can be accelerated by abatement policies, an option not considered in this paper.

The endogenous parts of FUND consist of the atmospheric concentrations of carbon dioxide, methane and nitrous oxide, the global mean temperature, the impact of carbon dioxide emission reductions on the economy and on emissions, and the impact of the damages to the economy and the population caused by climate change. Methane and nitrous oxide are taken up in the atmosphere, and then geometrically depleted. The atmospheric concentration of carbon dioxide, measured in parts per million by volume, is represented by the five-box model of Maier-Reimer and Hasselmann (1987). Its parameters are taken from Hammitt et al. (1992). The model also contains sulphur emissions (Tol, forthcoming[a]).

The radiative forcing of carbon dioxide, methane, nitrous oxide and sulphur aerosols is determined based on Shine et al. (1990). The global mean temperature T is governed by a geometric build-up to its equilibrium (determined by the radiative forcing RF), with a half-life of 50 years. In the base case, the global mean temperature rises in equilibrium by 2.5°C for a doubling of carbon dioxide equivalents. Regional temperature follows from multiplying the global mean temperature by a fixed factor, which corresponds to the spatial climate change pattern averaged over 14 GCMs (Mendelsohn et al., 2000). The global mean sea level is also geometric, with its equilibrium level determined by the temperature and a half-life of 50 years. Both temperature and sea level are calibrated to correspond to the best guess temperature and sea level for the IS92a scenario of Kattenberg et al. (1996).

The climate impact module, based on Tol (2002b,c) includes the following categories: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, and unmanaged ecosystems. Climate change related damages can be attributed to either the rate of change (benchmarked at 0.04°C) or the level of change (benchmarked at 1.0°C). Damages from the rate of temperature change slowly fade, reflecting adaptation (cf. Tol, 2002c). People can die prematurely due to temperature stress or vector-borne diseases, or they can migrate because of sea level rise. Like all impacts of climate change, these effects are monetized. The value of a statistical life is set to be 200 times the annual per capita income. The resulting value of a statistical life lies in the middle of the observed range of values in the literature (cf. Cline, 1992). The value of emigration is set to be 3 times the per capita income (Tol, 1995, 1996), the value of immigration is 40 per cent of the per capita income in the host region (Cline, 1992). Losses of dryland and wetlands due to sea level rise are modelled explicitly. The monetary value of a loss of one square kilometre of dryland was on average $4 million in OECD countries in 1990 (cf. Fankhauser, 1994). Dryland value is assumed to be proportional to GDP per square kilometre. Wetland losses are valued at $2 million per square kilometre on average in the OECD in 1990 (cf. Fankhauser, 1994). The wetland value is assumed to have logistic relation to per capita income. Coastal protection is based on cost-benefit analysis, including the value of additional wetland lost due to the construction of dikes and subsequent coastal squeeze.

Other impact categories, such as agriculture, forestry, energy, water, and ecosystems, are directly expressed in monetary values without an intermediate layer of impacts measured in their 'natural' units (cf. Tol, 2002b). Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum, which is determined by a variety of factors, including plant physiology and the behaviour of farmers. Impacts are positive or negative depending on whether the actual climate conditions are moving closer to or away from that optimum climate. Impacts are larger if the initial climate conditions are further away from the optimum climate. The optimum climate is of importance with regard to the potential impacts. The actual impacts lag behind the potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to new climate conditions are always negative (cf. Tol, 2002c). The impacts of climate change on coastal zones, forestry, unmanaged ecosystems, water resources, diarrhoea malaria, dengue fever, and schistosomiasis are modelled as simple power functions. Impacts are either negative or positive, and they do not change sign (cf. Tol, 2002c). Vulnerability to climate change changes with population growth, economic growth, and technological progress. Some systems are expected to become more vulnerable, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems and health (with higher per capita incomes). Other systems are projected to become less vulnerable, such as energy consumption (with technological progress), agriculture (with economic growth) and vector- and water-borne diseases (with improved health care) (cf. Tol, 2002c).

Note that we make use of data only for the year 2005. This is sufficient as static game theory is used but with a sophisticated stability concept.

