Evolution in time of Farsightedly Stable Coalitions

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Abstract

Game theory is used to analyze the formation and stability of coalitions for environmental protection. The paper extends further our previous research on farsightedly stable coalitions and preferred farsightedly stable coalitions (Osmani & Tol 2007a). The integrated assessment model FUND provides data for different time horizons as well as the cost-benefit function of pollution abatement. This allows for analysis of the evolution in time of farsightedly stable coalitions and their improvement to environment and welfare. Considering multiple farsightedly stable coalitions, the participation in coalitions for environmental protection is significantly increased, which is a positive result of our game theoretical approach. But the farsighted behavior can not be sustained for a long term which implies that we can not have big coalitions for environmental protection even in "a farsighted world".

Keywords: game theory, integrated assessment modeling, farsighted stability, coalition formation.

JEL: C02, C72, H41

1 Introduction

A considerable part of the literature uses game theory as a tool to realize the formation mechanism of International Environmental Agreements (IEA). There are two major views 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 (Chander & Tulkens 1997, Chander & Tulkens 2006, Eyckmans & Tulkens 2003, Chander 2007) shows that the grand coalition is stable, assuming transferable utility, then using the γ-core concept and implementing transfers to solve the heterogeneity of the countries involved. This is a rather optimistic view. The second direction uses the concepts of non-cooperative game theory to model

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the formation of IEAs (Barrett 1994, Barrett 2003, Botteon & Carraro 2001, Osmani & Tol 2005, Finus & Ierland & Dellnik 2006, Rubio & Ulph 2006, McGinty 2007). The usual approach of non-cooperative game theory to stable IEAs is based on the idea 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, while external stability means that a country does not have an incentive to join the coalition. This part of the literature reaches the conclusion that the size of a stable coalition is typically very small, thus representing a pessimistic view of global environmental goods.

At the first level, the link between the economic activity and the physical environment is established in order to generate the integrated-assessment 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, see Section 2) 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 not, and in the second stage, a 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 only the essential ones: decisions are simultaneous in both stages, countries can form single coalition; 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 while 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 play 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 on Ozone Depleting Substances. This calls for a modification of the standard assumptions. Following, we mention some of the modifications.

Asheim et. al (2006), Carraro (2000) and Osmani & Tol (2005) 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 but not in global ones.

Diamantoudi & Sartzetakis (2002), Eyckmans (2003) and Osmani & Tol (2007a, 2007b) use the farsighted stability concept instead of d'Aspremont myopic stability. The farsighted stability is firstly introduced by Chwe (1994). The idea of farsightedness means 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 predict more optimistic results by employing farsighted stability.

This research develops further our previous work (Osmani & Tol 2007a) on farsightedly stable coalitions and preferred farsightedly stable coalitions. In our previous paper we show that multiple preferred farsightedly stable coalitions include two thirds of countries and improve significantly the welfare and environment which are optimistic results. Here we extend the discussion on the issue, which farsightedly stable coalition are more likely to form in different time horizons and how much improvements they bring to welfare and environment. We raise the question if the farsightedly stable coalitions can be maintained for a long-term period. The improvements in welfare and abatement levels of full non-cooperative behavior (atom structure) and grand coalition are

considered also.
We make use of benefit-cost functions that comes form the *Climate Framework for Uncertainty, Negotiation and Distribution (FUND) model* which is described in section two. We continue by presenting our game-theoretic model and a discussion on single farsightedly stable coalitions. The preferred and dominated farsightedly stable coalition are considered in section four. In the following section multiple preferred farsightedly stable coalitions are taken into account. The next section examines why are preferred farsightedly stable coalitions varying in different time horizons. Section eight concludes. We discuss in Appendix the benefiters and losers from participation in coalitions for environmental protection for different year horizons.

2 FUND model

This paper uses version 2.8 of the Climate Framework for Uncertainty, Negotiation and Distribution (FUND).
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. 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.
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, 2006).
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).

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:

$$C_i = \alpha_i R_i^2 Y_i \quad (1)$$

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:

$$B_i = \beta_i \sum_j^n R_j E_j \quad (2)$$

where B denotes benefit and E unabated emissions. Tables 1, 2, 3 and 4 give the parameters of Equations (1) and (2) as estimated by or specified in FUND. Moreover the profit P is given as:

$$pi_i = B_i - C_i = \beta_i \sum_j^n R_j E_j - \alpha_i R_i^2 Y_i \quad (3)$$

Non-cooperative optimal emission reduction is then:

$$dpi_i/dR = \beta_i E_i - 2\alpha_i R_i Y_i = 0 \Rightarrow R_i = \beta_i E_i/(2\alpha_i Y_i) \quad (4)$$

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

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

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 (let's call 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 integrated-assessment model. This link is established through a social welfare function calibrated to FUND model, see equation 3. 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 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* $\upsilon(C) : C \rightarrow R$, $\upsilon(C) = max(\sum_1^c \pi_i) \quad \forall i \in C, \quad C \subset N_{16}, \quad c \leq 16.$

The 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 *very frequently (but not always)* exhibits *positive spillovers:*

Definition 3.3 *A game exhibits positive spillover properties 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). The superadditivity property is almost always satisfied with the exception of some coalition that contains as member Japan & South Korea or Australia & New Zealand which have negative marginal benefits (negative β's) from pollution abatement.
In our model framework, the farsighted stability is mainly based in two arguments. The first one is the *coalition inducement (or coalition change process)* which includes all possible ways in which a coalition can change. Basically coalition change process solves the question: Can a part of the members of the coalition improve their welfare (by help of non-members or not) by forming a new coalition. The players are farsighted in the sense that they check all possible ways for forming a new coalition in order to improve their welfare. The second argument is a behavioral assumption for the farsighted players that deters free-riding. We assume that our players are farsighted in the sense that they refuse to free-ride because the other members of coalition can act similarly which will finally result in a welfare decrease for everyone.

4 Single farsightedly stable coalitions

In the first stage, the formation of *a single farsightedly stable coalition* is considered. As we will consider only profitable coalitions, we define them at the very beginning. 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[1].

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

We concentrate in *the different ways that a coalition can change.* There are four ways[2] of a *coalition inducement*; the coalition grows 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 improvement is possible. This can be easily checked by a combinatorial algorithm.

Definition 4.1 *If no external improvement 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 improvement is possible.

Definition 4.2 *If no internal improvement 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 one. One needs to check if countries in a final coalition increase their profits by forming a new coalition. We call it *sub-coalition improvement.*

Definition 4.3 *If no sub-coalition improvement is possible than the coalition is sub-coalition farsightedly stable (SFS).*

It needs more combinatorial work to check if a sub-coalition improvement 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))[3], 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 4.4 *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 its members with *the profit of members of all possible coalitions (that can be induced or not) and finding the coalitions that can be induced.* Thus at the beginning, all single-farsightedly stable coalitions are found. We find that all farsightedly stable coalitions are profitable. This is a consequence of the positive spillover property (that is very frequently satisfied) which implies that the cooperation (when a profitable coalition is formed) does not decrease the profit of countries that are not members of coalition.

[2] We also introduce five ways of inducement process in Osmani & Tol (2007a), the fifth inducement process is used in order to prove the existence of Large Dynamic Consistent Set (modified from Chwe (1994). As as a short introduction is presented in this paper, we consider only four ways of inducement process.

[3] 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.

So that farsighted stability is not a function of free-riding (like d'Apremont myopic stability) *but farsighted stability is a function of profitability condition* which is hard to be satisfied for a single large coalition.
It is essential to note that the *asymmetry of countries* does not allow for *large profitable coalitions.* When coalition members maximize their joint welfare, the optimization process reduces more missions in those countries where it is cheaper to decrease emissions. As consequence those countries which have a low marginal abatement cost *will probably not satisfy profitability condition.* On the other side the benefits from pollution abatement vary for different countries. It implies that countries that benefits less from pollution abatement, *will probably not satisfy profitability condition.* It follows that farsighted stability is a function of asymmetry of countries. Free-riding does not allow to have large myopically stable coalition and asymmetry of counties does not allow to have large farsightedly stable coalitions.

4.1 Farsightedly stable coalitions for different time horizons

Finding all profitable coalitions needs simple algorithm although computational efforts are not small. One finds all coalitions and checks if all their member have higher profit compared to atom structure.
The computation of all farsightedly stable coalitions is time consuming and not always necessary. That is why we calculate all of them only for year 2005 and part of them for years 2025 and 2045. We calculate only *the preferred farsightedly stable coalitions* for years 2015 and 2035. The preferred farsightedly stable coalitions are a refinement of farsightedly stable coalitions (see next section).
For year 2005, there are more than fifty profitable coalitions and 29 farsightedly stable coalitions[4].
For year 2025, there are more than three hundred profitable coalitions and at least 159 farsightedly stable coalitions[5].
For year 2045, there are again more than three hundred profitable coalitions and at least 101 farsightedly stable coalitions[6].
As its is already shown there are many farsightedly stable coalitions[7]. We called the set of all farsightedly stable coalition as *farsighted cooperation space.* The farsighted cooperation space is big, it implies that there a lot of countries have economic incentives to participate in coalitions for environmental protection like Kyoto protocol.

[4]There are 56 profitable coalitions. By checking for internal, external and sub-coalition stability we find that we have 29 farsightedly stable coalitions: 1 seven-member coalition, 1 six-member coalition 7 five-member coalitions, 10 four-member coalitions and 10 three-member coalitions

[5]There are 374 profitable coalitions. The number of profitable coalitions is increased by a factor 6 compared to the year 2005. Numerical computation shows that there are 5 nine-members farsightedly stable coalitions, 27 eight-members farsightedly stable coalitions, 58 seven-members farsightedly stable coalitions and 69 six-members farsightedly stable coalitions. So there are at least 159 farsightedly stable coalitions as we have not considered the farsightedly stable coalitions with less than six members. So, there are at least 5 times more farsightedly stable coalitions compared to year 2005.

[6]There are 365 profitable coalitions. The number of profitable coalitions is a little less compared to the year 2025. Numerical computation shows that there are 1 nine-members farsightedly stable coalitions, 7 eight-members farsightedly stable coalitions, 47 seven-members farsightedly stable coalitions and 46 four-members farsightedly stable coalitions. So there are at least 101 farsightedly stable coalitions as we have not considered the five and six-members farsightedly stable coalitions as well as those with less than four-members. We think that there are less farsightedly stable coalitions compared to the year 2025 but there are three times more farsightedly stable coalitions compared to year 2005

[7]There are 80 profitable coalitions for year 2015, and 337 for year 2035. We assume that there are many farsightedly stable coalitions for these years too.

5 Preferred and dominated stable coalitions

The farsighted stability concept can be improved by looking carefully at the inducement process. The inducement process means how much the country-members can "see and change" in order to find the best coalition. Suppose we have a coalition structure (like atom structure) as starting state that *can't be induced* by two different farsightedly stable coalitions. The following question can be raised: *Which farsightedly stable coalition is most likely to be formed from this starting point ?* It is clear that the most usual starting point is the atom-structure. We will compare the farsightedly stable coalitions not only with coalitions that originate from general inducement process but also with the coalitions that originate from the most usual starting point, the atom structure. We can use this criterion in order to refine further our farsightedly stable coalitions.
The formal definition of *dominated coalition* is introduced below.

Definition 5.1 *A stable coalition C_m is dominated if and only if:*

$$\forall \textit{ country } i \in C_m \quad \exists\, C_{k_i} \quad |\pi_{C_{k_i}}(i) > \pi_{C_m}(i) \textit{ and } C_{k_i} \textit{ is a not-dominated coalition}$$

$$\pi_{C_{k_i}}(i),\ \pi_{C_m}(i) \textit{ are profits of country } i \textit{ as a member } C_k \textit{ and } C_m.$$

A coalition C_m is dominated if there are not-dominated stable coalitions (or a single coalition) where every country-member of C_m get higher profit.

Definition 5.2 *A coalition C_m is preferred over C_n, $C_m \succeq C_n$ if and only if:*

$$for\ the\ majority\ of\ country\ i \in C_m \cap C_n\ \pi_{C_m}(i) > \pi_{C_n}(i) \textit{ and no coalition is preferred over } C_m$$

$$\pi_{C_m}(i),\ \pi_{C_n}(i) \textit{ are profits of country } i \textit{ as a member } C_m \textit{ and } C_n.$$

A coalition C_m is preferred over C_n if the majority of their mutual countries gets higher profit in C_m.
It is essential to note that if C_m is preferred (or dominates) to C_n than C_m can not induce C_n or vice-versa (one can say *the inducement process* does not cover the *preference (dominance) relation*). Moreover, we see the dominance relation as complement of inducement process that somehow makes the inducement process complete. The coalitions that are easier to be formed will be not only farsightedly stable but also preferred coalitions. So that, *the preferred (dominated) farsightedly stable coalitions* are more probable to be formed.

6 Multiple preferred farsightedly stable coalitions

In this section *multiple preferred farsightedly stable (PFS) coalitions* are considered. Note that the costs of emission reduction of a region are independent of the abatement of other regions and the benefits are linear. As consequence in case of multi-coalitions the changes in the pay-off of every regions are independent of the behavior of other regions *if two coalitions do not exchange members.* It follows that our coalitions are farsightedly stable if the inducement process does not allow switching members between two coalitions. Besides we have numerically checked that there is no PFS coalition that results from exchanging members between two PFS coalitions which belong to the same year horizon.
Thus, for each of years 2005, 2015, 2025, 2035 and 2045, we have two PFS coalitions that exists simultaneously which are presented below (see Fig 1 also):

$(CAN, EEU, CAM, SAS, SIS)^{2005}$
$(USA, LAM, SEA, CHI, NAF, SSA)^{2005}$

$(CAN, EEU, FSU, CAM, LAM, SAS, SIS)^{2015}$
$(USA, WEU, CHI, NAF, SSA)^{2015}$

$(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SEA, SIS)^{2025}$
$(USA, WEU, CHI, NAF, SSA)^{2025}$

$(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SIS)^{2035}$
$(USA, NAF, SSA)^{2035}$

$(JPK, EEU, FSU, MDE, SAS, SIS)^{2045}$
$(USA, CAN, ANZ, CAM, LAM, SEA, SSA)^{2045}$

United Stated of America are always member of PFS coalitions. Another interesting development is that China and European Union are members of PFS coalitions only for the years 2025 and 2035, which has consequences for the improvement's volume in welfare and abatement levels of the farsighted stable coalitions (which will be discussed in the next section). Other interesting aspects are that Former Soviet Union is member of PFS coalitions from the year 2015 - 2045 and Japan and South Korea are member of PFS coalitions only in year 2045. We like to mention that total number of countries varies from eleven[8] to fourteen[9] which means that in "farsighted world" it is more likely that a lot of countries have economic incentives to join the environmental agreements like Kyoto protocol.
PFS coalitions vary for different time horizons. We do not expect in reality that a stable IEA can function in this way. One needs more than farsightedness assumption for a long term stable IEA. We assume that it is crucial to have transfers and a cooperative behavior in order to maintain in long-term an IEA, but the mechanisms of implementing a cooperative attitude are difficult to build as they are undermined by free-riding.

