81

■

Coalition theory and integrated assessment Modelling: Lessons for climate governance

Thierry Bréchet, Johan Eyckmans

January 2009

ENVIRONMENTAL
ECONOMICS & MANAGEMENT
MEMORANDUM

UCL
Université
catholique
de Louvain

Chair Lhoist Berghmans
in Environmental Economics
and Management

Center for Operations Research
and Econometrics (CORE)

Coalition Theory and Integrated Assessment Modeling: Lessons for Climate Governance[†]

Thierry Bréchet
Center for Operations Research and Econometrics, Chair Lhoist Berghmans in Environmental Economics and Management, Université catholique de Louvain

Johan Eyckmans
Center for Economics and Management, European University College Brussels, and affiliated researcher Center for Economics Studies, Katholieke Universiteit Leuven

January 22, 2009

Abstract

In this paper we make use and we combine concepts from coalition theory and applied integrated assessment modeling to provide some insights for climate governance. We first identify the key issues discussed in the debate on climate architectures and desirable features for future climate agreements. Then, we analyze how coalition theory can contribute to that debate and we give some numerical illustrations by using an integrated assessment economy-climate model. Particular attention is devoted to the stability versus efficiency of agreements, membership rules and to the role of transfers to implement such agreements.

1. Introduction

Since Hardin (1968) we know that people facing a common do not have the correct incentives for contributing efficiently to its preservation. Individual interest leads to overexploitation and degradation, or even destruction, of the commons. However, Hardin missed that point that some of these people may have an incentive to join forces for managing that commons (or part of it) together. Why this? Because they may be better off by joining their efforts in the group than standing alone. Finding a rational for this behavior is the very aim of *coalition theory* in economics. Why do people collaborate when they have no obligation for that? Conversely, is the all-together strategy necessarily doomed? Despite the fact that we all know that there is a problem, why can we not solve it together?

Climate governance is a natural application of this stream of literature. Firstly, there is no worldwide authority capable to enforce some policy that would be good for the whole. Secondly, even if there were some worldwide government, also some worldwide parliament and voting process would most probably be necessary. So, understanding the motives of each

---

[†] This research is part of the CLIMNEG project funded by Belgian Science Policy (contract SD/CP/05A).

country for agreeing to some global climate governance rules is key. Consequently, and thirdly, identifying the very characteristics of each country and the role these characteristics play for explaining its position in the negotiation process may, help to design effective policy agreements for solving the climate problem.

The purpose of this paper is to show how coalitional theory helps answering these questions and to derive some insights for climate governance. For that purpose, instead of relying a purely theoretical discussion, we will make use of an applied integrated assessment model, the CLIMNEG World Simulation model (CWS model in the sequel) developed under the Belgian CLIMNEG research project. This model will allow us to numerically illustrate the concepts used in coalition theory and their usefulness for guiding climate governance.

The paper is organized as follows. In the following section, the tools to be used will be presented briefly: coalition theory and the CWS applied integrated assessment model. In both cases the basic concepts will be explained without any mathematical formalization and the emphasis will be on their economic interpretation and usefulness for climate governance. Then, two representative applications will be provided. In section 3 we first discuss the issue of *stability* and *effectiveness* of climate agreements, both in terms of climate and welfare. We do this by comparing the *cooperative* and *non-cooperative* theory of coalitions, two compelling streams in the economic theory literature today. In this section we also question the composition of coalitions. What favors agreement's stability: *homogeneity* (in terms of stage of development of the coalition members) or *heterogeneity*? Section 4 discusses the link between *stability* and the *design* of climate agreements. The first question is: should we seek for one single large agreement or for some smaller, but sufficiently numerous, fragmented agreements? Can we say something about that in terms of stability and, again, effectiveness? The second question addressed is about exclusive membership *vs*. open membership: which rule favors stability? Is it always beneficial for a coalition to welcome new comers? For every issue the discussion will be made both theoretical and on the ground of numerical simulations made with the CWS integrated assessment model. Section 5 concludes.

2. Coalition formation theory and integrated assessment modeling: two complementary tools for climate governance

The methodological innovation of our approach is to combine both integrated assessment modeling and game theoretical arguments to answer the policy questions raised above. We first present the background concepts from coalition theory we will use. Then, the main characteristics of integrated assessment modeling are described.

2.1 Key background concepts from coalition theory

Game theory analyses choice behavior in settings where these choices are interdependent, *i.e.* the outcome of the strategic interaction for one particular subject depends on the strategy choices made by others subjects. A game consists of players (all countries in the World in the context of climate change), strategies (greenhouse gas emission levels and the decision to join or not international climate agreements limiting these emissions) and payoff functions (functions that predict the welfare level countries can achieve for given emission levels of their own and all other countries in the World).