2.1 Welfare function of FUND model

For the analysis of coalition formation, we approximate the FUND model with a linear quadratic structure. Specifically, the abatement cost function is represented as:

$$C_i = \alpha_i R_i^2 Y_i \tag{1}$$

where C denotes cost, R relative emission reduction, and Y gross domestic product; i indexes regions; α is the cost parameter. The benefit function is approximated as:

$$B_i = \beta_i \sum_j^n R_j E_j \tag{2}$$

where B denotes benefit and E unabated emissions. Tables 1 gives the parameters of Equations (1) and (2) as estimated by or specified in FUND. Moreover the profit P is given as:

$$P_i = B_i - C_i = \beta_i \sum_j^n R_j E_j - \alpha_i R_i^2 Y_i \tag{3}$$

Table 1: Our data from year 2005, α abatement cost parameter (unitless), β marginal damage costs of carbon dioxide emissions (in dollars per tonne of carbon) E carbon dioxide emissions (in billion metric tonnes of carbon) Y gross domestic product, in billion US dollar. Source: FUND

	α	β	E	Y
USA	0.01515466	2.19648488	1.647	10399
CAN	0.01516751	0.09315600	0.124	807
WEU	0.01568000	3.15719404	0.762	12575
JPK	0.01562780	-1.42089104	0.525	8528
ANZ	0.01510650	-0.05143806	0.079	446
EEU	0.01465218	0.10131831	0.177	407
FSU	0.01381774	1.27242378	0.811	629
MDE	0.01434659	0.04737632	0.424	614
CAM	0.01486421	0.06652486	0.115	388
LAM	0.01513700	0.26839935	0.223	1351
SAS	0.01436564	0.35566631	0.559	831
SEA	0.01484894	0.73159104	0.334	1094
CHI	0.01444354	4.35686225	1.431	2376
NAF	0.01459959	0.96627119	0.101	213
SSA	0.01459184	1.07375825	0.145	302
SIS	0.01434621	0.05549814	0.038	55

Non-cooperative optimal emission reduction is then:

$$dP_i/dR = \beta_i E_i - 2\alpha_i R_i Y_i = 0 \Rightarrow R_i = \beta_i E_i/(2\alpha_i Y_i) \tag{4}$$

If region i is in a coalition with region j, optimal emission reduction is:

$$dP_{i+j}/dR_i = 0 \Rightarrow E_i(\beta_i + \beta_j) - 2\alpha_i R_i Y_i = 0 \Rightarrow R_i = (\beta_i + \beta_j)E_i/(2\alpha_i Y_i) \tag{5}$$

The price for entering a coalition is therefore higher emission abatement at home. The return is that the coalition partners also raise their abatement efforts.

Note that our welfare functions are orthogonal, this indicates that the emissions change of a country do not affect the marginal benefits of other countries (independence assumption). In our game, countries outside the coalition benefit from the reduction in emissions achieved by the cooperating countries but they cannot affect the benefits derived by the members of the coalition. As our cost-benefit function are orthogonal our approach does not capture the effects of emissions leakage. But our cost benefit function are sufficiently realistic as they are approximation of complex model FUND and our procedure of dealing with farsighted stability is general and appropriate for non-orthogonal functions also.

3 Our model

There are 16 world regions (we name the set of all regions by N_{16}) in our game theoretic model of IEA's (or coalitions), which are shown in first column of Table 1. At the first level, the link between the economic activity and the physical environment is established in order to generate the economical-ecological model. This link is established through a social welfare function of FUND model, see 7. The social welfare function captures the difference between the profit from pollution and the environmental damage. Following this approach, countries play a two stage-game. In the first stage, each country decides to join the coalition $C \subseteq N_{16}$ and become a signatory (or coalition member) or stay singleton and non-signatory (*membership game*). These decisions lead to *coalition structure* S with c coalition-members (c denotes the cardinality of C) and 16-c non-members. *A coalition structure* simply fully describes how many coalitions (at the moment we assume that we have one coalition) are formed, how many members each coalition has and how many singleton players are. Given the simple coalition structure S is fully characterized by coalition C. In the second stage, every country decides on emissions (*strategic game*). Within the coalition, players play cooperatively (by maximizing their joint welfare) while the coalition and single countries compete in a non cooperative way (by maximizing their own welfare). Every coalition C is assigned a real number $\upsilon(C)$ (called characteristic function).