7 Discussion on farsightedly stable coalition for different time horizons

In this section we discuss, the variation of farsightedly stable coalitions for different time horizons as function of variation of α's, β's, E's and Y's of coalition members. In order to analyze this question we construct an optimization problem. The following example is introduced for illustration; let take coalition $(USA, LAM, SEA, CHI, NAF, SSA)$ (we call it second coalition of 2005, $Coal^2_{2005}$) which is farsightedly stable in year 2005 (see Fig 1) but it is not farsightedly stable in year 2015. The coalition members are indexed for simplifying the presentation of optimization problem USA i=1, LAM i=2, SEA i=3, CHI i=4, NAF i=5, SSA i=6. Then we define $\alpha(i) = x(i)\alpha_{2005}(i)$, $\beta(i) = z(i)\beta_{2005}(i)$, $E(i) = v(i)E_{2005}(i)$, and $Y(i) = w(i)Y_{2005}(i)$ for each member i of coalition;

[8] 70 % of all regions for year 2005 and 2035.
[9] 88 % of all countries for year 2025.

x, z, v, w are our variables; the subscript 2005 indicates that we use α's, β's, E's and Y's from the year horizon 2005 as starting value (we will elaborate more in this point); $\pi_{atom}(i)$, $\pi_{coal}(i)$ profit (see equation 3) in atom structure, and when the above coalition is formed. The optimization problem is stated below:

$$\max[S_1 + S_2 + \sum_{i=1:6}[v(i) + w(i)] \tag{6}$$

where
$S_1 = \sum_{i=1:k_1}(1 - x(i)) + \sum_{i=1:(6-k_1)} x(i)$ for $1 \leq k_1 \leq 5$ and
$S_2 = \sum_{i=1:k_2}(1 - z(i)) + \sum_{i=1:(6-k_2)} z(i)$ for $1 \leq k_2 \leq 5$

$\pi_{coal}(i) - \pi_{atom}(i) > 0 \; \forall i \in Coal^2_{2005}$

We just mention that for all (in)equalities below, we mean $\forall i \in Coal^2_{2005}$.
Below we introduce the lower bounds, **lb** and upper bound, **ub** of our variables[10].

$lb_x(i) < x(i) < ub_x(i)$, $lb_z(i) < z(i) < ub_z(i)$
$lb_v(i) < v(i) < ub_v(i)$, $lb_w(i) < w(i) < ub_w(i) \; \forall i \in Coal^2_{2005}$
At the very beginning let's have a closer look at our objective function which maximizes the deviation of x, z, v, w from their starting point; let explain the construction of S_1 and S_2; in order to build S_1 and S_2, the members of our coalition are divided in two groups; first group where each member satisfies $r_\alpha(i) < 1 \Rightarrow x(i) < 1$ (see footnote 10), then in order to maximize the deviation of x from his starting point 1, we maximize the sum of the amounts $(1 - x(i))$ (from 1 to k_1 that includes all the countries of first group), which implies the maximization of deviation $\alpha(i)$ from $\alpha(i)_{2005}$ for first group; second group with $r_\alpha(i) > 1 \Rightarrow x(i) > 1$, then again in order to maximize the deviation of x from his starting point 1, we maximize sum of the amounts $x(i)$ (from 1 to (6-k_1), that includes all the countries of first group, note also that maximizing $(x(i) - 1)$ is equivalent with maximizing $x(i)$), which implies the maximization of deviation $\alpha(i)$ from $\alpha(i)_{2005}$ for the second group. The S_2 is similarly build for variable z which is related to r_β. It is not necessary to introduce similar transformations for v, w as r_E and r_Y are always bigger than 1. It is clear that maximizing the sum of x's (or (1-x)), z's (or (1-z)), v's and w's implies maximizing the variation of α's, β's, E's and Y's. The six constrains request that the coalition must be profitable and profitability is a necessary condition for being a farsightedly stable coalition[11] (but not sufficient). The starting point is $x_0 = 1, z_0 = 1, v_0 = 1, w_0 = 1,$, that is, we use the values of alpha's, beta's, E's and Y's from 2005 and this is a feasible starting point. The bounds simply implies that we allow the alpha's, beta's, E's and Y's to move in the interval from their value to 2005 to 2015[12]

[10] The variable bounds explain also the construction of the objective function. Let's define $r_\alpha(i) = \alpha(i)_{2015}/\alpha(i)_{2005}$, then:
$if \;\; r_\alpha(i) > 1 \Rightarrow lb_x(i) = 1, \;\; ub_x(i) = r_\alpha(i)$
$if \;\; r_\alpha(i) < 1 \Rightarrow lb_x(i) = r_\alpha(i), \;\; ub_x(i) = 1$
$if \;\; r_\alpha(i) = 1 \Rightarrow lb_x(i) = 1, \;\; ub_x(i) = 1.$
The same clarifications can be made if we define $r_\beta(i) = \beta(i)_{2015}/\beta(i)_{2005}$, $r_E(i) = E(i)_{2015}/E(i)_{2005}$ and $r_Y(i) = Y(i)_{2015}/Y(i)_{2005}$.

[11] All farsightedly stable coalitions (that we have found) are profitable too. We claim that checking farsighted stability (in stead of profitability) increases significantly the number of nonlinear constrains and it is usually not necessary to check. The number of constrains for a coalition with six member, that are necessary to check only internal farsighted stability are $2^6 - 7$ (all sub-coalitions of our farsightedly stable coalition with at least two members). Moreover all profitable coalitions that we have checked are internally farsightedly stable. The size of a coalition does not vary too much from one time horizons to the next one. This implies that coalitions which are going to be discussed (which are farsightedly stable) must usually remain (but not always) externally and subcoalition farsightedly stable to the next time horizons.

[12] Note that that if $r_\alpha(i) = \alpha(i)_{2015}/\alpha(i)_{2005} > 1 \Leftrightarrow \alpha(i)_{2015} > \alpha(i)_{2005} \;\; \forall \alpha(i) > 0$ and if $lb_x(i) = 1 \Leftrightarrow lb_\alpha(i) = \alpha_{2005}(i)$ as $\alpha(i) = x(i)\alpha_{2005}(i)$. Besides $lb_x(i) = r_\alpha(i) \Leftrightarrow ub_\alpha(i) = r_\alpha(i)\alpha_{2005}(i) = \alpha(i)_{2015}$ as $\alpha(i) = x(i)\alpha_{2005}(i)$.

(or from value to 2015 to 2005, depending which value is bigger). As conclusion the optimization process finds *the maximum deviation of sum of alpha's, beta's, E's and Y's* of coalition members keeping *our coalition profitable in year 2015 (which implies giving a chance of being farsightedly stable coalition)* by letting alpha's beta's, E's and Y's *vary form their values in 2005 to 2015.*
The results of optimization process for coalition $(USA, LAM, SEA, CHI, NAF, SSA)$ are presented in Tables 5 and 6. The first column of Table 5 presents coalition-members, the next two columns are values of x's and z's that optimization process finds and the last four columns are the lower and upper bounds for x's and z's. The Table 6 is identical with Table 5, but presents variables v's and w's, that optimization process finds. The α's, β's and Y of each coalition-member (respectively variables x's, z's and w's in Tables 5 and 6) vary and and take the values of year 2015 (of their upper bounds). The E's (respectively the variables v's in Table 6) of each coalition member can take their value of 2015, except South East Asia (SEA). For keeping coalition profitable, *it is only necessary that SEA keeps emissions (respectively variable v for SEA) lower than the value of year 2015, namely lower than its upper bound*[13] (all other v's as well as x's, z's and w's can take the values of year 2015). The SEA is the country that increase his emissions and GDP (Y) more than any other coalition member from year 2005 to 2015. As consequence, the cost of pollution abatement of SEA are increased also. Note that, variation of emissions influences benefits and costs of coalition member from pollution abatement; as increase (or decrease) of emissions causes the increase (or decrease) of the *abatement level* R[14] which influences directly the costs and benefits from pollution abatement; increase of GDP raise the cost from pollution abatement only. The same phenomena[15] happens when we consider coalitions $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SEA, SIS)$, $(USA, WEU, CHI, NAF, SSA)$ of the year horizon 2025 (the results of optimization process are presented in Tables 7, 8, 9 and 10), and coalitions $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SIS)$ of the year horizons 2035 (the results of optimization process are presented in Tables 11 and 12)[16]. The only highlight we got form our optimization problem is the following, a coalition remain profitable in the next year horizons if the emissions of only one country remains under his value of the latest year horizons. In order to investigate more on this point (why coalitions are varying from one year horizon to the next one) we change a bit the optimization problem that we already introduced by *placing a different objective function (the bounds of variables are identical, so we do not rewrite them)*. We put the sum of constrains as objective function:

$$\max \sum_{i}^{6} (\pi_{coal}(i) - \pi_{atom}(i)) \ \forall i \in Coal^2_{2005} \tag{7}$$

$$\pi_{coal}(i) - \pi_{atom}(i) > 0 \ \forall i \in Coal^2_{2005}$$

So the bounds on x's simply imply that if $\alpha(i)_{2015} > \alpha(i)_{2005}$ then $lb_\alpha(i) = \alpha_{2005}(i)$ and $ub_\alpha(i) = \alpha_{2015}(i)$. So all bounds guarantee that α's, β's, E's and Y's move from their value of 2005 to their value to 2015.

[13]The value of v that optimization finds and its upper bound are in bold letters.

[14]As emissions reduction for each country j of our six member coalition are $R(j) = \mathbf{E(j)}/(2\alpha(j)Y(j)) \sum_i^6 \beta(i)$.

[15]The first coalition $(CAN, EEU, CAM, SAS, SIS)$ of year 2005 can not be checked by optimization proceeding because it is also profitable in year 2015. The same is true for both coalition of year 2015 $(CAN, EEU, FSU, CAM, LAM, SAS, SIS)$, $(USA, WEU, CHI, NAF, SSA)$ as well as for the second coalition $(USA, NAF, SSA)^{2035}$ of year 2035, which can not be checked by optimization proceeding because they are profitable in the following next year.

[16]That coalitions $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SEA, SIS)$, $(USA, WEU, CHI, NAF, SSA)$ remains profitable at year 2035, it is necessary that FSU (form first coalition) and USA (from second coalition) keeps their emissions level lower than the level of year 2035. That coalition $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SIS)$ remains profitable in year 2045, it is necessary that FSU keeps its emissions level lower than the level of year 2045. Note that FSU and USA increase their emissions and GDP more than majority of countries of their coalitions.

The optimization process (7) finds *the maximum satisfaction of profitability constrains* keeping *our coalition profitable in year 2015* by letting alpha's, beta's, E's and Y's *vary form their values in 2005 to 2015.* The results are presented in Tables 13 and 14 which have the same structure as Tables 5 and 6. The new optimization problem requests that we make our coalition as robust profitable as possible and it realizes this aim in two ways; the first one, *by decreasing of betas (marginal benefits from pollution abatement)* for all coalition members except China (China can not decrease its beta as its lower bound is 1) which *keeps small the variation in marginal benefits (MB)* among coalition members from pollution abatement; the second one, *by not increasing the emissions E* (equivalently keeping the variables v constant at their lower bound 1) of participants of coalition. The similar trend (with some minor differences[17]) occurs when we discuss coalitions $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SEA, SIS)$, $(USA, WEU, CHI, NAF, SSA)$ of the year horizon 2025 (the results of optimization process are presented in Tables 15, 16, 17 and 18), and coalitions $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SIS)$ of the year horizons 2035 (the results of optimization process are presented in Tables 19 and 20).
There is no surprise that E and β's play the important role on keeping the coalitions profitable (and giving a chance of being farsightedly stable) in the next year horizons. We already noted that emissions E influences the benefits and costs from pollution abatement; the change of beta's influences environmental benefits and costs of coalition member from each-other in two directions: firstly as variation of beta causes the change of abatement level of each coalition member which influences directly the benefits and costs[18], secondly as benefits of each coalition member is a function of his beta[19]. The Y (GDP) and α's influence only the costs (but not the benefits), that is why they play a minor role on maintaining the coalitions profitable from on year horizon to the next one.
The results of optimization (7) are presented also in Figure 2, 3, 4, 5 and 6. The relative change intervals[20] of alphas and betas are introduced in Figure 2. In the y-axis are alpha values (cost parameter, unitless) and in the x-axis are beta values (MB from pollution abatements in dollars for tonnes of carbon). If there is an circle for a certain country (for example USA) then the alpha and beta (of USA) can change from their value of year 2005 to the value of the year 2015 (or from year 2015 to year 2005 if the value of year 2015 is smaller than value of year 2005) and our coalition $(USA, LAM, SEA, CHI, NAF, SSA)$ remains profitable (*which implies giving a chance of being farsightedly stable coalition*). Moreover the diameter of circle which is parallel to y-axis represents the relative interval change of alpha and the diameter of circle which is parallel to x-axis represents the relative interval change of beta. If there is only a line (in stead of a circle) parallel to y-axis for a certain country (for example China, CHI) it indicates that for maintaining our coalition profitable, it is compulsory that only alpha (of China) changes its value[21](beta not). As alphas and betas vary from their lower bounds to their upper bounds or they do not vary at all we get circles with diameter one or lines with length one. The same explanation can be carried out for Figure 2 where relative changes for emissions E (in billion metric tonnes of carbon) and Y (GDP, in billion US dollars) are presented. We have only lines with length one (no circles) in

[17]For the coalition $(ANZ, EEU, FSU, MDE, CAM, LAM, SAS, SEA, SIS)$, FSU decrease its beta but it doest not reach its lower bound while ANZ increase its GDP (Y) but not up to its upper bound (similar phenomena occurs with other coalitions).

[18]As emissions reduction for each country j of our six member coalition are $R(j) = E(j)/(2\alpha(j)Y(j))\sum_i^6 \beta(i)$.

[19]As benefits of each country i is $B(i) = \beta(i)\sum_j^n R(j)E(j)$ where n is total number of countries.

[20]The relative change of alpha is equal $(\alpha_{op} - lb(\alpha))/(ub(\alpha) - lb(\alpha))$ where α_{op} is the value that optimization finds and $lb(\alpha), ub(\alpha)$ are lower and upper bounds of alpha. Similarly one speaks for the relative changes of beta, E and Y.

[21]If there is only a line parallel to x-axis for a certain country it signifies that for maintaining coalition profitable, it is necessary that only beta changes, or in case that there is only a point for a certain country it indicates that for maintaining coalition profitable, it is compulsory that neither alpha nor beta changes (but the two last cases do not occur when considering our coalition).

Figure 2 as emissions E of every participant of coalition does not change.
The Figure 4 introduces the absolute change intervals of alphas and betas. The description is identical for Figure 2 but in stead of circles we have ellipses as absolute change intervals of alphas and betas are different. The same description can be carried out for Figure 4 where results for emissions E and Y are presented. There are only lines (no ellipses) in Figure 4 as emissions E of every coalition member does not change.
The Figure 6 presents the absolute variation intervals of alphas (x-axis), betas (y-axis) and Y (GDP, z-axis) simultaneously. We have an ellipsoid for every coalition member except China which has an ellipse in a plane parallel to zy-plan as MB (beta) of China does not vary.
As conclusion the profitability condition of farsighted stable coalitions (and as consequence the farsighted stability) can be maintained by changing a little the emissions of one coalition member. In order to have robust profitable coalitions it is necessary that disproportionable variation on marginal benefits from pollution abatement among coalition members are prevented and emissions are not increased. Nevertheless, emissions and marginal benefits from pollution abatement are controlled by rate of economic growth of each country and can not be influenced.

8 Conclusion

The paper analyzes the problem of evolution of farsightedly stable coalition for different time horizons. The FUND model supplies the cost-benefit function of pollution abatement which governs the results. It is clear that the profit functions of pollution abatement consider only economic incentives.
The number of farsightedly stable coalitions is big especially for last time horizons, this implies that there are a lot of countries which have economic incentives to join international environmental agreements like Kyoto protocol in a "farsighted world". We refine further the farsightedly stable coalitions to preferred farsightedly stable coalitions. The preferred farsightedly stable coalitions are farsightedly stable coalitions where the majority of coalition members reach higher profits compared to all other farsightedly stable coalitions. There are two preferred farsightedly stable coalitions for each time horizons which includes more than two thirds (from eleven to fourteen) of sixteen world regions and they improve substantially the welfare and abatement levels compare to atom structure.
The farsighted stability is fragile with respect to small variations in parameters and circumstances. In order to have robust farsightedly stable coalitions for different time horizons, one needs to keep the emissions of each coalition member and the variation of marginal benefits from pollution abatement among coalition members as low as possible. However, emissions and marginal benefits from pollution abatement are determined by rate of economic growth of each country and can not be controlled. Furthermore, the members and size of farsightedly stable coalitions are very sensible to the emissions variation of certain coalition members from one year horizon to the future one. Then, it follows that farsightedly stable coalitions can not be sustained for long terms, which implies that the "selfish farsighted world" can assure only temporary big international coalitions. This appeals for further research that considers not only economic incentives but also commitment to environmental protection as well as a more cooperative approach.