Broadly speaking, two counteracting forces drive the payoff structures. On the one hand, forming larger coalitions leads to higher aggregate welfare. Given the particular nature of climate change damage functions and greenhouse gas emission reduction cost functions, coalitions could achieve jointly better outcomes than if its members were to act individually (provided outsiders to the coalition do not change their strategy choices). In game theory, this property is called *superadditivity* and it is this process that gives incentives to form larger coalitions[1]. On the other hand however, outsiders to a coalition benefit from the efforts made by coalition members. In transboundary pollution problems like global climate change, outsiders, *i.e.* non-members of an agreement, typically enjoy more benefits if they can free ride on the efforts of a big coalition compared to a small coalition. This property is called *Positive Externalities to coalition formation* (PEP in the sequel) and induces countries to free ride, especially if a big coalition is forming. The combination of both forces results in a tendency to cooperate for some countries but this collaboration usually falls short of the full cooperative potential that could be achieved if all countries were to participate.

Two categories of games are considered in the literature, namely *cooperative* and *non-cooperative* ones. In either case the players are countries, each player's strategies are the values chosen for the economic decision variables (for instance investment in physical capital, emission abatement and adaptation efforts) and the players' payoffs are the countries' welfare level over their whole decision horizon. A family of strategies, one for each player, defines what we call a *scenario*. Among the many conceivable scenarios, we shall deal with (*i*) the Nash equilibrium scenario, (*ii*) scenarios of partial agreement Nash equilibrium with respect to given coalitions, and (*iii*) the Pareto efficient scenario.

Non-cooperative games are those that consider strategies enacted by individual players. The Nash equilibrium concept is the dominant solution concept in this setting. Cooperative games, by contrast, typically consider in addition the strategies chosen jointly by groups of players, usually called "coalitions", that is, subsets of players (including singletons and the grand coalition of all players). In either case the behavioral assumption is that the strategy chosen by individual players, as well as the strategies chosen by coalitions, results from payoff maximization between alternative options: the individual payoffs in the non-cooperative setting and the joint payoffs of the coalition members in the cooperative setting (this joint payoff being called the *worth* of the coalition). This illustrates the basic hypotheses of game theory: players are assumed to be rational (*i.e.* maximizing some objective function) and serving their own (in case of non-cooperative games) or group (in case of cooperative games) interest. By doing so, they compare the costs and the benefits of joining a coalition, where costs are emission abatement efforts, and benefits are a better climate and less climate change damages.

Stability concepts

First, the cooperative approach focuses on strategies chosen jointly by the members of the grand coalition, the set of all players. This scenario, and the grand coalition that generates it, are then said to be *stable in the core sense* if the scenario belongs to the core of a suitably defined cooperative game (see Chander and Tulkens 1995, 1997 for a precise definition of the gamma core in the context of environmental externalities), that is, if it is such that:

---

[1] It should be noted that superadditivity of games of multilateral environmental externalities is not always guaranteed. The benefits of expanding a given coalition can be eroded by the strategic free riding reaction by the outsiders, nonmembers of the coalition.

1. no individual player can reach a higher payoff by *not* adopting the strategy assigned to him in the efficient scenario and choosing instead the best individual strategy he could find if none of the other players form a coalition; this property is called *individual rationality*;

2. no subset of players can similarly do better for its members, that is, by rejecting the strategies assigned to them by the efficient scenario and adopting a group optimal strategy of their own assuming that all non-members play an individual Nash strategy against them; this property is called *coalitional rationality*.

Second, the non-cooperative approach considers some strategies and the resulting individual payoffs that can be reached by every player in that scenario according to whether he is *inside* or *outside* of the coalition.[2] Being *inside* means for the player to follow the strategy he is assigned to within the coalition he is a member of, whereas being *outside* means behaving as a singleton. The internal and external stability concept was introduced by d'Aspremont et al. (1984) in the context of cartel formation in Industrial Organization and was later applied by Barrett (1994) and Carraro and Siniscalco (1993) in the context of International environmental agreements. A coalition and the Partial Agreement Nash Equilibrium[3] (*PANE*) scenario it generates are then said to be *stable in the internal-external sense* if the scenario is such that no insider prefers to stay out of the coalition (*internal stability*, denoted by *IS*) and no outsider prefers to join the coalition rather than stay aside (*external stability*, denoted by *ES*). The set of all internally and externally stable coalitions corresponds to all Nash equilibria of a simple announcement game in which players have to announce 'Yes' or 'No' and where a coalition is formed among all players that have announced 'Yes'. This announcement game is said to be an *open membership game* since players can join coalitions without explicit approval of fellow coalition members.

Predictions regarding stability of international climate agreements

It should be pointed out that these two approaches rest on different views regarding the behaviour of players and coalitions in light of defection of a coalition member. On the one hand, the core-stability approach assumes that, if one or several countries attempt to free-ride on an efficient agreement with transfers, the other countries do not cooperate among themselves any longer and cooperation unravels completely leading to the Nash non-cooperative scenario. Clearly, this prospect of complete lack of cooperation constitutes an important threat for potential free riders. Put differently, the threat to revert to the non-cooperative Nash equilibrium induces core stability.

In the internal-external stability approach, on the other hand, stability of an agreement within a coalition is obtained if no country attempts to free-ride on it, assuming that the other countries continue cooperating among themselves. Defection of a player from a coalition does not make the remaining players split up further. Therefore, potential defectors can benefit from the efforts of the remaining coalition members, even though the remaining players will

---

[2] It is assumed that a player can only either join the coalition or remain alone.