Definition 3.1 *By the* ***characteristic function*** *of our 16-player game (played by c and* $16 - c$ *players, where c is cardinality of coalition C) we mean a real-valued function* $\upsilon(C) : C \rightarrow R$,
$\upsilon(C) = max(\sum_1^c \pi_i) \quad \forall i \in C, \quad C \subset N_{16}, \quad c \leq 16.$

Characteristic function is simple the total profit that coalition-member reach by maximizing their joint welfare. As π are strictly concave, their sum is strictly concave also, which simplifies the maximization problem. The game satisfies the superadditivity property:

Definition 3.2 *A game is superadditive if for any two coalitions,* $C_1 \subset N_{16}$ *and* $C_2 \subset N_{16}$:
$\upsilon(C_1 \cup C_2) > \upsilon(C_1) + \upsilon(C_2) \quad C_1 \cap C_2 = \emptyset.$

The *superadditivity property* means that if C_1 and C_2 are disjoint coalitions (here C_1 and C_2 can be single players too), it is clear that they should accomplish at least as much as by joining forces as by remaining separate. But the game *almost always (with some exceptions)* exhibits *positive spillovers:*

Definition 3.3 *A game exhibits positive spillover property if and only if for any two coalitions* $C_1 \subset N_{16}$ *and* $C_2 \subset N_{16}$ *such as* $C_1 \nsubseteq C_2$ *and* $C_2 \nsubseteq C_1$ *we have:*
$\forall k \notin C_1 \cup C_2 \quad \upsilon_k(C_1 \cup C_2) > \upsilon_k(C_1) \wedge \upsilon_k(C_1 \cup C_2) > \upsilon_k(C_2)$

It indicates that there is an external gain (C_1 and C_2 can be single players too) or a positive spillover from cooperation, making free-riding (i.e., not joining $C_1 \cup C_2$) attractive. It just implies that every player $k \notin C_1 \cup C_2$ has higher profit when two coalitions C_1 and C_2 cooperate compared to the situation where two coalitions stay separated. It indicates that from a non-signatory's point of view (player k here), the most favorable situation is the one in which all other countries take part in the coalition (except k). As we have already mentioned the positive spillover property is almost always satisfied with the exception of some coalitions that contain as members Japan & South Korea or Australia & New Zealand which have negative marginal benefits (negative β's) from pollution abatement.
As our game is formally defined, we concentrate the attention to farsighted stability. In our model framework, the farsighted stability is mainly based in two arguments. The first one is the *coalition change process* (sometimes we will call it *coalition inducement*[1]) which includes all possible was that a coalition can change. Basically coalition change process solves the question: Can a part of members of our coalition (or all) improve their welfare (by help of non-member coalition or not) by forming a new coalition. The players are farsighted in the first sense that they check all possible ways for forming a new coalition in order to improve their welfare. The second arguments is a behavioral assumption for our farsighted players (or regions) in order to deter free-riding. Suppose that there is no way to improve the welfare for a coalition, but a country can still free-ride and improve his welfare alone! We assume that our players are farsighted in another sense namely

[1] In our previous paper Osmani & Tol (2007a) in stead of concept *coalition change process* we use only the notation of *inducement process* by introducing a strict definition of it.

they refuse to free-ride because they take into account that the other members of coalition can act similarly, which will finally result in welfare decrease for everyone.

3.1 Farsightedly stable coalitions

Below a short introduction of farsighted stability is introduced, and then farsighted coalitions ,which we are going to consider, are presented.

As we will consider only profitable coalition. The situation in which each country maximizes its own profit is referred to as *the atom structure*; it is a standard Nash equilibrium; the maximum coalition size is unity. A coalition that performs better than atom-structure is *a profitable coalition.* We limit our attention to coalitions, which are profitable and this is sufficient to find all farsightedly stable coalitions[2].

We concentrate in *the different ways that a coalition can change.* There are four ways[3] of a *coalition change* (or *coalition inducement*); the coalition gets bigger; gets smaller; some coalition-member leave coalition and some other join it; fourth way is a special one, namely *the free-riding*, one country or more leave the coalition and increase their welfare.