Table 1: Abatement cost parameter α (unitless) for all time horizons. Source: FUND

	2005	2015	2025	2035	2045
USA	1.5155	1.5194	1.5229	1.5236	1.5241
CAN	1.5168	1.5205	1.5244	1.525	1.5253
WEU	1.568	1.568	1.5646	1.5607	1.559
JPK	1.5628	1.5591	1.568	1.568	1.568
ANZ	1.5106	1.5149	1.5196	1.5215	1.5229
EEU	1.4652	1.4733	1.4777	1.4813	1.4842
FSU	1.3818	1.3839	1.3979	1.4053	1.4107
MDE	1.4347	1.44	1.4528	1.4643	1.473
CAM	1.4864	1.4911	1.4985	1.5039	1.5084
LAM	1.5137	1.5161	1.5216	1.5256	1.5291
SAS	1.4366	1.4455	1.458	1.4674	1.4753
SEA	1.4849	1.4881	1.4967	1.5033	1.5088
CHI	1.4444	1.4589	1.4666	1.473	1.4785
NAF	1.46	1.4706	1.4853	1.4955	1.5029
SSA	1.4592	1.4718	1.4865	1.4964	1.5039
SIS	1.4346	1.4387	1.4498	1.4579	1.4648

Table 2: Marginal damage costs of carbon dioxide emissions β, in dollars per tonne of carbon for all time horizons. Source: FUND

	2005	2015	2025	2035	2045
USA	2.2	1.98	1.76	1.54	1.33
CAN	0.09	0.1	0.1	0.1	0.09
WEU	3.16	3.05	2.86	2.62	2.35
JPK	-1.42	-0.86	-0.44	-0.13	0.07
ANZ	-0.05	0	0.03	0.06	0.07
EEU	0.1	0.11	0.11	0.11	0.1
FSU	1.27	1.1	0.95	0.82	0.71
MDE	0.05	0.17	0.26	0.31	0.33
CAM	0.07	0.1	0.12	0.13	0.13
LAM	0.27	0.24	0.22	0.19	0.17
SAS	0.36	0.38	0.39	0.39	0.37
SEA	0.73	0.69	0.64	0.57	0.51
CHI	4.36	5.21	5.56	5.54	5.28
NAF	0.97	0.83	0.71	0.6	0.51
SSA	1.07	0.82	0.64	0.51	0.41
SIS	0.06	0.07	0.07	0.08	0.07

Table 3: Carbon dioxide emissions E in billion metric tonnes of carbon, for all time horizons. Source: FUND

	2005	2015	2025	2035	2045
USA	1647	1816	1926	2157	2402
CAN	124	139	146	164	183
WEU	762	810	889	999	1111
JPK	525	610	676	761	846
ANZ	79	92	102	115	128
EEU	177	201	262	336	414
FSU	811	1093	1339	1702	2093
MDE	424	551	690	823	976
CAM	115	137	160	188	222
LAM	223	266	310	365	429
SAS	559	756	883	1039	1224
SEA	334	492	575	676	795
CHI	1431	1798	2228	2764	3428
NAF	101	120	139	163	192
SSA	145	169	196	231	271
SIS	38	49	58	69	82

Table 4: Gross domestic product Y in billion US dollar for all time horizons. Source: FUND

	2005	2015	2025	2035	2045
USA	10399	13372	16199	19089	22029
CAN	807	1054	1277	1506	1739
WEU	12575	15569	18781	22114	25495
JPK	8528	11130	14408	17589	20794
ANZ	446	606	785	960	1136
EEU	407	544	780	1085	1429
FSU	629	872	1249	1735	2281
MDE	614	871	1335	1940	2707
CAM	388	524	733	996	1332
LAM	1351	1804	2519	3414	4554
SAS	831	1296	1858	2587	3545
SEA	1094	1770	2535	3526	4826
CHI	2376	3795	5420	7619	10560
NAF	213	309	481	710	1005
SSA	302	445	694	1026	1456
SIS	55	76	107	146	196

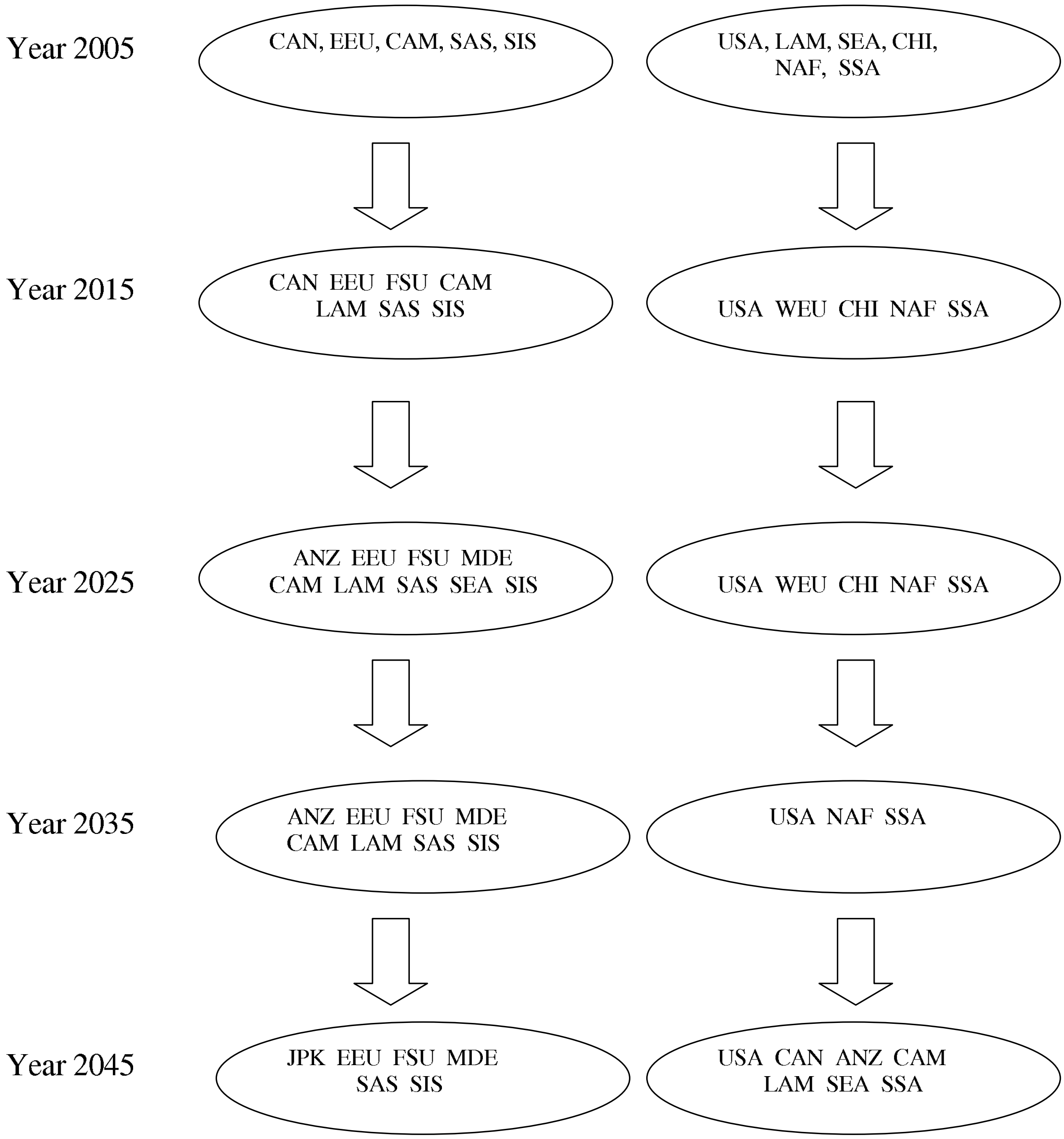

Figure 1: Farsighted stable coalitions for different time horizons.

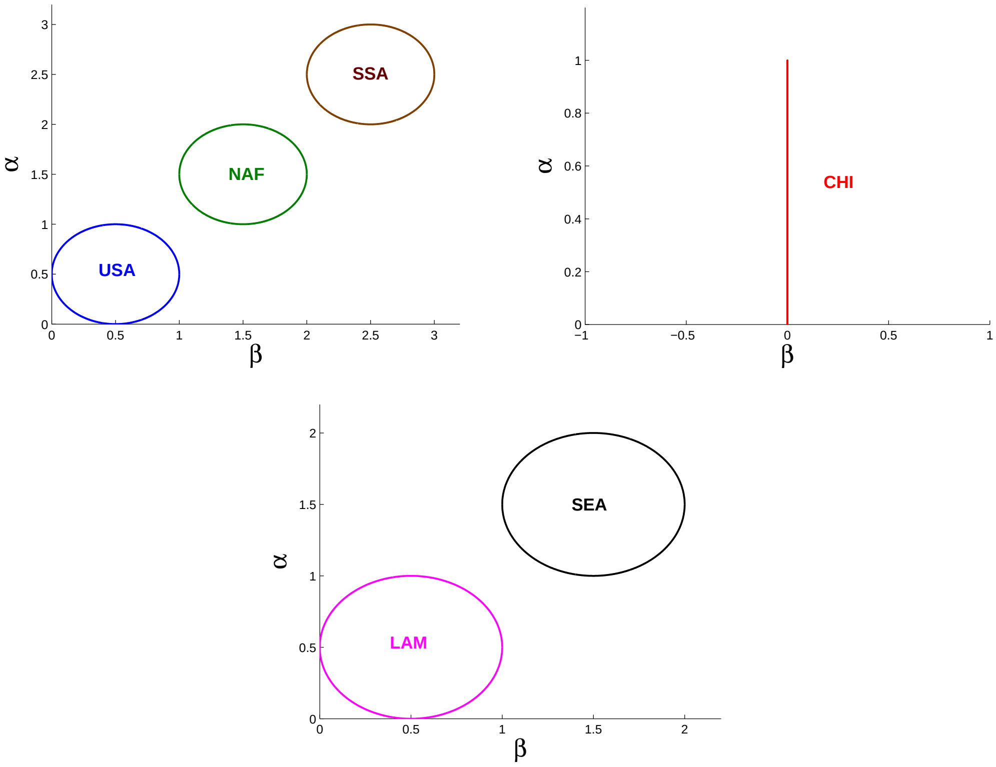

Figure 2: The relative change intervals of alphas and betas of each coalition-member that give a chance our coalition (USA, LAM, SEA, CHI, NAF, SSA) of being FS coalitions, *second optimization problem.*

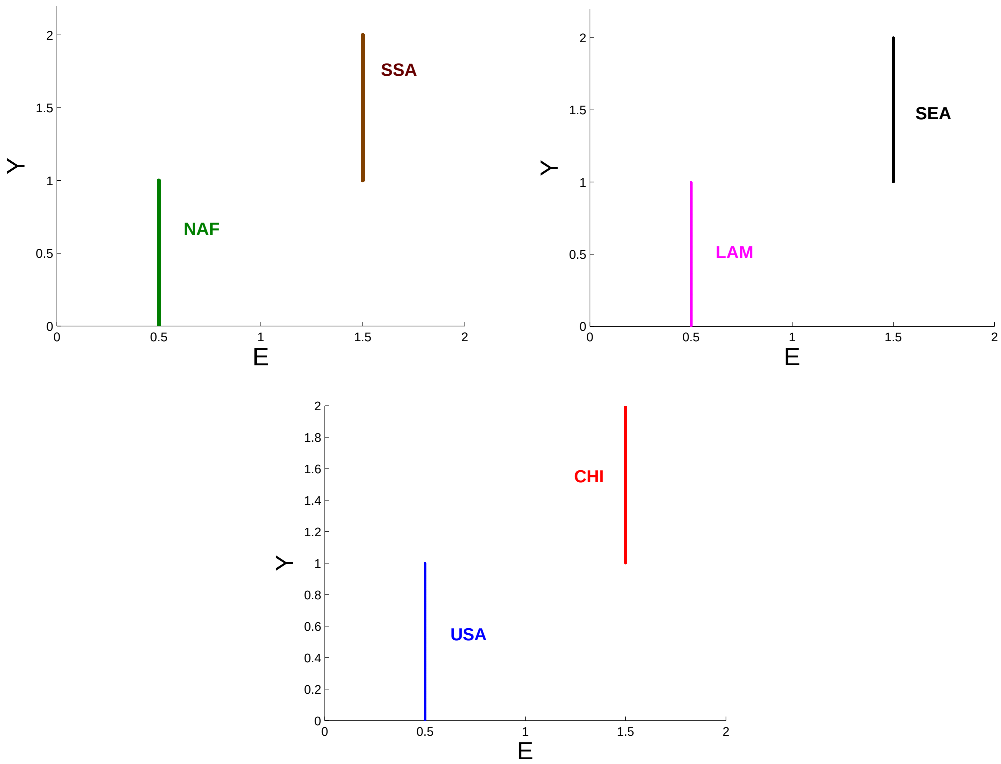

Figure 3: The relative change intervals of E and Y (GDP) of each coalition-member that give a chance our coalition (USA, LAM, SEA, CHI, NAF, SSA) of being FS coalitions, *second optimization problem.*

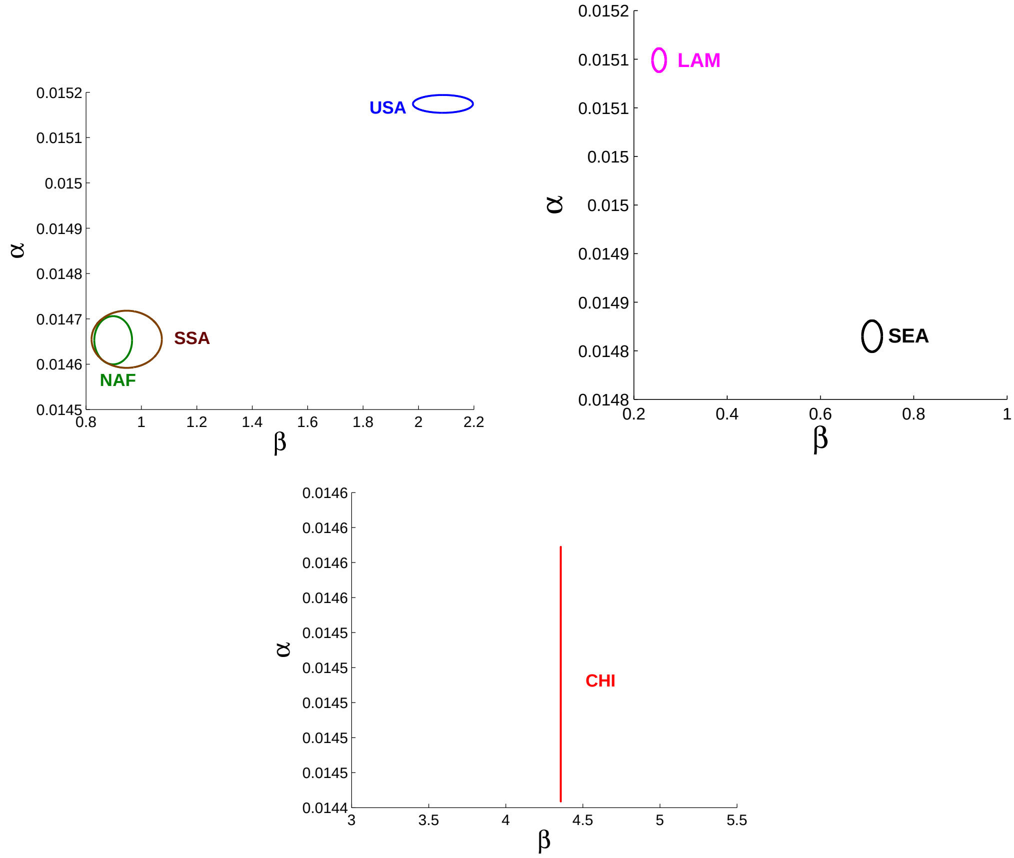

Figure 4: The absolute change intervals of alphas and betas of each coalition-member that give a chance our coalition (USA, LAM, SEA, CHI, NAF, SSA) of being FS coalitions, *second optimization problem*.