[3] A Partial Agreement Nash Equilibrium is a game theoretic concept describing which strategies will be chosen by all players when a coalition of players interacts with a set if non-members, see Chander and Tulkens (1995, 1997).

re-optimize their economic strategies (*i.e.* their emission level) to take into account the new coalitional setting. It is clear that this assumption makes free riding a more attractive option compared to the assumption in the cooperative approach that coalitions dissolve after defection of one, or several, of its members.

Given the different assumptions behind both approaches, it should not come to a surprise that these two approaches lead to different conclusions. The main message of the cooperative approach is that the grand coalition can be stabilized (by appropriate transfers, see Chander and Tulkens 1995, 1997 and below) whereas the non-cooperative approach stresses that most likely, the grand coalition will not be able to generate enough surplus to compensate the free riding claim of all of its members (see for instance Barrett 1994, Carraro and Siniscalco 1993, or more recently Diamantoudi and Sartzetakis 2006).[4]

The need for appropriate transfer schemes

In the context of the cooperative approach, transfers schemes were proposed by Chander and Tulkens (1995, 1997) for the standard game with multilateral externalities used to deal with international environmental agreements. Chander and Tulkens proved that appropriate transfers can induce the core stability property. These transfers guarantee that each player receives a payoff at least equal to what it is in case of no cooperation, and it divides the surplus of cooperation over non-cooperation according to some pre-determined weights. In the multilateral environmental model, the weight of each player is given by its share in marginal climate change damage costs.

The non-cooperative approach proposes no specific transfer formula but introduces instead the notion of *potentially internally stable* coalitions, see Eyckmans and Finus (2004). A coalition is potentially internally stable (*PIS*) if it guarantees to all its members at least their free-rider payoff. For a given coalition, the free-rider payoff of any of its members is the payoff the member would obtain in the *PANE* scenario *w.r.t.* that coalition if it would stay out and behave as a singleton in the face of that coalition. The free rider pay off assumes that if a player defects from a coalition, the remaining players will continue to cooperate, though after re-optimizing their economic strategies in function of the new coalitional setting.

The free rider payoff of a player *vis-à-vis* some coalition may be seen as the minimum payoff that player requires to remain a member of the coalition. Coalitions whose worth under their *PANE* is large enough to meet this requirement for all their members can thus be potentially stabilized, at least internally. Eyckmans and Finus (2004) showed also that using this type of transfer schemes makes it possible to stabilize, both internally and externally, the coalition that generates the highest global welfare among all *PIS* coalitions. Hence, adopting transfers of the Eyckmans-Finus type allows one to achieve the best possible global welfare as a *PANE*, constrained by the requirement of internal and external stability.

---

[4] It should be noted that successful attempts were made to reconcile both approaches. For instance, Chander (2006) shows that core stability is consistent with internal and external stability if one assumes “farsighted”, i.e. a more sophisticated notion of rationality, behavior by the players. In particular, in the farsighted approach, players are assumed to anticipate further deviations by other coalition members when assessing the benefits of defecting from a coalition.

One may wonder what these transfers represent, in practice. Actually, in such a generic framework they only represent abstract wealth transfers. In practice, one should specify the transfer mechanisms, *i.e.* the policy instruments leading to wealth transfers. Any policy instrument yielding wealth transfers among countries could be identified as such. Some examples are endowments of emission permits in an international system of tradable pollution licences, technological transfers, or an international carbon tax with redistribution of the revenues.

2.2 Integrated Assessment Modeling: the CWS model

Our integrated assessment model, named CWS (CLIMNEG World Simulation model), resembles closely the original RICE model by Nordhaus and Yang (1996) or variations on it as in Eyckmans and Tulkens (2003) or Yang (2008).[5] The model is worldwide and distinguishes 6 regions or countries (USA, EU, China, Japan, Former Soviet Union and Rest of the World).[6] An essential characteristic of an IA model is that it contains an endogenous feedback between economic decision variables like emission levels and the rate of capital accumulation and ensuing changes in the global climate system leading to climate change damages that decrease consumption possibilities. This is illustrated in Figure 1. The block on the left contains the economy module which consists of a description of the physical production process, climate change damages, emission reduction costs, capital accumulation process and a material balance equation linking these different concepts. The block on the right hand sides describes the carbon cycle and temperature change module. Basically, this block translates all individual countries' emissions of greenhouse gases into changes in atmospheric carbon concentration and ultimately changes in global mean temperature. This change in temperature feeds back into the economy module via the climate change damage function.

While choosing climate policy actions, countries' policy makers weigh the benefits (avoided future climate change damages) and costs (costs of re-orientating their economies towards lower carbon emissions level). While speaking about welfare, we will refer to some notion of Green National Product that takes into account both climate change damages and emission reduction costs. More precisely, welfare in a country is given by the stream of discounted consumption net of damage and mitigation costs. In every region and time period, the budget constraint holds, *i.e.* consumption equals production *minus* investment *minus* abatement costs *minus* climate change damages. Because climate change has long-term impacts the time horizon considered in the model is 300 years.