If a coalition get bigger, it follows that the original members of coalitions see an increase in profits and the new members see an increase too; we say that an external inducement is possible. This can be easily checked by a combinatorial algorithm.

Definition 3.4 *If no external inducement is possible than the coalition is external farsightedly stable (EFS).*

If a coalition gets smaller, its remaining members see an increase in profits; we say that an internal inducement is possible.

Definition 3.5 *If no internal inducement is possible than the coalition is internal farsightedly stable (IFS).*

The third way of coalition inducement is if a number of old coalition members leave and a number of new members join the coalition. The new coalition may be larger or smaller than the original

[2]See Observation 3.1 in Osmani & Tol (2007a).

[3]We also introduce five ways of inducement process in Osmani & Tol (2007a), and here only four, as we present a short introduction only.

one. One needs to check if countries in a final coalition increase their profits by forming a new coalition. We call it *sub-coalition inducement.*

Definition 3.6 *If no sub-coalition inducement is possible than the coalition is sub-coalition farsightedly stable (SFS).*

It needs more combinatorial work to check if a sub-coalition inducement is possible.

As we noted one special coalitional change is caused by free-riding. In our model, free-riding is deterred based on motivation that originates from experimental game theory (Fehr & Gächter (2000), Ostrom (2000))[4], which predicts that if a player free-rides, as the rest of players get this information, a part of them (not all) is going to free-ride also. This results in worsening of the welfare for every player. We assume that our players (countries in our approach) possess the knowledge that if free-riding appears, it will be spread out and other players countries will start to free-ride. This assumption deters free-riding and fits well to farsighted behavior as takes into account the counter reaction of other countries. As free-riding is prevented based on behavioral assumption, which implies that there is no free-riding for any coalitions then inducement caused by free-riding can not be included in definition of farsighted stability.

Now we are able to present the definition of farsighted stability:

Definition 3.7 *If no internal, external and sub-coalition improvement is possible than the coalition is farsightedly stable.*

Testing a coalition for farsighted stability means comparing the profit of his country members with *the profit of country members of all possible coalitions (that can be induced or not) and finding the coalitions that can be induced.* The farsightedly stable coalition that will be discussed are:

$(USA, LAM, SEA, CHI, NAF, SSA)$

$(CAN, EEU, CAM, SAS, SIS)$

Further more we are going to discuss two sub-coalitions of above coalitions:

[4]The mentioned papers consider behavior of the people not of countries as we would like. But we consider the assumption (on spreading of free-riding behavior) relevant for our framework as it go well with the spirit of farsighted behavior and takes into account the counter reaction of other players.

$(USA, SEA, CHI, NAF, SSA)$

(CAN, EEU, CAM, SAS)

For a more detailed description how the farsightedly stable coalitions are found please see Osmani & Tol (2007a).

4 Different sharing schemes

The joint welfare maximization is compared with Shapley Value, Nash Bargaining solution and Consensus Value. In the following subsection we will describe them shortly.

4.1 Shapley Value

Suppose we form a coalition C by entering the players into this coalition one at a time; $\upsilon(C)$ is the *characteristic function* of coalition C, see definition 3.1; $|C|$ is cardinality of coalition C, and n is total number of players. As each player enters the coalition, he receives the amount by which his entry increases the value of the coalition he enters. The Shapley value is just the average payoff to the players if the players are entered in completely random order.

Definition 4.1 *The Shapley value is given by,* $\phi = (\phi_1, ..., \phi_n)$ *where for* $i = 1, ..., n$*:*

$$\phi_i(\upsilon) = \sum_{C \subset N, i \subset C} \frac{(|C|-1)!(n-|C|)!}{n!}(\upsilon(C) - \upsilon(C - \{i\})) \tag{6}$$

The interpretation of this formula is as follows. Suppose we choose a random order of the players with all n! orders (permutations) of the players equally likely. Then we enter the players according to this order. If, when player i enters, he forms coalition C (that is, if he finds $C - \{i\}$ there already), he receives the amount $(\upsilon(C) - \upsilon(C - \{i\}))$. The probability that when i enters he will find coalition $S - \{i\}$ there already is $\frac{(|C|-1)!(n-|C|)!}{n!}$. The denominator is the total number of permutations of the n players. The numerator is number of these permutations in which the $|S| - 1$ members of $C - \{i\}$ come first $((|C| - 1)!$ ways), then player i, and then the remaining $n - |C|$ players $((n - |C|)!$ ways). So this formula shows that $\phi_i(\upsilon)$ is just the average amount player i contributes to the coalition if the players sequentially form this coalition in a random order.