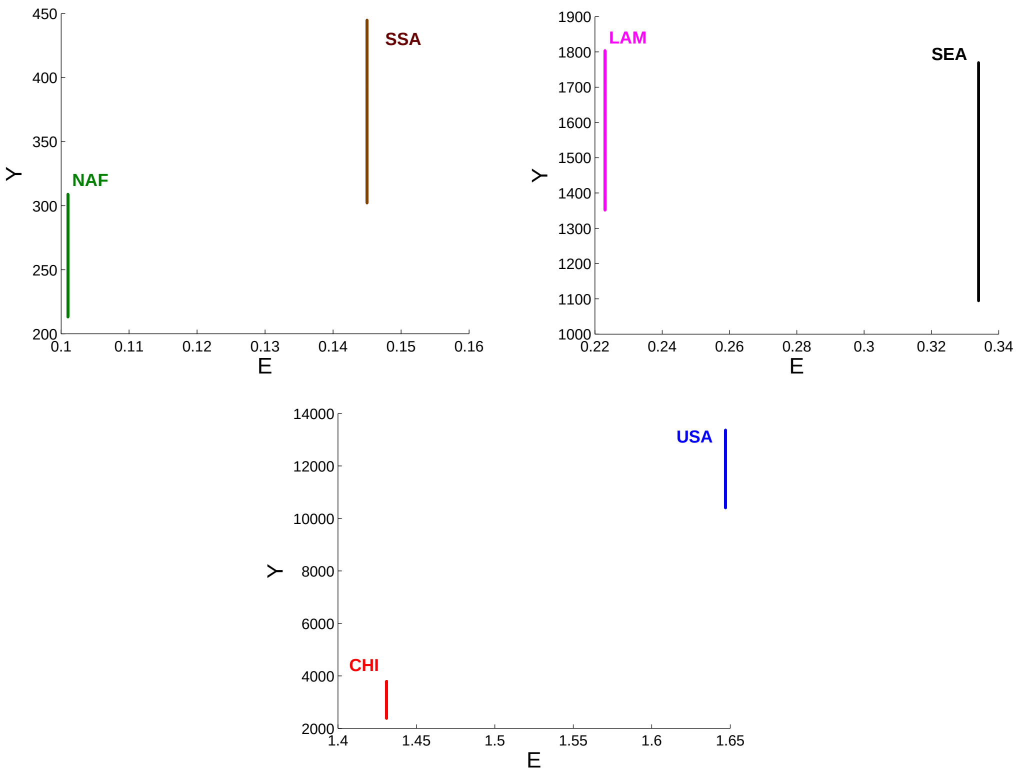

Figure 5: The absolute change intervals of E and Y (GDP) of each coalition-member that give a chance our coalition (USA, LAM, SEA, CHI, NAF, SSA) of being FS coalitions, *second optimization problem.*

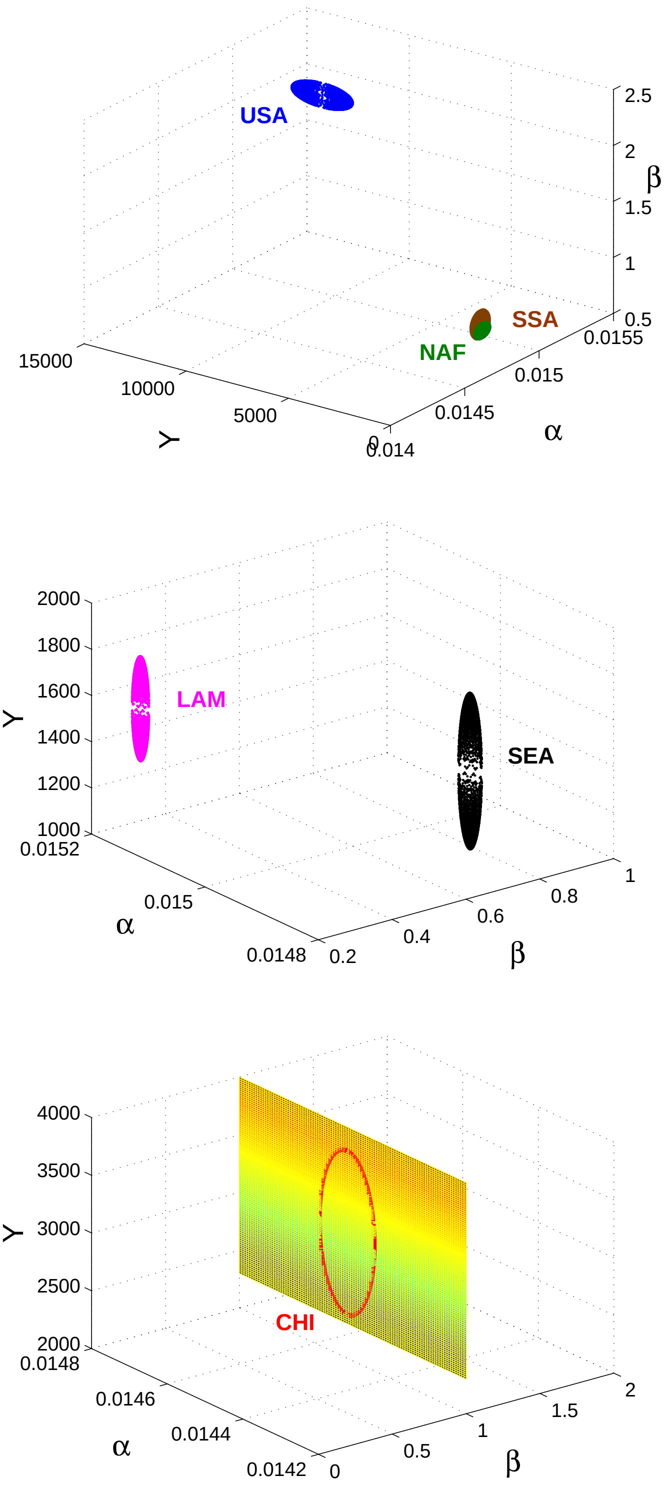

Figure 6: The absolute change intervals of alphas and betas and Y (GDP) of each coalition-member that give a chance our coalition (USA, LAM, SEA, CHI, NAF, SSA) of being FS coalitions, *second optimization problem.*

Table 5: Second coalition 2005, first optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
USA	1.0026	0.9014	1	1.0026	0.9014	1
LAM	1.0016	0.8942	1	1.0016	0.8942	1
SEA	1.0022	0.9431	1	1.0022	0.9431	1
CHI	1.0101	1.1958	1	1.0101	1	1.1958
NAF	1.0073	0.859	1	1.0073	0.859	1
SSA	1.0086	0.7637	1	1.0086	0.7637	1

Table 6: Second coalition 2005, first optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
USA	1.1026	1.2859	1	1.1026	1	1.2859
LAM	1.1928	1.3353	1	1.1928	1	1.3353
SEA	**1.3841**	1.6179	1	**1.4731**	1	1.6179
CHI	1.2565	1.5972	1	1.2565	1	1.5972
NAF	1.1881	1.4507	1	1.1881	1	1.4507
SSA	1.1655	1.4735	1	1.1655	1	1.4735

Table 7: First coalition 2025, first optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
ANZ	1.0013	2	1	1.0013	1	2
EEU	1.0024	1	1	1.0024	1	1
FSU	1.0053	0.8632	1	1.0053	0.8632	1
MDE	1.0039	1.1923	1	1.0079	1	1.1923
CAM	1.0036	1.0833	1	1.0036	1	1.0833
LAM	1.0026	0.8636	1	1.0026	0.8636	1
SAS	1	1	1	1.0064	1	1
SEA	1.0044	0.8906	1	1.0044	0.8906	1
SIS	1.0056	1.1429	1	1.0056	1	1.1429

Table 8: First coalition 2025, first optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
ANZ	1.1275	1.2229	1	1.1275	1	1.2229
EEU	1.2824	1.391	1	1.2824	1	1.391
FSU	**1.0796**	1.3891	1	**1.2711**	1	1.3891
MDE	1.1928	1.4532	1	1.1928	1	1.4532
CAM	1.175	1.3588	1	1.175	1	1.3588
LAM	1.1774	1.3553	1	1.1774	1	1.3553
SAS	1.1767	1.3924	1	1.1767	1	1.3924
SEA	1.1757	1.3909	1	1.1757	1	1.3909
SIS	1.1897	1.3645	1	1.1897	1	1.3645

Table 9: Second coalition 2025, first optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
USA	1.0005	0.875	1	1.0005	0.875	1
WEU	0.9975	0.9161	0.9975	1	0.9161	1
CHI	1.0044	0.9964	1	1.0044	0.9964	1
NAF	1.0069	0.8451	1	1.0069	0.8451	1
SSA	1.0067	0.7969	1	1.0067	0.7969	1

Table 10: Second coalition 2025, first optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
USA	**1.1167**	1.1784	1	**1.1199**	1	1.1784
WEU	1.1237	1.1775	1	1.1237	1	1.1775
CHI	1.2406	1.4057	1	1.2406	1	1.4057
NAF	1.1727	1.4761	1	1.1727	1	1.4761
SSA	1.1786	1.4784	1	1.1786	1	1.4784

Table 11: First coalition 2035, first optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
ANZ	1.0009	1.1667	1	1.0009	1	1.1667
EEU	1.002	0.9091	1	1.002	0.9091	1
FSU	1.0038	0.8659	1	1.0038	0.8659	1
MDE	1.0059	1.0645	1	1.0059	1	1.0645
CAM	1.003	1	1	1.003	1	1
LAM	1.0023	0.8947	1	1.0023	0.8947	1
SAS	1.0054	0.9487	1	1.0054	0.9487	1
SIS	1.0047	0.875	1	1.0047	0.875	1

Table 12: First coalition 2035, first optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
ANZ	1.113	1.1833	1	1.113	1	1.1833
EEU	1.2321	1.3171	1	1.2321	1	1.3171
FSU	**1.0827**	1.3147	1	**1.2297**	1	1.3147
MDE	1.1859	1.3954	1	1.1859	1	1.3954
CAM	1.1809	1.3373	1	1.1809	1	1.3373
LAM	1.1753	1.3339	1	1.1753	1	1.3339
SAS	1.1781	1.3703	1	1.1781	1	1.3703
SIS	1.1884	1.3425	1	1.1884	1	1.3425

Table 13: Second coalition 2005, second optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
USA	1.0026	0.9014	1	1.0026	0.9014	1
LAM	1.0016	0.8942	1	1.0016	0.8942	1
SEA	1.0022	0.9431	1	1.0022	0.9431	1
CHI	1.0101	1	1	1.0101	1	1.1958
NAF	1.0073	0.859	1	1.0073	0.859	1
SSA	1.0086	0.7637	1	1.0086	0.7637	1

Table 14: Second coalition 2005, second optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
USA	1	1.2859	1	1.1026	1	1.2859
LAM	1	1.3353	1	1.1928	1	1.3353
SEA	1	1.6179	1	1.4731	1	1.6179
CHI	1	1.5972	1	1.2565	1	1.5972
NAF	1	1.4507	1	1.1881	1	1.4507
SSA	1	1.4735	1	1.1655	1	1.4735

Table 15: First coalition 2025, second optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
ANZ	1.0013	1	1	1.0013	1	2
EEU	1.0024	1	1	1.0024	1	1
FSU	1.0053	**0.9421**	1	1.0053	**0.8632**	1
MDE	1.0079	1	1	1.0079	1	1.1923
CAM	1.0036	1	1	1.0036	1	1.0833
LAM	1.0026	0.8636	1	1.0026	0.8636	1
SAS	1.0064	1	1	1.0064	1	1
SEA	1.0044	0.8906	1	1.0044	0.8906	1
SIS	1.0056	1	1	1.0056	1	1.1429

Table 16: First coalition 2025, second optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
ANZ	1	**1.1750**	1	**1.1275**	1	1.2229
EEU	1	1.391	1	1.2824	1	1.391
FSU	1	1.3891	1	1.2711	1	1.3891
MDE	1	1.4532	1	1.1928	1	1.4532
CAM	1	1.3588	1	1.175	1	1.3588
LAM	1	1.3553	1	1.1774	1	1.3553
SAS	1	1.3924	1	1.1767	1	1.3924
SEA	1	1.3909	1	1.1757	1	1.3909
SIS	1	1.3645	1	1.1897	1	1.3645

Table 17: Second coalition 2025, second optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
USA	1.0005	**1**	1	1.0005	**0.875**	1
WEU	1	0.9161	0.9975	1	0.9161	1
CHI	1.002	0.9964	1	1.0044	0.9964	1
NAF	1.0069	0.8451	1	1.0069	0.8451	1
SSA	1.0067	0.7969	1	1.0067	0.7969	1

Table 18: Second coalition 2025, second optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
USA	1	1.1784	1	1.1199	1	1.1784
WEU	1	1.1775	1	1.1237	1	1.1775
CHI	1.0048	**1.3994**	1	1.2406	1	**1.4057**
NAF	1	1.4761	1	1.1727	1	1.4761
SSA	1	1.4784	1	1.1786	1	1.4784

Table 19: First coalition 2035, second optimization problem, variables x and z.

Coalition	x	z	lb_x	ub_x	lb_z	ub_z
ANZ	1.0009	1	1	1.0009	1	1.1667
EEU	1.002	0.9091	1	1.002	0.9091	1
FSU	1.0038	**0.9591**	1	1.0038	**0.8659**	1
MDE	1.0059	1	1	1.0059	1	1.0645
CAM	1.003	1	1	1.003	1	1
LAM	1.0023	0.8947	1	1.0023	0.8947	1
SAS	1.0054	0.9487	1	1.0054	0.9487	1
SIS	1.0047	0.875	1	1.0047	0.875	1

Table 20: First coalition 2035, second optimization problem, variables v and w.

Coalition	v	w	lb_v	ub_v	lb_w	ub_w
ANZ	1	**1.1582**	1	1.113	1	**1.1833**
EEU	1	1.3171	1	1.2321	1	1.3171
FSU	1	1.3147	1	1.2297	1	1.3147
MDE	1	1.3954	1	1.1859	1	1.3954
CAM	1	1.3373	1	1.1809	1	1.3373
LAM	1	1.3339	1	1.1753	1	1.3339
SAS	1	1.3703	1	1.1781	1	1.3703
SIS	1	1.3425	1	1.1884	1	1.3425

9 Appendix

9.1 Numerical comparison between different coalition structure for different time horizons

As it is expected the preferred farsightedly stable (PFS) coalitions improve substantially the welfare (*or profit*) and abatement levels[22] compared to atom structure[23], and the grand coalitions improve significantly welfare and abatement levels compared to PFS coalitions (and atom structure too)[24]. The PFS coalitions improve the welfare (and abatement level) until 2025 as European Union and China are members of PFS coalitions. Then it decreases again till 2045 when European Union and China are not members any longer, see Fig 7 (see Fig 8). The profit of grand coalition (and atom structure, see Fig 11) increases until 2035, than it decreases till year 2045, see Fig 9. On the other side, the abatement of grand coalition (and atom structure, see Fig 12) decreases constantly all the time, see Fig 10. Our claim is that decreasing emissions becomes more expensive from year to year.

The grand coalitions, PFS coalitions and atom structure improve the abatement levels for different time horizons, 2005, 2025 and 2045. China, Former Soviet Union and USA have economic incentives for reducing the carbon dioxide emissions (by more around $80-90\%$) (for atom structure see Fig 13, 14 and 15, for farsighted stable coalitions see Fig 16, 17 and 18, for grand coalitions see Fig 19, 20 and 21). Besides, the Former Soviet Union has a higher economic incentive to lower carbon dioxide emissions. South Asia and Middle East have bigger economic incentives to decrease carbon dioxide emissions in grand coalition compared to atom structure.