Production is assumed a function of labor and capital. Total factor productivity increases exogenously over time and capital accumulation is endogenous in the model. Production causes emissions of greenhouse gases according to an exogenous intensity parameter. Still, emissions can be reduced by means of some specific measures, like replacing a coal fired power plant by renewable energy sources, investment in more fuel efficient cars or energy demand management, what is called *emission abatement* in the model. The abatement costs are increasing with the emission reduction rate. Emission abatement cost functions are

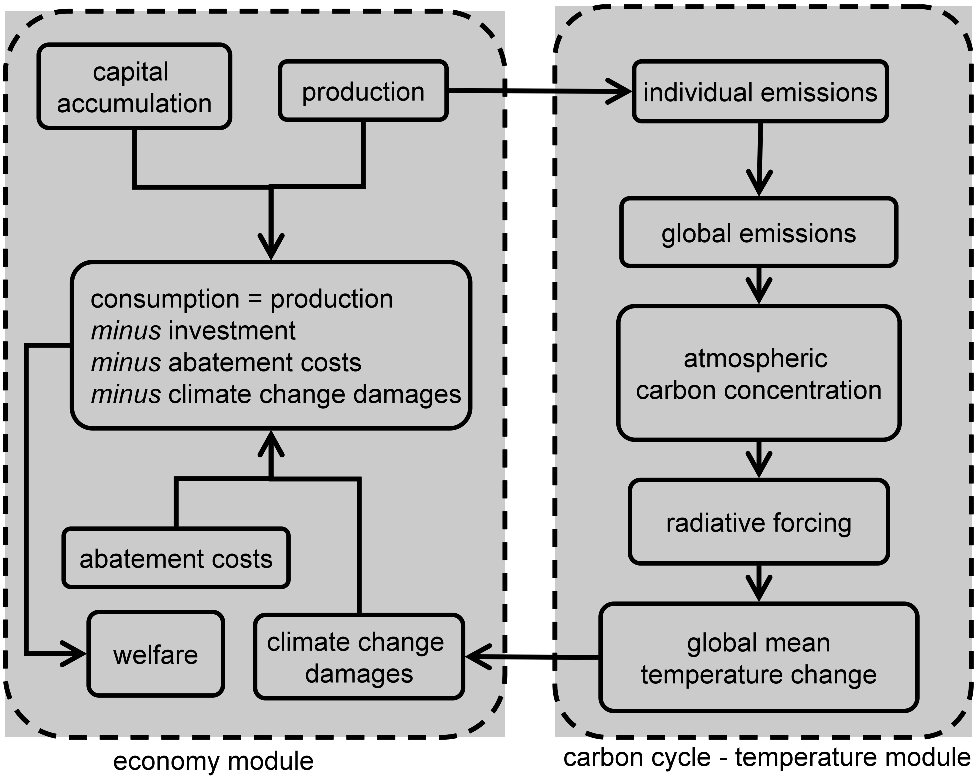
---

[5] See Kolstad and Toman (2005) for an introduction and overview of integrated assessment climate-economy models and Bréchet and Luterbacher (2009) for a discussion on their usefulness for policy support.

[6] A new version of the model distinguishes 18 regions: see Gérard and Holzweber (2008).

relatively well-known and easy to estimate (see Chapter 11 in the IPCC (2007) Working Group III Report for a recent overview on cost estimates). We use cost estimates taken from the RICE model by Nordhaus and Yang (1996).

Figure 1: Overview of the CWS integrated assessment model



Emissions of greenhouse gases accumulate in the atmosphere, thereby disturbing the global carbon cycle and causing ultimately climate change. The physical processes are captured by a simplified carbon cycle and climate model. Temperature change has a variety of physical impacts, among which sea level rise, changes in precipitation patterns and extreme weather events. The economic valuation of the damages caused by these impacts is summarized in a damage function. This function represents the loss due to some temperature increase expressed in terms of GDP. Estimating damage functions is a quite tricky task (see for instance the Stern Review (2006) or IPCC (2007) Working Group II Report), but necessary to implement integrated assessment. First, *physical* impacts must be estimated, and several studies are now available on that. Second, damages must be evaluated in monetary terms, including non-market damage like biodiversity losses and changes in living amenities. This remains quite challenging, for no market prices are available for their valuation. Further, weighting costs and benefits requires normative judgments regarding intergenerational justice and intragenerational justice (*i.e.* weighing costs and benefits accruing to different generations over time or to citizens that differ strongly in wealth position within one particular generation).

We can now turn to two applications. These applications provide a good illustration of the kind of lessons that can be drawn for climate governance.

3. Stability and efficiency of climate agreements: two compelling objectives?

The purpose in this first application is to shed some light on the properties of potential coalitions in three respects: stability, climate performance and global welfare.[7] By doing so we make use of the two theoretical strands mentioned in Section 2. Assessing the properties of alternative climate coalitions in a concrete numerical context gives a powerful justification for recommendations as to the size and nature (homogeneity *vs.* heterogeneity) of possible climate coalitions. Moreover, by showing explicitly which transfers among countries are appropriate to stabilize efficient coalitions, we also identify wider room for negotiation. It is important to keep in mind that, in the following numerical simulations, the agreements are supposed to hold forever.[8]

3.1 Stability analysis of climate agreements

Given the six regions identified in the CWS model, 63 coalitions can possibly form, for each of which we compute the worth at a *Partial Agreement Nash Equilibrium* (*PANE*) of the model.