4.2 Nash Bargaining solution

The axiomatic theory of bargaining originated in a fundamental paper by Nash (1950), we simply adapt it to our problem. If a part (or all) of countries (we suppose that we have six countries without loss of generality) agree to form a coalition and behave cooperatively and the rest of countries optimize their own welfare function. We concentrate to 6 countries that form the coalition. The scenario is that 6 world regions have access to any of the alternatives in some set $\Re^6$, called the feasible utility set. Their preferences over the alternatives in the utility set are given by welfare function P:

$$P_i = B_i - C_i = \beta_i \sum_j^n R_j E_j - \alpha_i R_i^2 Y_i \tag{7}$$

where C denotes cost, R relative emission reduction, and Y gross domestic product; i indexes regions; α is the cost parameter; B denotes benefit and E unabated emissions.

If no coalition is formed, they end up at a pre-specified alternative in the feasible set called the disagreement point, which is denoted by vector d. In our model d is *profit vector of atom structure* with 6 elements where every country optimize his own profits. More formally, a bargaining problem is defined by the tuple $(\Re^6; d)$ where the utility set $(\Re^6)$ has to be (and is) a non-empty, convex, and compact subset. We further assume that there exists an $p \in \Re^6$, such that $p \gg d$. In our case, Nash bargaining solution, denoted $f_N(\Re^6; d)$ is given by

$$f_N(\Re^6; d) = \arg\max \textstyle\prod_{i=1\ldots6}(P_i - d_i) \quad where \quad P_i = B_i - C_i = \beta_i \sum_j^n R_j E_j - \alpha_i R_i^2 Y_i$$

This means simply we need to find the abatement level R of 6 coalition members that maximize f_N (as P_i is function of R). Note than the abatement level R of ten remaining countries are known as they simply maximize their own welfare function (we need them in order to calculate the benefit function $B_i = \beta_i \sum_j^n R_j E_j$).

4.3 Consensus Value

Let us consider an arbitrary 2-person cooperative TU game with player set $N = \{1, 2\}$ and characteristic function v determined by the values: $v(\{1\}), v(\{2\})$ and $v(\{1, 2\})$. A reasonable solution is that player 1 gets:

$v(\{1\}) + [v(\{1,2\}) - v(\{1\}) - v(\{2\})]/2$

and player 2 gets:

$v(\{2\}) + [v(\{1,2\}) - v(\{2\}) - v(\{1\})]/2$

That is, the (net) surplus generated by the cooperation between player 1 and 2, $v(\{1,2\}) - v(\{2\}) - v(\{1\})$, is equally shared between the two players. This solution is called the standard solution for 2-person cooperative games. Ju, Y., Borm, P., Ruys, P. (2004) provide a generalization of the standard solution for 2-person games into n-person cases. Consider a n-person game (N, v) while the grand coalition $C_n = \{1, 2, .., n\}$ is formed than the player $(n+1)$ (let call the new player just player (n+1)) joins the coalition and the coalition $C_{n+1} = \{1, 2, .., n, n+1\}$ is formed. The generalization of player $(n+1)$ share is:

$$\underbrace{v(\{n+1\})}_{v\ of\ the\ single\ player\ (n+1)} + \underbrace{[v(\{1,...,n+1\}) - v(\{n+1\}) - v(\{1,..,n\})]}_{the\ surplus\ from\ cooperation\ of\ C_n\ and\ player\ (n+1)} \cdot 1/2$$

The interpretation of above formula is as follows. We can see the above situation as 2-person game. The coalition $C_n = \{1, 2, .., n\}$ is considered as one player and the next player is the new player $(n+1)$ that joins the coalition. The (net) surplus generated by the cooperation between coalition C_n and the new player is $v(\{1,...,n+1\}) - v(\{n+1\}) - v(\{1,..,n\})$. The equation above says that the new player take the amount he gets alone $v(\{n+1\})$ plus the half of the surplus.

$$\underbrace{v(\{i \mid i \in C_n\})}_{v\ of\ a\ member\ of\ C_n} + \underbrace{[v(\{1,...,n+1\}) - v(\{n+1\}) - v(\{1,..,n\})]}_{the\ surplus\ from\ cooperation\ of\ C_n\ and\ player\ (n+1)} \cdot 1/2 \cdot 1/n$$

Each of n-players that was already in coalition C_n gets his payoff as member of coalition C_n plus half of the surplus divided by n.