The welfare distribution, when two PFS coalitions (also true for grand coalition and atom structure) are formed (for different time horizons, 2005, 2025 and 2045) shows that China, Former Soviet Union and USA receive around half of all profits, but they contribute to $80-90\%$ of all emissions reductions (for atom structure see Fig 22, 23 and 24, for farsighted stable coalitions see Fig 25, 26 and 27, for grand coalitions see Fig 28, 29 and 30). It is sometimes possible for above countries to improve those disproportionalities (between abatement levels and profits) by joining (FSU joins PFS coalitions after year 2005) or leaving (China and Western European Union leave the PFS coalitions after year 2025) the PFS coalitions. The biggest winner remains always European Union[25] and the biggest loser is Former Soviet Union[26]. Moreover the loss of Former Soviet Union is increasing. Another big loser (only for years 2005 and 2015) is Japan[27]. Only for year 2045, it is possible for Japan to realize some profits by joining the PFS coalitions. A big loser is China also, it contributes strongly in decreasing of abatement levels but her welfare increases in small amount. Summing up the results, we reinforced the conclusion that it is not possible to imagine an IEA

[22]As our numerical results depend highly on assumptions of FUND model, one should take *the numerical comparison with carefulness*

[23]The preferred farsightedly stable coalitions improve the welfare (and abatement levels from 2.6 times for year 2045 to 5 times for year 2025) substantially compared to atom structure for all the years, from around 55 % for year 2045 to 2.4 times more for the year 2035. But the rate of welfare improvement (and abatement levels) decreases as China and European Union are not member of farsightedly stable coalition for the years 2035 and 2045.

[24]The welfare "gap" (and abatement "gap") between atom structure and grand coalitions remains more or less constant for all years, grand coalition improves the welfare by more than a factor 4 (and abatement level by a factor of 14-15) compared to atom structure. The grand coalition improves the welfare (and abatement levels) compared to farsightedly stable coalitions for all years. As it is expected the welfare "gap" (and abatement "gap") between grand coalition and farsightedly stable coalitions is smaller when China and European Union are members of farsightedly stable coalition (for years 2035 and 2045).

[25]Western European Union reduces its emissions less 2% but he receives $28-38\%$ of profits (taking the average of welfare and abatement levels of each coalition structure on different time horizons).

[26]Former Soviet Union decreases his emissions by $18-38\%$, but his welfare varies from -20% to 8% (taking the average of welfare and abatement levels of each coalition structure on different time horizons)

[27]Japan decreases its emissions by $0.02-0.4\%$, but her welfare lowers by $6-8\%$ (taking the average of welfare and abatement levels of each coalition structure on different time horizons)

without participation of countries like Western European Union, USA, China and Soviet Union. As only economic incentives are considered, we receive a picture that is not realistic. European Union is not a member of farsightedly coalitions till 2025 which contradicts the reality. This occurs because we do not consider any commitment to environmental protection, and perhaps the cost of environmental protection are too high[28]. The above numerical comparison is a appealing point that a more cooperative attitude and transfers are essential in order to have a stable IEA. Besides, FUND suggests that the transfers should flow mostly from European Union (or in a smaller amount from USA) to Former Soviet Union or China. A "farsightedly non-cooperative world" shifts the costs of environmental protection to China and Former Soviet Union (sometimes to South Asia and Middle East) while the profits are reallocated mainly to European Union and USA.

[28]On the contrary, in a cooperative approach, WEU is a key player (we check only year 2005, when WEU is not a member of farsightedly stable coalitions), but the cooperative attitude is out of scope of our paper. WEU is always a member of coalitions (CHI, FSU and USA too) which achieve the maximum welfare improvement, although they are not stable. "Only a cooperative behavior", which determines also how to distribute the welfare, can make the above coalitions stable. As its is known, enforcing a cooperative behavior is difficult because of free-riding.

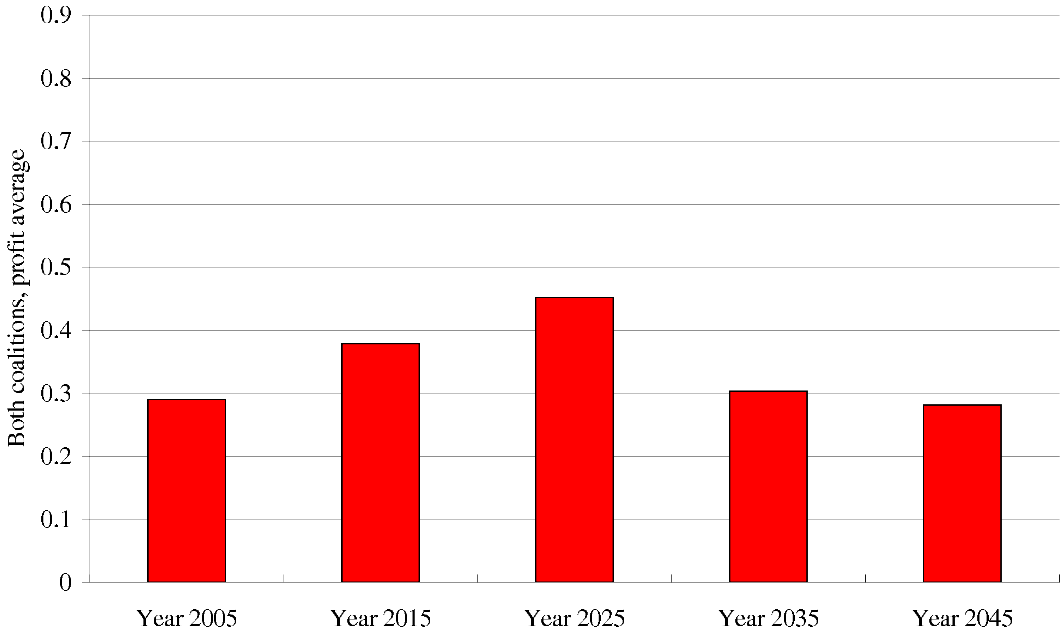

Figure 7: Average profit when two farsighted stable coalitions are formed, different time horizons.

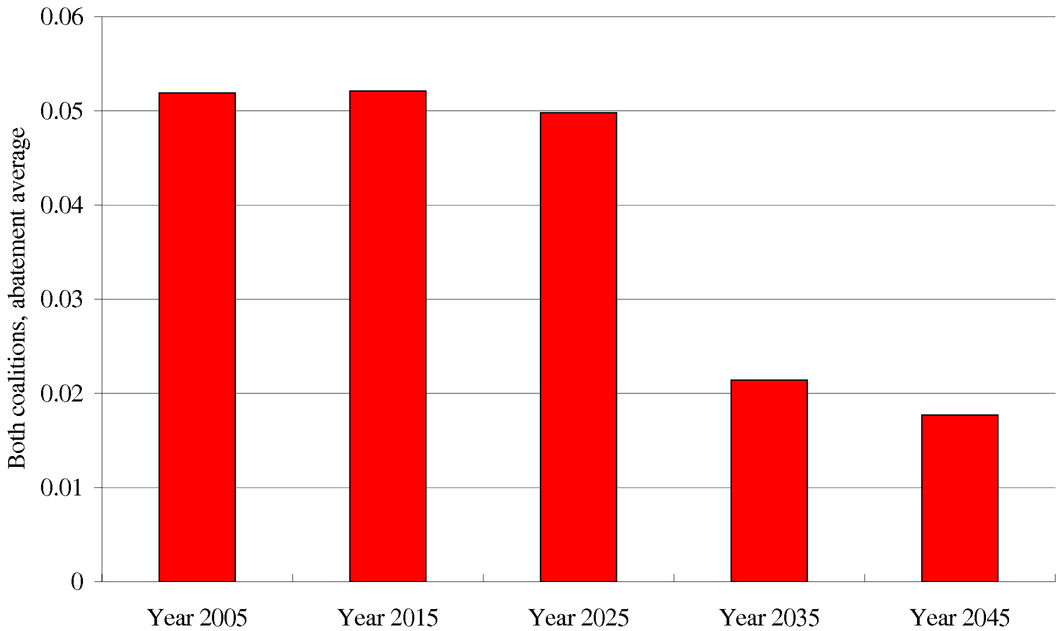

Figure 8: Average abatement when two farsighted stable coalitions are formed, different time horizons.

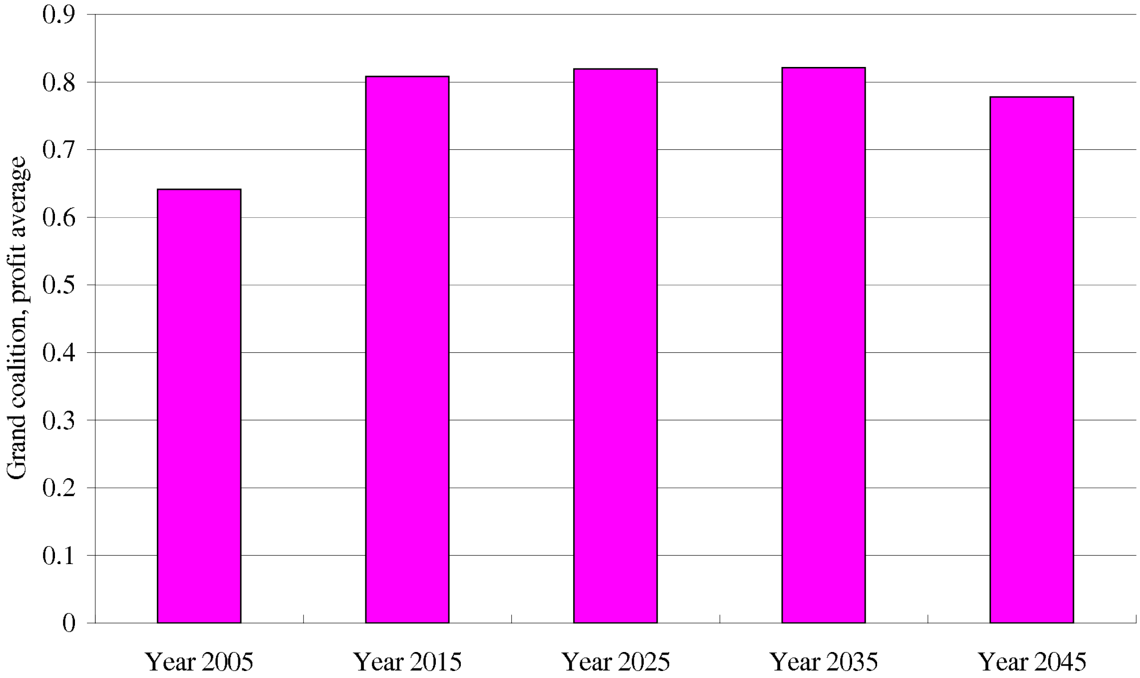

Figure 9: Average profit for grand coalition, different time horizons.

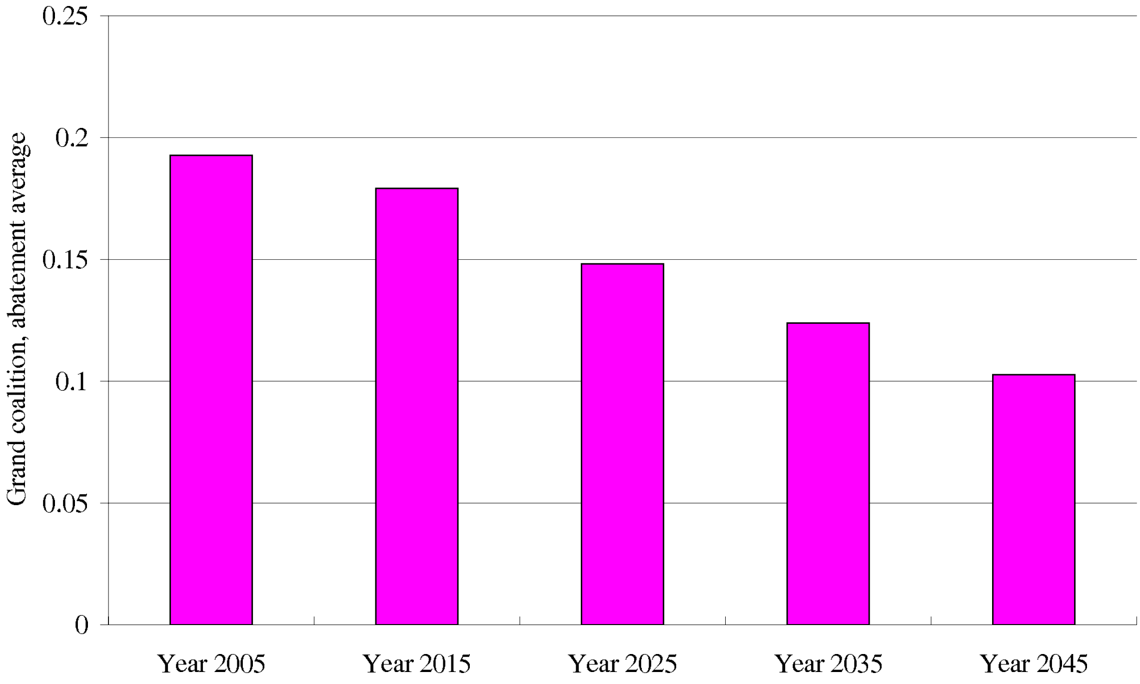

Figure 10: Average abatement for grand coalition, different time horizons.

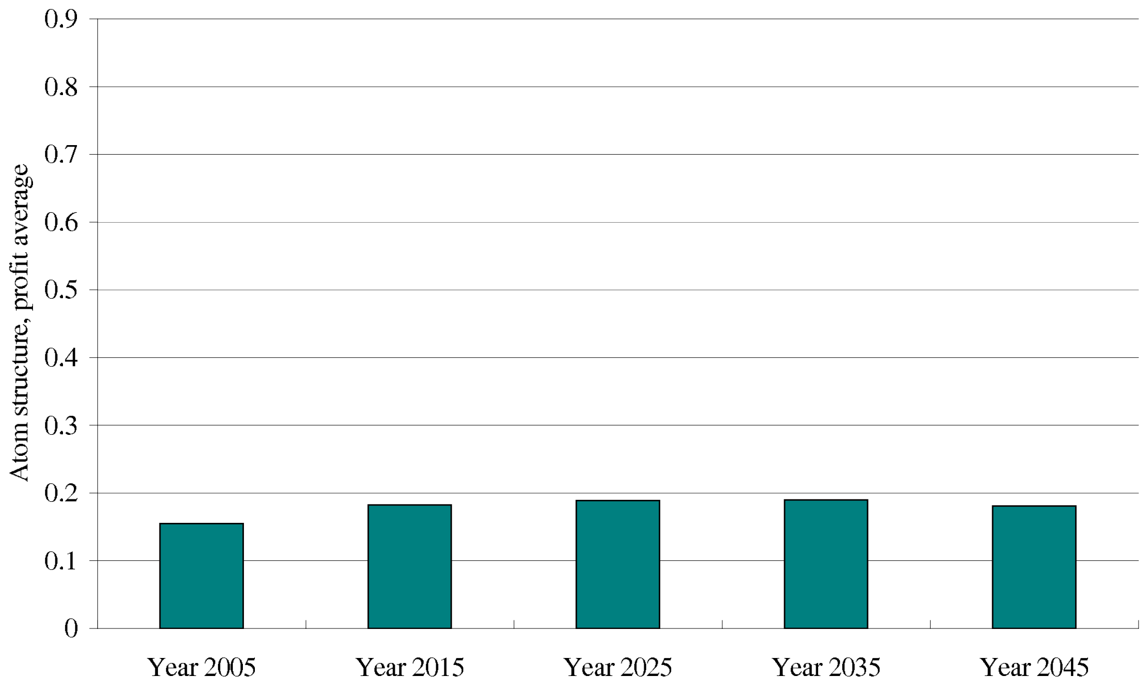

Figure 11: Average profit for atom structure, different time horizons.