Focusing first on the cooperative approach it appears that, without transfers, the Pareto solution, which needs the grand coalition to be achieved, is not core-stable: 18 smaller coalitions (out of 63) can improve upon it. Still, the grand coalition can be stabilized with adequate transfers among countries.[9] This first result is especially important, as it confirms the possibility of achieving core stability of the world efficient allocation, thanks to adequate transfers.

As far as the non-cooperative approach is considered, the results can be summarized as follows. Without transfers the following appears: (*i*) few coalitions are internally stable (7, out of 57, *i.e.* excluding singletons) and the grand coalition, in particular, does not pass it; (*ii*) only one coalition is both internally and externally stable, the USA + EU. Complementary to the *IS* and *ES* tests, the *PIS* test is one that implicitly refers to transfers within the coalitions, with the purpose of inducing internal stability. With transfers among countries, applying the *PIS* concept leads to the following outcomes: (*i*) the grand coalition does not pass the test; (*ii*) 4 five-country coalitions and 5 four-country coalitions do not pass the test, whereas 1 five-country and all other coalitions of four countries or less do pass it.

Summarizing, the numerical results obtained with the CWS model confirm the theoretical insights put forward by Chander and Tulkens (1995, 1997) for the cooperative approach: appropriate transfers are capable of stabilizing the grand coalition in the sense of the core; and the results by Barrett (1994) and Carraro and Siniscalco (1993) for the non-cooperative approach: very few coalitions are stable in the internal – external sense.

---

[7] For the complete analysis, see Bréchet, Gerard and Tulkens (2007).

[8] This clearly constitutes a shortcoming of this type of analysis. It will be discussed further later in the paper. Because of that, the figures might be considered as an optimistic view of the agreement in the sense where stability is checked over the whole time horizon considered in the CWS model.

[9] See Germain *et al.* (2003) for the adequate type of transfers.

3.2 Stability and environmental performance

Can some policy implications be derived from the above stability discussion and simulation results? In particular, how important are the coalitional stability properties we have identified? Should they serve as an argument to support or advocate specific structures for climatic international agreements such as small coalitions rather than large ones, or homogeneous rather than heterogeneous ones? To answer these questions, we consider two criteria measuring the global outcome resulting from an agreement:

- the aggregate welfare level reached at the world level,
- the environmental performance achieved, expressed by atmospheric carbon concentration (in year 2200).

The results for some representative coalitions are gathered in Table 1. Environmental and welfare performance are measured by so-called "closing the gap" indices that assign value 0 to the non-cooperative Nash scenario and value 100% to the cooperative (*i.e.* the grand coalition) PARETO scenario.

Table 1. Performance and stability for some coalitions with transfers

PANE	Welfare index (%)	Environmental index (%)	Stability
NASH	0	0	--
Annex B(1) without USA	2	1	*PIS*
Annex B(1)	8	3	*PIS*
USA+China	20	15	*PIS*
China+FSU+RoW	24	49	Not *PIS*
USA+Japan+China+FSU+RoW	92	80	*PIS*
USA+EU+China+RoW	97	92	Not *PIS*
PARETO	100	100	--

(1) *In the CWS model Annex B gathers USA, EU, FSU and Japan.*

The first striking result from Table 1 is that the Kyoto agreement, characterised by Annex B commitment, is quite close to the non-cooperative NASH situation, both is term of welfare and climate. This agreement has virtually no positive effects. This result is even reinforced when considering the Annex B without the USA. The second result is that some coalitions are rather close to the PARETO situation. Interestingly, withdrawing the EU from the Grand Coalition makes it potentially internally stable with very goods records regarding welfare (92% of PARETO is achieved). Substituting the EU by Japan ranks even higher (97% of PARETO), but this coalition cannot be stabilized. If one is interested in small coalitions, an example is the one formed by China and the USA: it can be stabilized, but its performance is rather low. Other examples of this type may be provided.

Clearly, accepting or recommending small coalitions because of their potential internal stability virtues entails a loss on both counts that striving for an efficient and core stable alternative could avoid. Internal stability *per se* thus appears to be a weakly desirable objective. What matters is the effectiveness of the agreement, and effectiveness sharply increases with coalition size and/or composition, for countries are not symmetric. The rational behind this result is that the larger the coalition, the stronger the internalization of the climate externality. But on the other hand, including large emitters provides the coalition with strong climate benefits. So the debate on the kind of agreement that is desirable cannot be reduced to a single question, like the size. Actually, size matters. But the size of what remains an open question.

3.3 Should coalitions be homogeneous?

A common argument in the climate policy debate is that developed countries should engage themselves first, after what developing countries would be invited to join the agreement and participate to the mitigation of global warming. Although this argument seems reasonable on the basis of historical responsibilities[10], one may question its effectiveness. We can analyze how the composition of a coalition, that is, its degree of *homogeneity* (which is to be defined), affects its stability. The regions/countries considered in the CWS model can be split into two categories:

- on the one hand, developed-Annex B countries (USA, EU and JPN), with high per capita emissions and GDP level, steep emission abatement cost and climate change damage functions;
- on the other hand, developing-non-Annex B countries (CHN and ROW), with low per capita emissions and GDP level, relatively flat abatement cost functions and relatively low valuation of climate change damages.