5 Results

Before presenting results, we define:

$P_{joint}, P_{shap}, P_{nash}, P_{cons}$: the sharing profit according to joint welfare maximization, Shapley Value, Nash Bargaining solution and Consensus Value.

$\frac{(P_{joint}-P_{shap})}{P_{joint}} \cdot 100$: relative difference in percentage between joint welfare maximization and Shapley value.

$\frac{(P_{joint}-P_{nash})}{P_{joint}} \cdot 100$: relative difference in percentage between joint welfare maximization and Nash Bargaining Solution.

$\frac{(P_{joint}-P_{cons})}{P_{joint}} \cdot 100$: relative difference in percentage between joint welfare maximization and Consensus Value.

Our numerical computations are programmed in Matlab[5] programming language, and results are introduced in Appendix. Table (2) presents the results for the first coalition $(USA, LAM, SEA, CHI, NAF, SSA)$, Table (3) for the second coalition $(CAN, EEU, CAM, SAS, SIS)$, Table (4) for the third coalition $(USA, SEA, CHI, NAF, SSA)$ and Table (5) for the forth coalition (CAN, EEU, CAM, SAS). The Tables are similar, in the first column are coalition members, and in the second, third and fourth column the relative differences of joint welfare maximization compared to Shapley Value, Nash Bargaining Solution and Consensus Value.

The results show that joint welfare maximization is very similar to Nash Bargaining solution. Their relative differences are almost always less than 1% for four coalitions (in only one case more than 1%). The Shapley Value and Consensus Value differ significantly to joint welfare maximization for the first and third coalition, but they are similar for the second and fourth coalition.

In order to have a more complete picture of results, the absolute value of joint welfare maximization, Shapley Value, Nash Bargaining Solution and Consensus Value for every coalition[6] are

[5]Programs can be provided to the reader on request.
[6]The absolute values ca be also used to check the validity of conclusions.

provided in Table (6), Table (7), Table (8) and Table (9). The Tables are identical, in the first column are coalition members, and in the second, third, fourth and fifth column are values of joint welfare maximization, Shapley Value, Nash Bargaining Solution and Consensus Value. The last row presents the sum of all coalitions members value for every welfare sharing scheme used. It is clear that the sum has to be equal for every welfare sharing scheme used (for the same coalition), but due to round errors they are only approximately the same. The errors are less than 0.01 for the first coalition ($USA, LAM, SEA, CHI, NAF, SSA$), and less than 0.001 for all three other coalitions.

. . .

One way to see the numerical comparisons, is that Shapley and Consensus Value take into account *the possible ways of coalition formation*. The Shapley Value considers all the ways of coalition formation while the Consensus Value assumes a specific way of coalition formation. On the opposite the joint welfare maximization and Nash Bargaining Solution are ways of maximizing the total profit of coalition *without considering how the coalition is formed.*

6 Conclusions

The literature in international environmental agreements supposes that countries within a coalition maximize their joint welfare while the single countries play non-cooperatively against the coalition and against each-other. We investigate if joint welfare maximization shares the welfare level fairly among coalition members. The joint welfare maximization is compared to classical cooperative game value like Shapley Value, Nash bargaining solution and Consensus Value for four different coalitions. The Nash bargaining solution gives similar solution compared to joint welfare maximization. The Shapley Value and Consensus Value differ significantly compared to joint welfare maximization. One can consider the joint welfare maximization as reasonable assumption as it is similar also with another well-known scheme such as Nash Bargaining solution. Further work is needed in considering more coalitions and approach that is more general.

7 Appendix

Table 2: The relative differences (in percentage) between the joint welfare maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(USA, LAM, SEA, CHI, NAF, SSA)$.