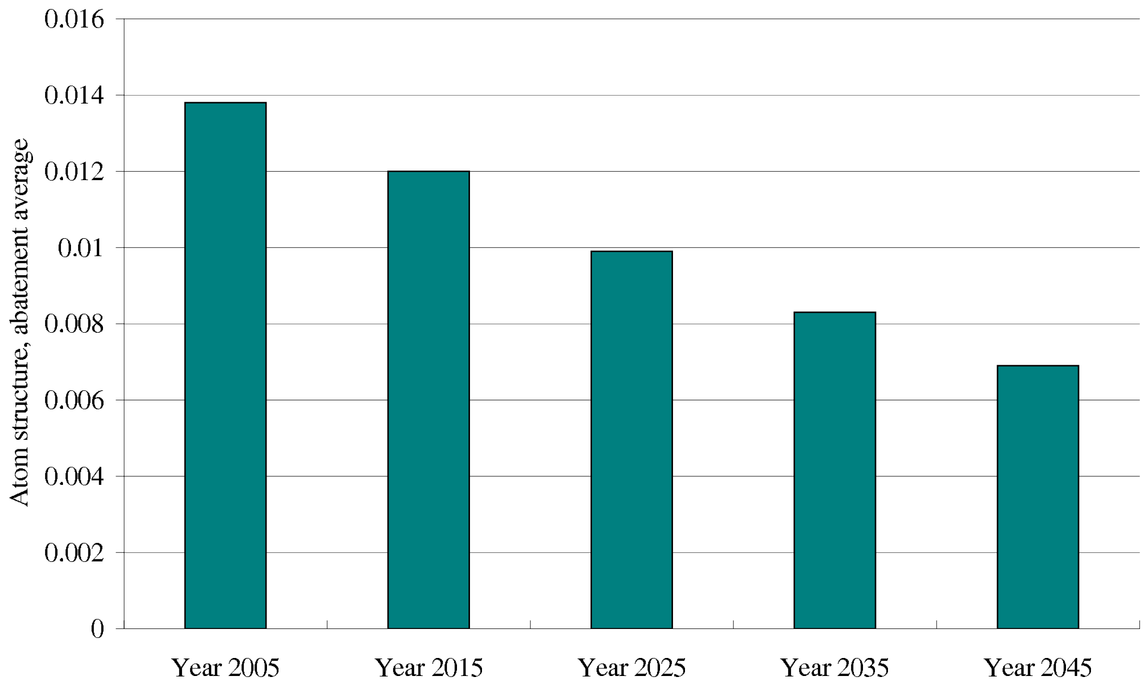

Figure 12: Average abatement for atom structure, different time horizons.

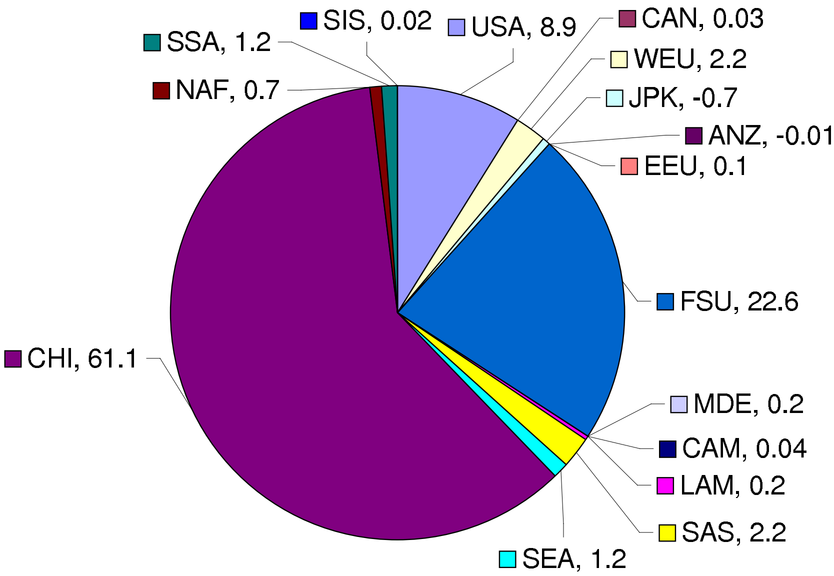

Figure 13: The share of abatement level for each region (in percentage) in atom structure, year 2005.

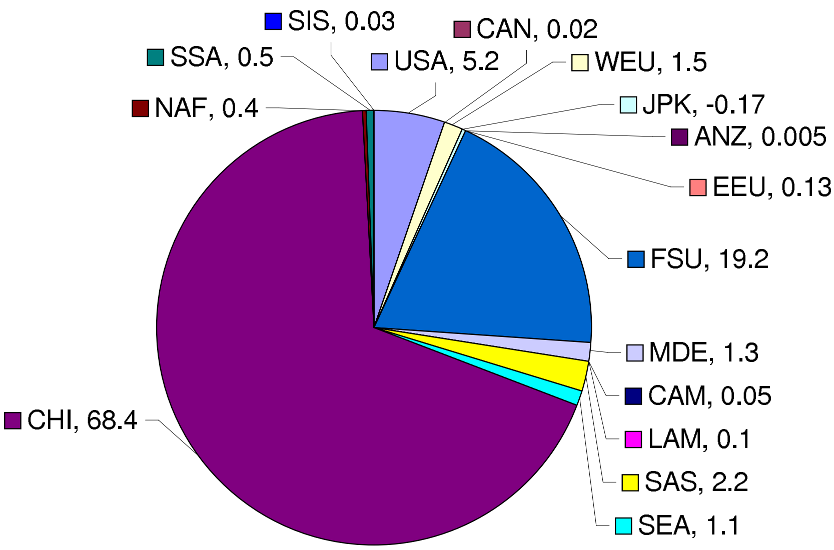

Figure 14: The share of abatement level for each region (in percentage) in atom structure, year 2025.

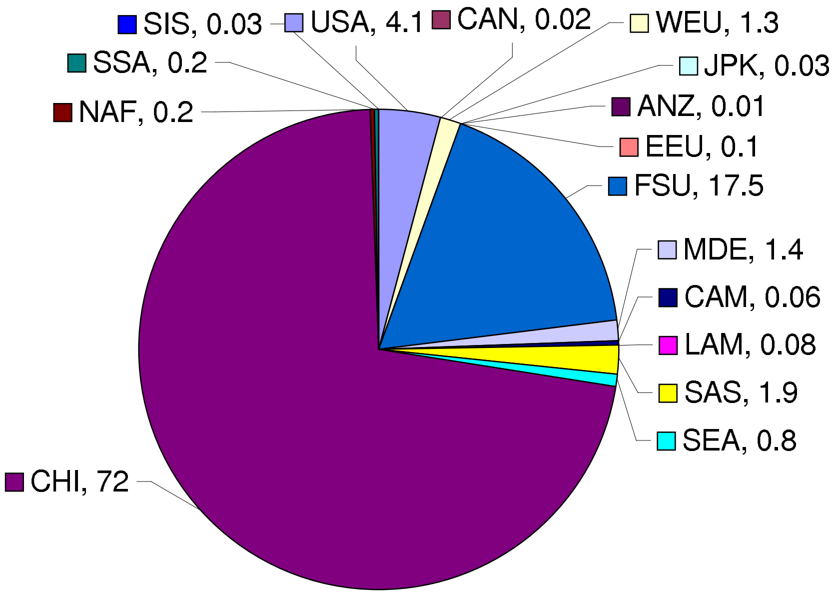

Figure 15: The share of abatement level for each region (in percentage) in atom structure, year 2045.

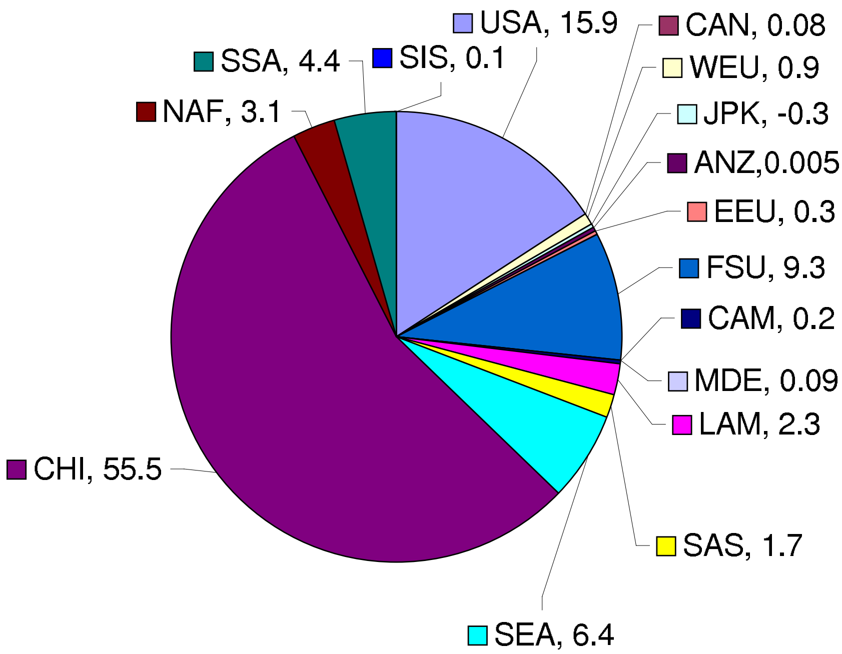

Figure 16: The share of abatement level for each region (in percentage) when two preferred far-sighted stable coalition are formed, year 2005.

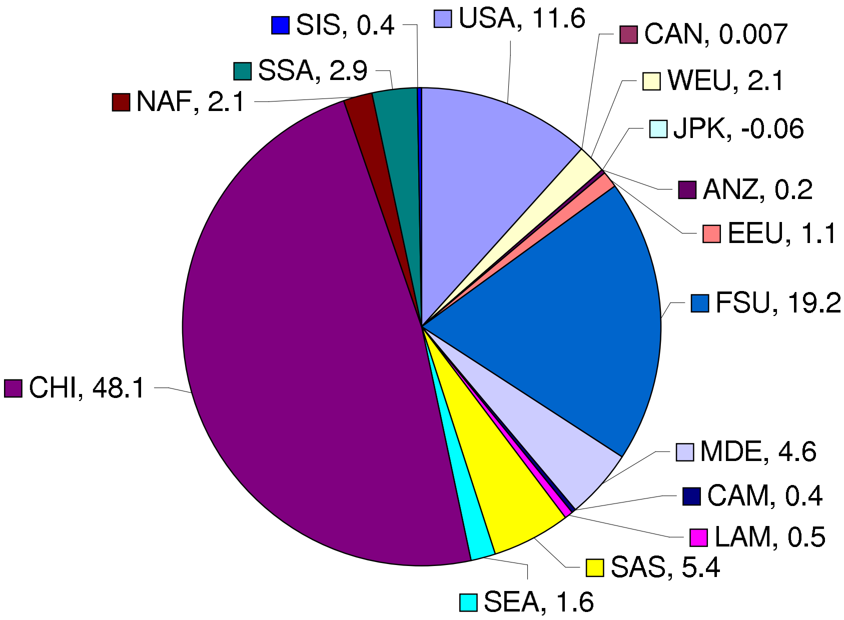

Figure 17: The share of abatement level for each region (in percentage) when two preferred far-sighted stable coalition are formed, year 2025.

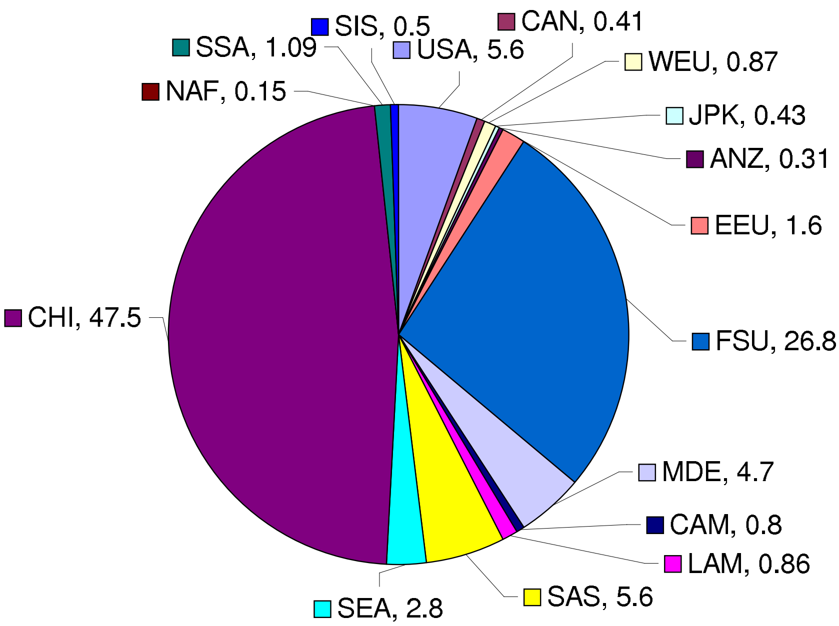

Figure 18: The share of abatement level for each region (in percentage) when two preferred far-sighted stable coalition are formed, year 2045.

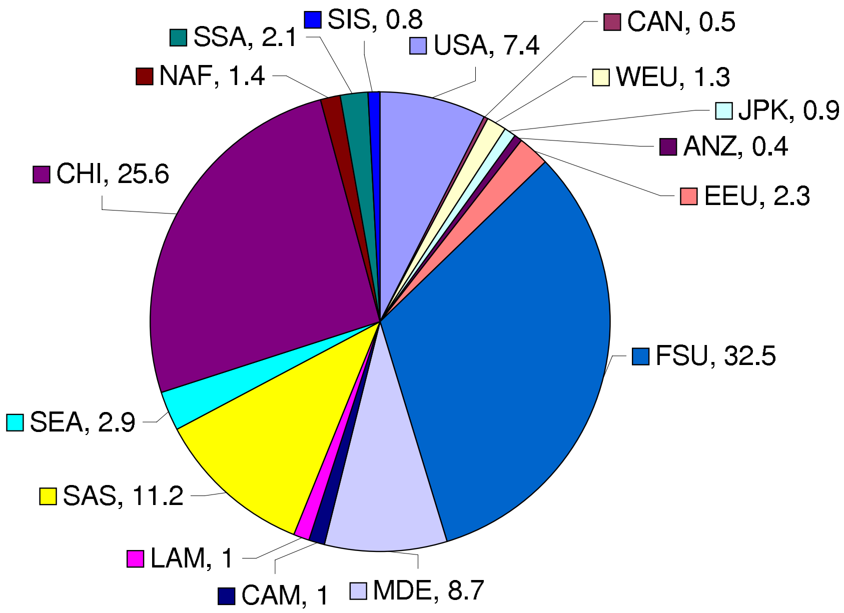

Figure 19: The share of abatement level for each region (in percentage) for grand coalition, year 2005.

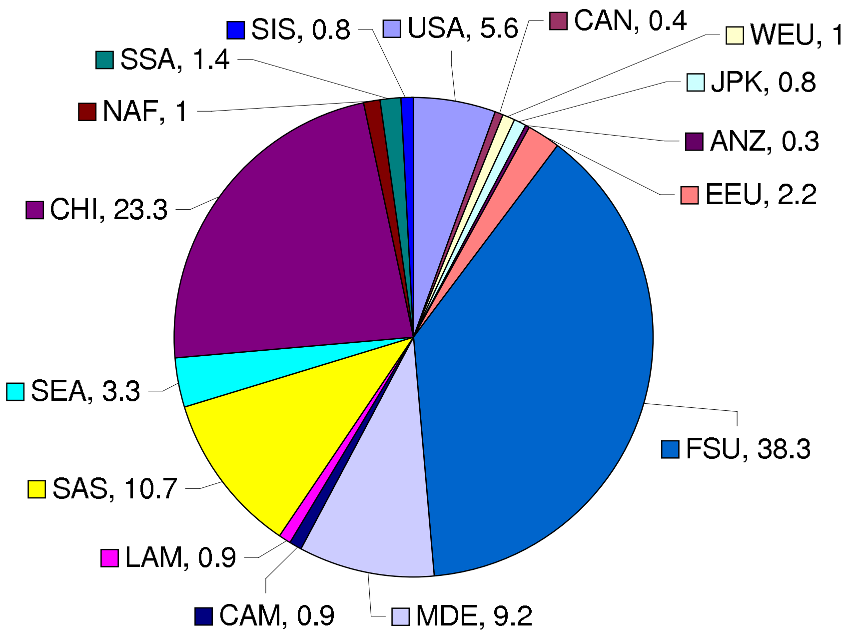

Figure 20: The share of abatement level for each region (in percentage) for grand coalition, year 2025.