In what follows, a *homogeneous coalition* will designate a coalition formed by countries from a single category. Conversely, a *heterogeneous coalition* will designate a coalition formed by countries coming from the two categories. A special case is the FSU as it displays the characteristics of both a developed country (high emissions per capita) and a developing one (low cost abatement opportunities, low GDP per capita). According to these definitions, the 57 possible coalitions (*i.e.* excluding singletons) can be organized into 42 heterogeneous coalitions and 15 homogeneous ones.

The question we can now address is the following: is there any relation between the composition of a coalition and its stability? Computing the CWS model reveals the following.

Without transfers, all the 4 homogeneous coalitions involving FSU and developing-non-Annex B countries are internally stable, and the coalition USA + EU is both internally and externally stable. So homogeneity seems good for stability. On the other hand, none of the coalitions involving at least one of the two main polluters of each category (that is, USA or EU, on the one hand, and CHN or ROW on the other hand) is internally stable. Integrating a major polluter to an agreement seems detrimental to its stability. Finally, in the same spirit, the largest heterogeneous coalition, which is the grand coalition, is not core-stable without transfers, with four more blocking coalitions. Intuitively, the reason for instability of coalitions involving high marginal climate change damage and low marginal abatement cost

---

[10] This is the principle of common but differentiated responsibilities of countries enounced in the UN Framework Convention. Notice that this argument will be no longer valid for some countries in a future that may be close: Botzen *et al*. (2008) show that China could overtake the USA as major cumulative contributor to GHG concentrations.

players is clear. The high marginal climate change damage coalition members (for instance EU) ask for important emission reduction commitments of the coalition but most of the emission reduction burden falls on the low marginal abatement cost coalition members (for instance China) in a cost efficient *PANE*. Without compensation, the additional abatement costs outweigh the reduction in climate change damages for the low marginal cost countries, hence they are bound to lose from coalition membership compared to nonparticipation.

When the possibility of transfers is introduced, stability appears also to be enhanced by homogeneity. All homogenous coalitions are *potentially internally stable*.[11] Furthermore, the Annex B coalition turns out to be more stable than the "Annex B without the USA" coalition.[12] Paradoxically, this latter coalition does not satisfy the *external stability* property: the CWS model suggests that the United States would be better off by coming back to the Annex B coalition. Out of the 42 possible heterogeneous coalitions, 11 are not stable in the *PIS* sense. Indeed, no four-country, or more, coalitions involving simultaneously the USA and the EU and at least one non-Annex B countries pass the *PIS* test.

The homogeneity *vs* heterogeneity debate can also be analyzed by looking at Table 1 above. One can see that the *best* (in terms of global welfare) homogeneous coalition (CHN + FSU + ROW) leads to far lower global welfare and far higher carbon concentrations than both the *best* heterogeneous coalition (the grand coalition) and the *best* heterogeneous coalition satisfying the *PIS* property (USA + JPN + CHN + FSU + ROW). As a consequence, promoting homogeneous coalitions may lead to very low mitigation policies at the world level, unable to tackle climate change issue as heterogeneous (larger) coalitions could do. Intuitively, appropriately designed transfers are able to overcome the participation problem that we sketched higher for the no transfer case. Combining high marginal climate change damage countries with low marginal abatement cost countries leads to ambitious coalitional emission abatement targets and potential imbalances of costs and damages for individual coalition members can be mitigated by means of appropriate transfers.

As a conclusion, there seems to be a trade-off between stability and environmental effectiveness. Homogeneity in climate coalitions fosters stability but is detrimental to climate effectiveness. Heterogeneity in cost and damage structures leads to more ambitious abatement targets but requires substantial redistribution of the surplus to keep all countries on board in the climate agreement boat.

4. Stability and institutional design of climate agreements

Besides the crucial importance of transfers to sustain stable climate agreements, economists have also pointed out the importance of more specific design features of global climate agreements. Several institutional aspects have been investigated in this respect in the literature, but we focus only on two of them: firstly, the question whether one broad agreement (single coalition agreement) is better than several smaller agreements (multiple

---

[11] In the previous version of the CWS model, calibrated on 1990 data, only Annex B coalition {USA, JPN, EU, FSU} out of the 15 homogeneous coalitions did not pass the *PIS* test (the so-called *Old Kyoto* coalition in Carraro, Eyckmans and Finus, 2007). So it seems that there is more room for cooperation between these countries today than ten years earlier.

[12] The so-called *Present Kyoto* coalition in Carraro, Eyckmans and Finus (2007).

coalitions agreement), and secondly, the question whether external stability can be promoted by making accession of newcomers conditional on approval by existing coalition members (open versus exclusive membership).

4.1 Single *vs*. fragmented climate agreements

The first question is of major importance for climate governance. Should one strive for one broad single agreement signed by as many countries as possible, or should one allow that several small agreements coexist? We will not enter the debate on the legal status of such sub-agreements in relation to the existing UNFCCC legal framework.[13] Instead, we will focus on the impact of stable coalitions when allowing for multiple coalitional agreements on their size and their environmental and welfare performance.