Coalition members	Shapley Value	Nash Bargaining	Consensus Value
USA	3.7 %	0.022 %	9.4 %
LAM	-27.2 %	-0.69 %	-49.9 %
SEA	-26.0 %	-0.18 %	-51.7 %
CHI	-15.4 %	0.27 %	-0.82 %
NAF	24.1 %	-0.78 %	13.3 %
SSA	18.6 %	0.43 %	8.0 %

Table 3: The relative differences (in percentage) between the joint welfare maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(CAN, EEU, CAM, SAS, SIS)$.

Coalition members	Shapley Value	Nash Bargaining	Consensus Value
CAN	1.25 %	0.27 %	1.25 %
EEU	-0.92 %	0.46 %	-0.46 %
CAM	-0.15 %	0.55 %	-0.15 %
SAS	-0.13 %	0.0013 %	0.0013 %
SIS	0.04 %	-0.79 %	-0.79 %

Table 4: The relative differences (in percentage) between the joint welfare maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(USA, SEA, CHI, NAF, SSA)$.

Coalition members	Shapley Value	Nash Bargaining	Consensus Value
USA	2.47 %	0.49 %	7.29 %
SEA	-27.27 %	-3.26 %	-51.82 %
CHI	-15.07 %	0.28 %	-2.62 %
NAF	22.71 %	0.1 %	12.42 %
SSA	17.2 %	0.12 %	6.76 %

Table 5: The relative differences (in percentage) between the joint welfare maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition (CAN, EEU, CAM, SAS).

Coalition members	Shapley Value	Nash Bargaining	Consensus Value
CAN	0.99 %	0 %	0.49 %
EEU	-0.92 %	-0.46 %	-0.92 %
CAM	0 %	-0.7 %	-0.7 %
SAS	0 %	0.13 %	0 %

Table 6: The absolute value of Joint Welfare Maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(USA, LAM, SEA, CHI, NAF, SSA)$.

Coalition members	Joint Welfare Max.	Shapley Value	Nash Bargaining	Consensus Value
USA	0.7218	0.6953	0.7216	0.6539
LAM	0.0806	0.1026	0.0812	0.1209
SEA	0.2143	0.27	0.2147	0.3251
CHI	0.8443	0.9747	0.842	0.8512
NAF	0.4163	0.316	0.4195	0.3609
SSA	0.4367	0.3554	0.4348	0.4019
—	2.714	2.714	2.7138	2.7139

Table 7: The absolute value of Joint Welfare Maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(CAN, EEU, CAM, SAS, SIS)$.

Coalition members	Joint Welfare Max.	Shapley Value	Nash Bargaining	Consensus Value
CAN	0.0204	0.0201	0.0203	0.0201
EEU	0.0217	0.0219	0.0216	0.0218
CAM	0.0144	0.0144	0.0143	0.0144
SAS	0.0753	0.0754	0.0753	0.0753
SIS	0.012	0.012	0.0121	0.0121
—	0.1438	0.1438	0.1436	0.1437

Table 8: The absolute value of Joint Welfare Maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition $(USA, SEA, CHI, NAF, SSA)$.

Coalition members	Joint Welfare Max.	Shapley Value	Nash Bargaining	Consensus Value
USA	0.6916	0.6745	0.6882	0.6412
SEA	0.2057	0.2618	0.2124	0.8384
CHI	0.817	0.9401	0.8147	0.3123
NAF	0.3976	0.3073	0.3972	0.3891
SSA	0.4173	0.3455	0.4168	0.3482
—	2.5292	2.5292	2.5293	2.5292

Table 9: The absolute value of Joint Welfare Maximization and three other different sharing schemes, respectively Shapley value, Nash bargaining solution and Consensus Value for coalition (CAN, EEU, CAM, SAS).

Coalition members	Joint Welfare Max.	Shapley Value	Nash Bargaining	Consensus Value
CAN	0.0202	0.02	0.0202	0.0201
EEU	0.0216	0.0218	0.0217	0.0218
CAM	0.0143	0.0143	0.0144	0.0144
SAS	0.0752	0.0752	0.0751	0.0752
—	0.1313	0.1313	0.1314	0.1315

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