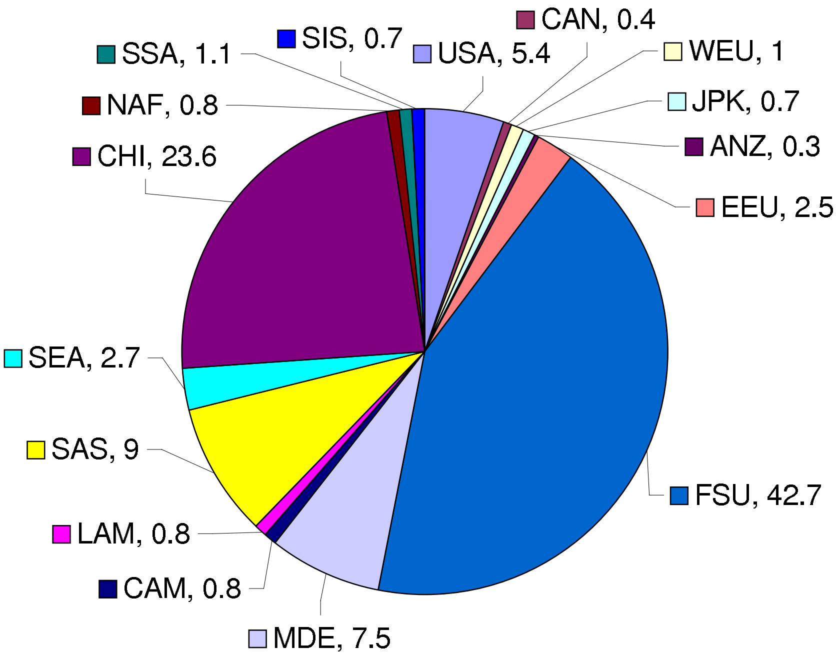

Figure 21: The share of abatement level for each region (in percentage) for grand coalition, year 2045.

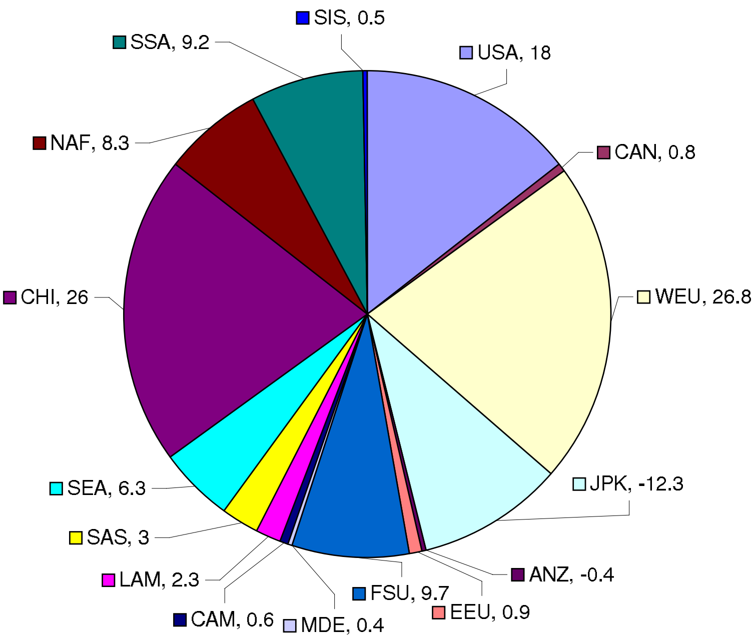

Figure 22: The profit share for each region (in percentage) in atom structure, year 2005.

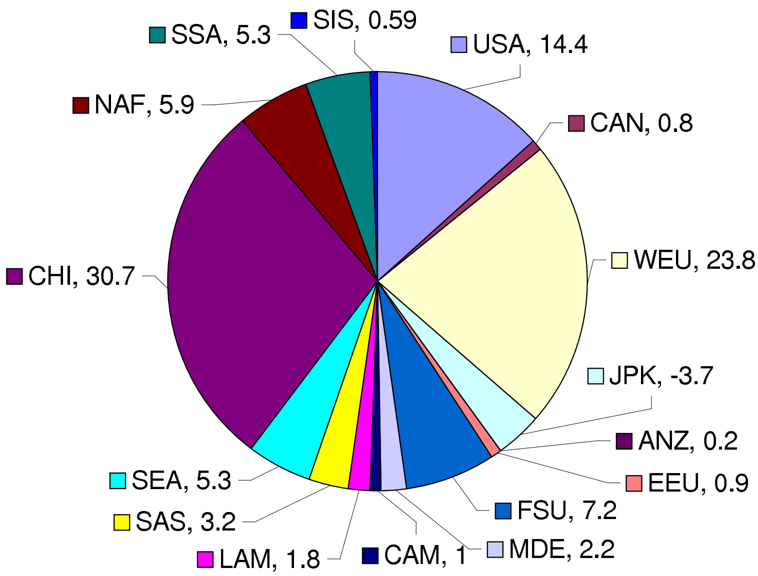

Figure 23: The profit share for each region (in percentage) in atom structure, year 2025.

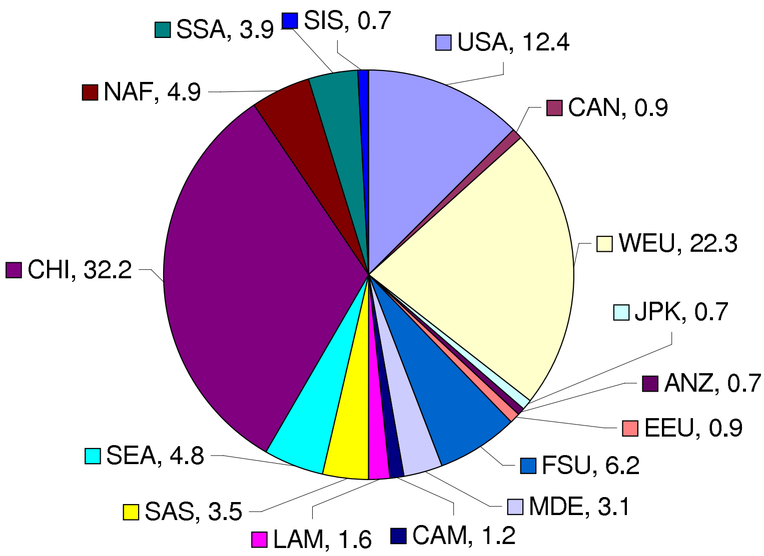

Figure 24: The profit share for each region (in percentage) in atom structure, year 2045.

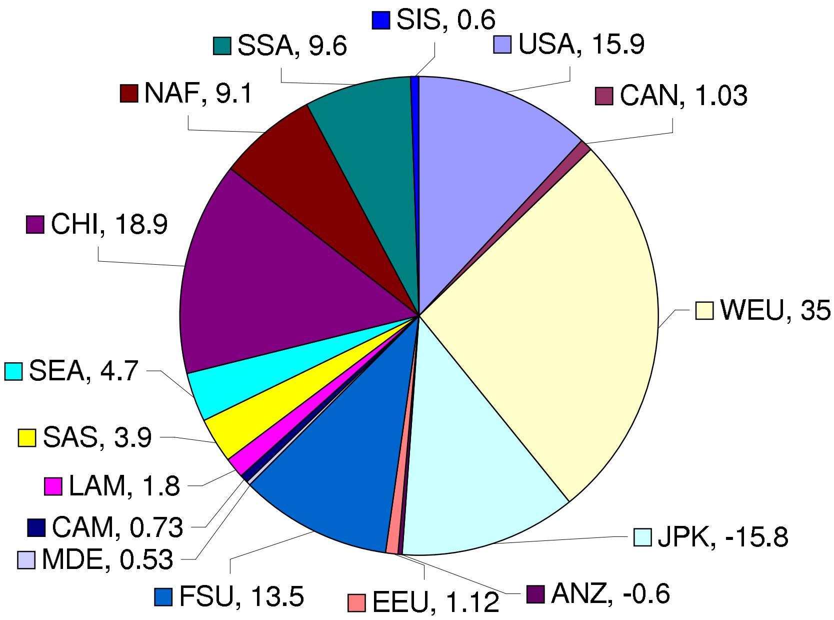

Figure 25: The profit share for each region (in percentage) when two preferred farsighted stable coalition are formed, year 2005.

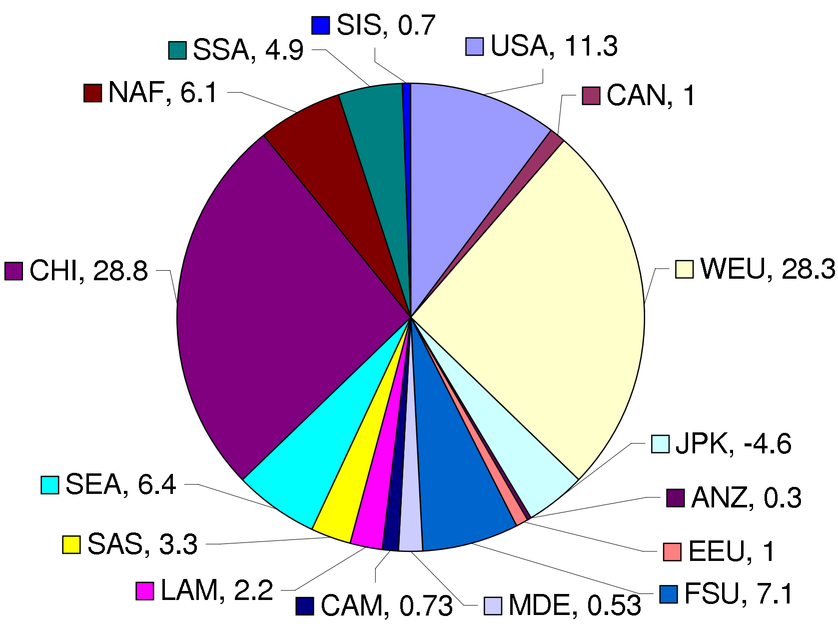

Figure 26: The profit share for each region (in percentage) when two preferred farsighted stable coalition are formed, year 2025.

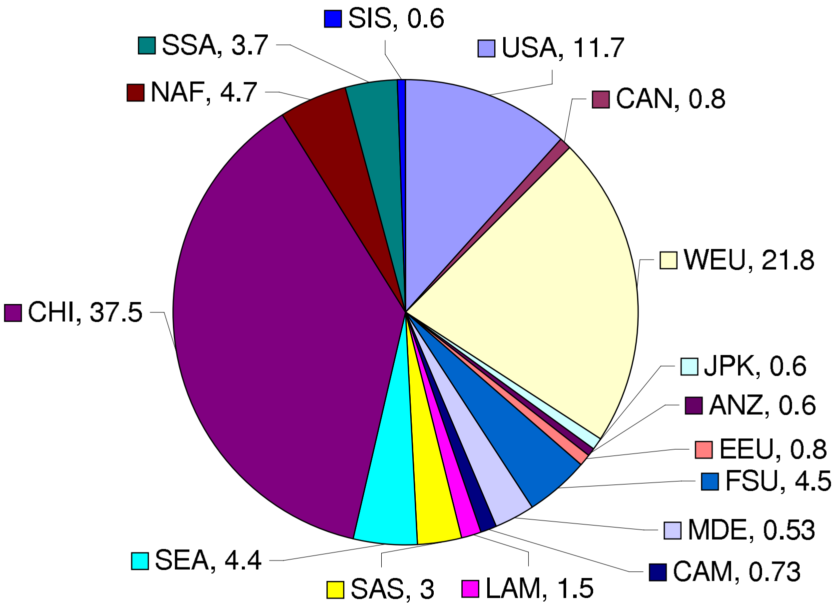

Figure 27: The profit share for each region (in percentage) when two preferred farsighted stable coalition are formed, year 2045.

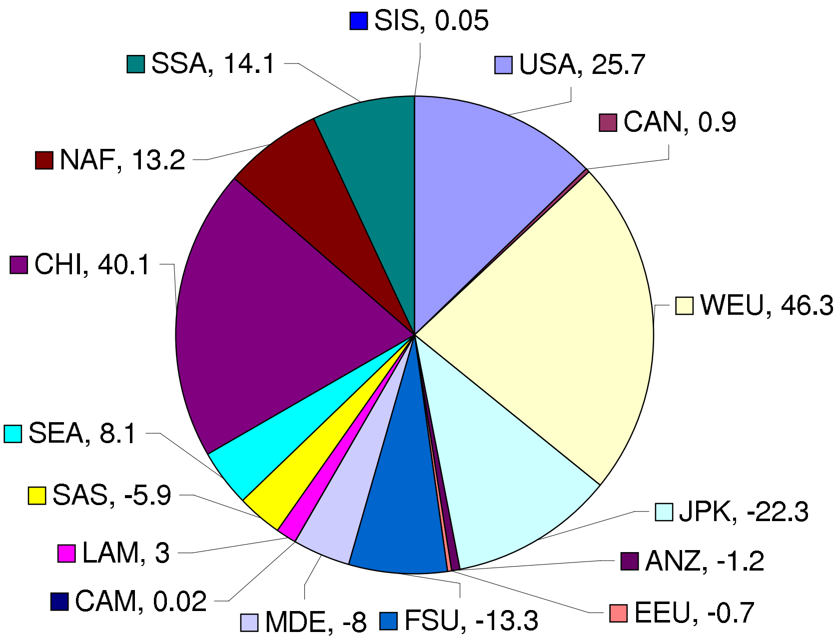

Figure 28: The profit share for each region (in percentage) in grand coalition, year 2005.

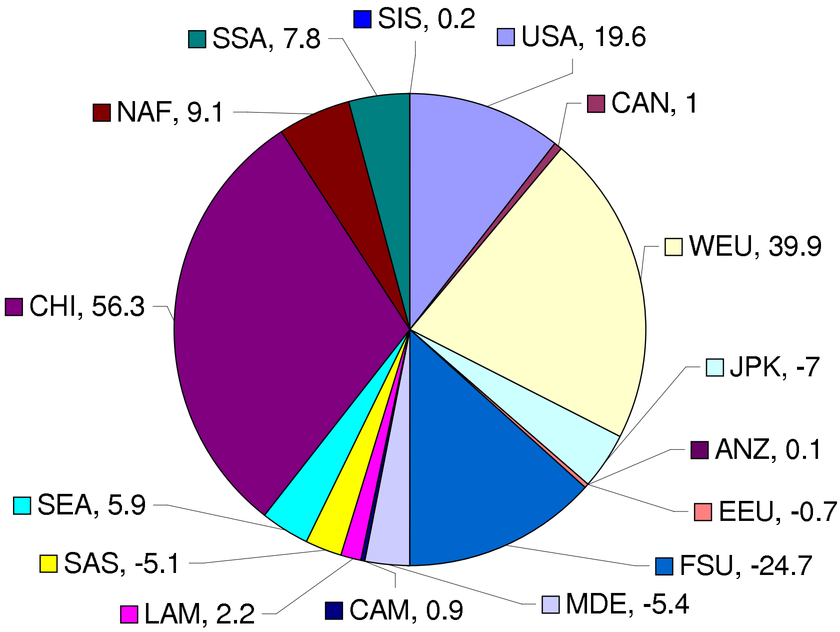

Figure 29: The profit share for each region (in percentage) in grand coalition, year 2025.