At first sight one might argue that it is better to have one single large agreement instead of several small agreements coexisting, based upon arguments of economies of scale. In many economic production processes, average unit costs of production decrease for bigger production volumes generating so-called economies of scale. The intuition behind this observation is that fixed costs, *i.e.* costs that are independent of the scale of production, are preferably spread out over larger instead of smaller production volumes. Likewise, one might argue that one big climate agreement is to be preferred over a collection of small ones because it allows for cost savings, for instance in the degree to which the externality is internalized or in the set up and practical operation of a system of tradable emission permits. In addition, a broad agreement is to be preferred also if carbon leakage, *i.e.* the phenomenon that CO_2 intensive industries would relocate to regions with loose environmental regulation, is a serious concern, see Victor (2007).

Although there are surely some aspects of scale related to climate agreements, one should also take into account strategic issues, *i.e.* the stability and level of commitment of coalitions. Carraro (2007) uses game theoretical arguments to make a case for a bottom up approach to the formation of new climate agreements. Eyckmans and Finus (2006a, b), using numerical simulation results from CWS, demonstrated that multiple coalition structures can emerge as internally and externally stable equilibria and can lead to higher welfare levels than some single coalition agreements. Table 2 (based upon Table 2 in Eyckmans and Finus, 2006b), shows stable coalition structures for a variety of agreement architectures. Without transfers, the results are basically the same: open membership games, be it single or multicoalitional, do not lead to stable climate agreements. Heterogeneity among regions is simply too strong to overcome conflicting incentives. However, it appears that more coalitions are stable and they lead to better welfare and ecological performances, in the multiple coalition setting compared to the single coalition setting without transfers. For instance, we observe that coalition structure ({USA, JPN}, {EU, ROW}, {CHN}, {FSU}) consisting of two couples, performs better than any single coalition structure with *Exclusive Membership Majority Voting* framework (see below). Basically, allowing for more flexibility in coalition formation increases the chances of building stable agreements.

---

[13] In fact, one might argue that already the 1997 Kyoto protocol is of a multicoalitional nature since only a subset of parties (Annex B countries) accepted quantified greenhouse gases emission limits. The other countries ratified but did not commit to emission targets.

These results are also in line with the argument put forward by Barrett (1994) that there is often a trade-off in international environmental agreements. Either one observes agreements with many members but with little more commitment than in the plain non-cooperative Nash equilibrium. Or one observes small stable agreements with substantial commitment to reduce emissions but since they participants constitute only a small part of the total number of polluters, global environmental quality is not enhanced significantly either.

These results show that (*i*) allowing for flexibility in coalition formation might lead to more participants in stable coalition structures, (*ii*) these multi-coalition structures might lead to substantial improvement of global environmental quality. In practice, multi-coalitional agreements can also be thought of as agreements that allow for heterogeneity in commitments by the participants. As in the 1997 Kyoto Protocol, one could perfectly allow for differentiated commitments among for instance developing countries and industrialized countries under the common umbrella of for instance the UNFCCC.

4.2 Is everybody welcome to join the climate club?

Concerning the second question, it is easy to see that the problem of external stability, *i.e.* outsiders wanting to join an existing agreement and thereby upsetting the internal stability of the agreement, can be mitigated to some extent by making accession of newcomers conditional on approval of existing coalition members. Games in which no approval for approval of newcomers is required are called *open membership games*. On the contrary, *exclusive membership games* require some form of approval, though there is a large variety in the degree of consensus required, for instance majority versus unanimity voting procedures. Important from a conceptual point of view is that the generally held belief that unconditional accession of newcomers promotes cooperation might prove to be false if one accounts for coalitional stability considerations.

Table 2 nicely illustrates how different degrees of exclusive membership result in different degrees of effective and stable climate policy. Under open membership (*OM*), no coalition is stable, neither in a single nor in a multi-coalitional setting. Requiring that newcomers can join a coalition only of a 50% majority of existing members agrees to it (*i.e.* is better off in welfare terms after accession of the newcomer) leads to several stable coalition structures (both single and multi-coalitional), some of which are able to close the gap between cooperation and non-cooperation by more than half. The even stricter accession requirement that all existing members have to agree (unanimity voting, *UV*) leads to additional stable coalitions and better environmental and welfare performances.

Practically speaking, exclusive membership is widely used in many international cooperative structures. For instance in NATO and in the EU, new members can only join after a formal approval procedure in which existing members can have their say on the accession. Again, this simple modification of agreement architecture, which at first sight would hamper accession of newcomers unnecessarily, might in the end lead to broader and more effective global climate agreements.

5. Conclusion

In this paper we have combined results from game theory and an integrated assessment climate-economy model to derive conclusions for global climate governance. We have pointed out that agreements that bring together countries with similar emission reduction costs and climate change damage characteristics, *i.e.* homogeneous agreements, tend to be more stable than heterogeneous agreements. However, heterogeneous agreements have a tendency to aim for more ambitious greenhouse gas emission reduction targets. We showed that appropriately designed transfer schemes can stabilize such ambitious heterogeneous climate agreements, both in the cooperative and non-cooperative game theory frameworks. Crucial for the transfer schemes is that they should be designed in the first place to limit free riding behavior. We also showed that small institutional changes of climate agreements can have important stability implications. For instance, allowing for a multitude of small fragmented agreements can yield better global welfare and environmental results compared to a situation in which we would limit cooperation to big unique agreements only. Finally, making membership to international climate agreements exclusive, *i.e.* conditional upon consent of the other members can foster instead of hamper stability of a future climate agreement.