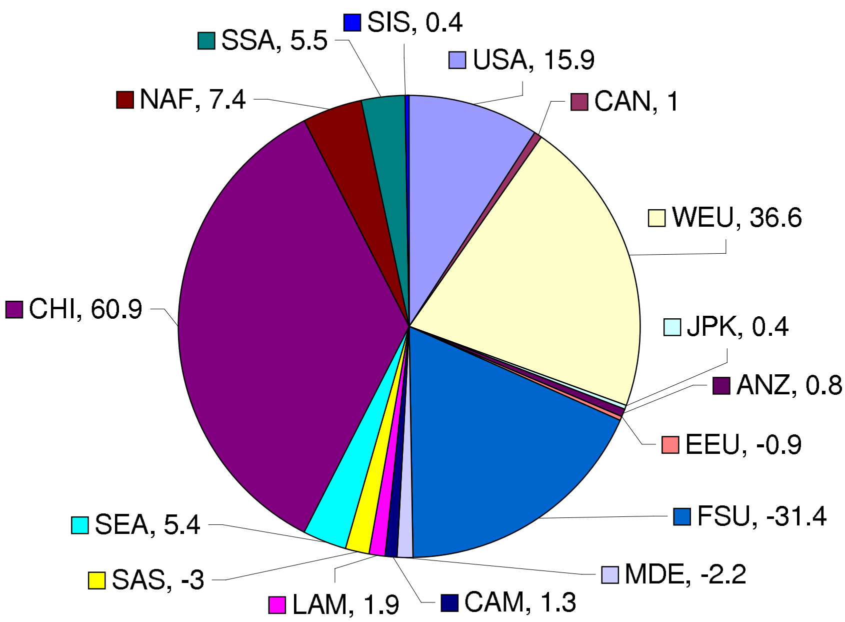

Figure 30: The profit share for each region (in percentage) in grand coalition, year 2045.

References

[1] Asheim, B.G, Froyn, B.C, Hovi. J, Menz, C.F. (2006) Regional versus Global Cooperation for Climate Control *Journal of Environmental Economics and Management 51,* 92-109.

[2] Barrett, S. (1994) Self-Enforcing International Environmental Agreements *Oxford Economic Papers 46,* 878-894.

[3] Barrett, S. (2003) Environment and Statecraft: The strategy of Environmental Treaty- Making *Oxford University Press, Oxford.*

[4] Batjes J.J, Goldewijk C.G.M. (1994) The IMAGE 2 hundred year (18901990) database of the global environment (HYDE) 410100082. *RIVM, Bilthoven.*

[5] Botteon, M, Carraro, C. (2001) Environmental coalitions with heterogeneous coun- tries: Burden-sharing and carbon leakage *in A.Ulph ed., Environmental Policy, Inter- national Agreements, and International Trade, Oxford, O.U.P.*

[6] Carraro, C, Eyckmans, J, Finus, M. (2006) Optimal Transfers and Participation Decisions in International Environmental Agreements *The Review of International Organization 1(4),* 379-396.

[7] Carraro, C, Siniscalco, D. (1998) International Environmental Agreements: Incentives and Political Economy *European Economic Review 42,* 561-572.

[8] Chander, P. (2007) The gamma-core and coalition formation *International Journal of Game Theory 35(4),* 379-401.

[9] Chander, P, Tulkens, H. (1995) A Core-Theoretic Solution for the Design of Cooperative Agreemnets on Transfrontier Pollution *International Tax and Public Finance 2,* 279-293.

[10] Chander, P, Tulkens, H. (1997) The Core of an Economy with Multilateral Environmental Externalities *International Journal of Game Theory,* 379-401.

[11] Chander, P, Tulkens, H. (2006) Cooperation, Stability and Self-Enforcement in International Environmental Agreements: A Conceptual Discussion *Working Papers FEEM 34.*

[12] Chwe, M. (1994) Farsighted coalitional stability *Journal of Economic Theory 63,* 299-325.

[13] Cline W.R. (1992) The economics of global warming. *Institute for International Economics, Washington, DC.*

[14] D'Aspremont, C.A, Jacquemin, J, Gabszeweiz, J, Weymark, J.A. (1983) On the Stability of Collusive Price Leadership *Canadian Journal of Economics 16,* 17-25.

[15] Diamantoudi, E. Sartzetakis, E. (2002) International environmental agreements the role of foresight *mimeo.*

[16] Eyckmans, J. (2003) On the farsighted stability of international climate agreements *mimeo.*

[17] Eyckmans, J, Tulkens, H. (2003). Simulating coalitionally stable burden sharing agreements for the climate change problem *Resource and Energy Economics 25,* 299-327.

[18] Fankhauser, S. (1994) Protection vs. Retreat – The Economic Costs of Sea Level Rise *Environment and Planning A 27,* 299-319.

[19] Fehr, E, Gaechter, S. (2000) Cooperation and punishment in public goods experiments *American Economic Review 90,* 980-994.

[20] Finus, M. (2003) Stability and Design of International Environmental Agreements: The Case of Global and Transboundary Pollution *Folmer, H. and T. Tietenberg eds., International Yearbook of Environmental and Resource Economics, 2003/4, Edward Elgar, Cheltenham, UK,* 82-158.

[21] Finus, M, van E. Ierland, Dellink, R. (2006) *Stability of climate coalitions in a cartel formation game. Economics of Governance 7,* 271-291.

[22] Hammitt J.K, Lempert R.J, Schlesinger M.E. (1992) A sequential-decision strategy for abating climate change *Nature 357,* 315318.

[23] Ioannidis. A, Papandreou. A, Sartzetakis. E. (2000) International Environmental Agreements: a Literature Review *Working Papers, GREEN.*

[24] Kattenberg, A, Giorgi, F, Grassl, H, Meehl, G. A, Mitchell, J. F. B, Stouffer, R. J, Tokioka, T, Weaver, A. J, Wigley, T. M. L. (1996), Climate Models - Projections of Future Climate, in Climate Change 1995: The Science of Climate Change *Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, 1 edn, J. T. Houghton et al., eds., Cambridge University Press, Cambridge, pp. 285-357.*

[25] Leggett, J, Pepper, W. J, Swart, R. J. (1992), Emissions Scenarios for the IPCC: An Update, in Climate Change 1992 *The Supplementary Report to the IPCC Scientific Assessment, 1 edn, vol. 1 J. T. Houghton, B. A. Callander, S. K. Varney, eds., Cambridge University Press, Cambridge, pp. 71-95.*

[26] Link, P. M, Tol, R. S. J. (2004) Possible economic impacts of a shutdown of the thermohaline circulation: an application of FUND *Portuguese Economic Journal 3,* 99-114.

[27] Maier-Reimer, E, Hasselmann, K. (1987) Transport and storage of carbon dioxide in the ocean: an inorganic ocean circulation carbon cycle model *Climate Dynamics 2, 6390*

[28] McGinty, M. (2007) International environmental agreements among asymmetric nations *Oxford Economic Papers 59,* 45-62.

[29] Mendelsohn, R, Morrison, W, Schlesinger, M. E, Andronova, N. G. (2000) Country-specific market impacts of climate change *Climatic Change 45,* 553-569.

[30] Osmani, D, Tol, R. S. J. (2006) The Case of Two Self-Enforcing International Environmental Agreements for Environmental Protection *Working Papers, FNU-82.*

[31] Osmani, D, Tol, R. S. J. (2007a) Toward Farsightedly Stable International Environmental Agreements: Part One *Working Papers, FNU-140.*

[32] Osmani, D, Tol, R. S. J. (2007b) Toward Farsightedly Stable International Environmental Agreements: Part Two *Working Papers, FNU-149.*

[33] Ostrom, E. (2000) Collective action and the evolution of social norms *The Journal of Economic Perspectives, 14(3)* 137-158.

[RU] Rubio, J. S, Ulph. U. (2006) Self-enforcing international environmental agreements revisited. *Oxford Economic Papers 58,* 223-263.

[34] Shine, K. P, Derwent, R. G, Wuebbles, D. J, Morcrette, J. J. (1990) Radiative Forcing of Climate in Climate Change *The IPCC Scientific Assessment, 1 edn, vol. 1 J. T. Houghton, G. J. Jenkins, J. J. Ephraums, eds. (eds.), Cambridge University Press, Cambridge, pp. 41-68.*

[35] Tol, R. S. J. (1995) The Damage Costs of Climate Change Toward More Comprehensive Calculations *Environmental and Resource Economics 5, 353-374.*

[36] Tol, R. S. J. (1996) The Damage Costs of Climate Change Towards a Dynamic Representation *Ecological Economics 19, 67-90.*

[37] Tol, R. S. J. (1999a) Spatial and Temporal Efficiency in Climate Change: Applications of FUND *Environmental and Resource Economics, 14 (1)* 33-49.

[38] Tol, R. S. J. (1999b) Kyoto, Efficiency, and Cost-Effectiveness: Applications of FUND *Energy Journal Special Issue on the Costs of the Kyoto Protocol: A Multi-Model Evaluation,* 130-156.

[39] Tol, R. S. J. (2001) Equitable Cost-Benefit Analysis of Climate Change *Ecological Economics, 36(1),* 71-85.

[40] Tol, R. S. J. (2002a) Estimates of the Damage Costs of Climate Change - Part 1: Benchmark Estimates *Environmental and Resource Economics, 21,* 47-73.

[41] Tol, R. S. J. (2002b) Estimates of the Damage Costs of Climate Change - Part 2: Dynamic Estimates *Environmental and Resource Economics, 21,* 135-160.

[42] Tol, R. S. J. (2002c) Welfare specifications and optimal control of climate change: an application of FUND *Energy Economics, 24,* 367-376.

[43] Tol, R. S. J. (2005a) The Marginal Damage Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties *Energy Policy, 33(16),* 2064-2074.

[44] Tol, R. S. J. (2005b) An Emission Intensity Protocol for Climate Change: An Application of FUND *Climate Policy, 4,* 269-287.

[45] Tol, R. S. J. (2006) Multi-Gas Emission Reduction for Climate Change Policy: An Application of FUND *Energy Journal 11.*

[46] W.R.I World Resources Database (2000-2001) *World Resources Institute, Washington, DC.*

[47] Xue, L. (1998) Coalitional Stability under Perfect Foresight *Economic Theory 11,* 603-627.

[48] Zeeuw, A. de (2005) Dynamic Effects on the Stability of International Environmental Agreements *Working Papers FEEM 41.*

Working Papers
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Osmani, D. (2008) Evolution in time of Farsightedly Stable Coalitions, FNU-162 (submitted)

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Rehdanz, K. and D.J. Maddison (2006), Local Environmental Quality and Life Satisfaction in Germany, FNU-119 (forthcoming, Ecological Economics)

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Rckmann, C., U.A. Schneider, M.A. St.John, and R.S.J. Tol (2005), Rebuilding the Eastern Baltic cod stock under environmental change - a preliminary approach using stock, environmental, and management constraints, FNU-84 (Natural Resources Modelling, 20 (2), 223-262)

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Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), The impact of climate on holiday destination choice, FNU-55 (Climatic Change, 76 (3-4), 389-406)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), A global database of domestic and international tourist numbers at national and subnational level, FNU-54 (International Journal of Tourism Research, 9, 147-174)

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Zhou, Y. and Tol, R.S.J. (2004), Evaluating the costs of desalination and water transport, FNU-41 (Water Resources Research, 41 (3), W03003)

Lau, M. (2004), Kstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg,FNU-40 (Coastline Reports (1), 213-224.)

Rehdanz, K. and D.J. Maddison (2004), The Amenity Value of Climate to German Households, FNU-39 (submitted)

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise, FNU-38 (Environmental and Resource Economics, 37, 549-571)

Schwoon, M. and Tol, R.S.J. (2004), Optimal CO2-abatement with socio-economic inertia and induced technological change, FNU- 37 (Energy Journal, 27 (4), 25-60)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), The Effects of Climate Change on International Tourism, FNU-36 (Climate Research, 29, 255-268)

Hansen, O. and R.S.J. Tol (2003), A Refined Inglehart Index of Materialism and Postmaterialism, FNU-35 (submitted)

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Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), Climate change and international tourism: a simulation study, FNU-31 (Global Environmental Change, 15 (3), 253-266)

Link, P.M. and R.S.J. Tol (2003), Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea, FNU-30 (ICES Journal of Marine Science, 63 (4), 611-625)

Link, P.M. (2003), Auswirkungen populationsdynamischer Vernderungen in Fischbestnden auf die Fischereiwirtschaft in der Barentssee, FNU-29 (Essener Geographische Arbeiten, 35, 179-202)

Lau, M. (2003), Coastal Zone Management in the Peoples Republic of China An Assessment of Structural Impacts on Decisionmaking Processes, FNU-28 (Ocean & Coastal Management, No. 48 (2005), pp. 115-159.)

Lau, M. (2003), Coastal Zone Management in the Peoples Republic of China A Unique Approach?, FNU-27 (China Environment Series, Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), An Integrated Assessment Model of Economy-Energy-Climate The Model Wiagem: A Comment, FNU-26 (Integrated Assessment, 6 (1), 75-82)

Yetkiner, I.H. (2003), Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration, FNU-25

Yetkiner, I.H. (2003), A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions, FNU-24

Schneider, U.A. and B.A. McCarl (2003), Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry, FNU-23 (submitted)

Zhou, Y. and Tol, R.S.J. (2003), The Implications of Desalination to Water Resources in China - an Economic Perspective, FNU-22 (Desalination, 163 (4), 225-240)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), The Cyclical Advancement of Drastic Technologies, FNU-21

Rehdanz, K. and Maddison, D. (2003) Climate and Happiness, FNU-20 (Ecological Economics, 52 111-125)

Tol, R.S.J., (2003), The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties, FNU-19 (Energy Policy, 33 (16), 2064-2074).

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation, FNU-18 (submitted).

Schneider, U.A. and B.A. McCarl (2003), Implications of a Carbon Based Energy Tax for U.S. Agriculture, FNU-17 (submitted).

Tol, R.S.J. (2002), Climate, Development, and Malaria: An Application of FUND, FNU-16 (forthcoming, Climatic Change). Hamilton, J.M. (2003), Climate and the Destination Choice of German Tourists, FNU-15 (revised and submitted).

Tol, R.S.J. (2002), Technology Protocols for Climate Change: An Application of FUND, FNU-14 (Climate Policy, 4, 269-287).

Rehdanz, K (2002), Hedonic Pricing of Climate Change Impacts to Households in Great Britain, FNU-13 (Climatic Change 74).

Tol, R.S.J. (2002), Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of FUND, FNU-12 (Environment and Development Economics, 10, 615-629).

Rehdanz, K. and Tol, R.S.J. (2002), On National and International Trade in Greenhouse Gas Emission Permits, FNU-11 (Ecological Economics, 54, 397-416).

Fankhauser, S. and Tol, R.S.J. (2001), On Climate Change and Growth, FNU-10 (Resource and Energy Economics, 27, 1-17).

Tol, R.S.J.and Verheyen, R. (2001), Liability and Compensation for Climate Change Damages A Legal and Economic Assessment, FNU-9 (Energy Policy, 32 (9), 1109-1130).

Yohe, G. and R.S.J. Tol (2001), Indicators for Social and Economic Coping Capacity Moving Toward a Working Definition of Adaptive Capacity, FNU-8 (Global Environmental Change, 12 (1), 25-40).

Kemfert, C., W. Lise and R.S.J. Tol (2001), Games of Climate Change with International Trade, FNU-7 (Environmental and Resource Economics, 28, 209-232).

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions, FNU-6 (submitted).

Kemfert, C. and R.S.J. Tol (2001), Equity, International Trade and Climate Policy, FNU-5 (International Environmental Agreements, 2, 23-48).

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions, FNU-4. (Pollution Atmosphrique Numro Spcial: Combien Vaut lAir Propre?, 155-179).

Tol, R.S.J. (2000), How Large is the Uncertainty about Climate Change?, FNU-3 (Climatic Change, 56 (3), 265-289).

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), How Much Damage Will Climate Change Do? Recent Estimates, FNU-2 (World Economics, 1 (4), 179-206)

Lise, W. and R.S.J. Tol (2000), Impact of Climate on Tourism Demand, FNU-1 (Climatic Change, 55 (4), 429-449).