6. References

Aldy J.E., S. Barrett and R.N. Stavins (2003). "Thirteen plus one: a comparison of global climate policy architectures", *Climate Policy* 3(4): 383-397.

Aldy J.E. and R.N. Stavins (eds) (2007). *Architectures for Agreement. Addressing Global Climate Change in the Post-Kyoto World*. Cambridge University Press.

Biermann F. (2005). "Between the USA and the South: strategic choices for European climate policy", *Climate Policy* 5, 273-290.

Botzen W.J.W., J.M. Gowdy and J.C.J.M. Van Den Bergh (2008). "Cumulative CO_2 emissions: shifting international responsibilities for climate debt", *Climate Policy* 8(6), 569-576.

Bréchet Th., F. Gérard and H. Tulkens (2007). "Efficiency *vs*. stability of climate coalitions: a conceptual and computational appraisal", CORE discussion paper 2007/3, Université catholique de Louvain.

Bréchet Th., J. Eyckmans, F. Gérard, Ph. Marbaix, H. Tulkens and J-P. van Ypersele (2008). "The impact of the unilateral EU commitment on the stability of international climate agreements", CORE discussion paper 2008/61, Université catholique de Louvain.

Bréchet Th. and U. Luterbacher (2009). "Computational models for policy support in climate issues", in: U. Luterbacher and D.F. Sprinz (eds), *The Evolving Climate Change Regime*, MIT Press, forthcoming.

Carraro C. (2007). "Incentives and institutions: a bottom-up approach to climate policy", in Aldy J.E. and Stavins R.N. (eds), *Architectures for Agreement. Addressing Global Climate Change in the Post-Kyoto World*. Cambridge University Press, 161-172.

Carraro C., J. Eyckmans and M. Finus (2007). "Optimal transfers participation decisions in international environmental agreements", *Review of International Organizations* 1(4): 379-396.

d'Aspremont, C., A. Jacquemin, J. J. Gabszewicz and J. A. Weymark (1983). "On the Stability of Collusive Price Leadership". *Canadian Journal of Economics*, 16, 17-25.

Diamantoudi E. and E.S. Sartzetakis (2006). "Stable International Environmental Agreements: An Analytical Approach", *Journal of Public Economic Theory*, 8, 247–263.

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

Eyckmans, J. and M. Finus (2004). "An almost ideal sharing scheme for coalition games with externalities", CLIMNEG Working Paper #62, Leuven, Belgium: Katholieke Universiteit Leuven.

Eyckmans, J. and Finus, M. (2006). "Coalition formation in a global warming game: how the design of protocols affects the success of environmental treaty-making", *Natural Resource Modeling*, 19, 323–358.

Eyckmans, J. and Finus, M. (2006). "New Roads to International Environmental Agreements: The Case of Global Warming", *Environmental Economics and Policy Studies* 7, 391–414.

Gérard A. and P. Holzweber (2008). "CWS 2.0: a 18-region integrated assessment model", CLIMNEG working paper #101, CORE, Université catholique de Louvain.

Germain, M., Ph. Toint, H. Tulkens and A. de Zeeuw (2003). "Transfers to Sustain Dynamic Core-Theoretic Cooperation in International Stock Pollutant Control", *Journal of Economic Dynamics and Control*, 28, 79-99.

Kolstad C.D. and Toman M. (2005). "The economics of climate policy", in: K. G. Mäler and J. R. Vincent (eds.), *Handbook of Environmental Economics*, Vol. 3, 1561-1618, Elsevier.

Hardin, G. (1968). "The tragedy of the commons", *Science*, 162, 1243-1248.

Nordhaus W.D. and Z. Yang (1996). "A regional dynamic general-equilibrium model of alternative climate-change strategies", *American Economic Review*, 86(4), 741-765.

Victor D.G. (2007). "Fragmented carbon markets and reluctant nations: implications for the design of effective architectures", in Aldy J.E. and R.N. Stavins (eds), *Architectures for Agreement. Addressing Global Climate Change in the Post-Kyoto World*. Cambridge University Press, 133-160.

Yang Z. (2008). *Strategic Bargaining and Cooperation in Greenhouse Gas Mitigations – An Integrated assessment Modeling Approach.* MIT Press.

Environmental Economics & Management Memoranda

91. Thierry BRECHET, Henry TULKENS. Beyond BAT : Selecting optimal combinations of available techniques, with an example from the limestone industry. *Journal of Environmental Management*, 90 (2009) :1790-1801.

90. Giorgia OGGIONI, Yves SMEERS. Equilibrium models for the carbon leakage problem. December 2008 (also CORE DP 2008/76)

89. Giorgia OGGIONI, Yves SMEERS. Average power contracts can mitigate carbon leakage. December 2008 (also CORE DP 2008/62)

88. Thierry BRECHET, Johan EYCKMANS, François GERARD, Philippe MARBAIX, Henry TULKENS, Jean-Pascal van YPERSELE. The impact of the unilateral EU commitment on the stability of international climate agreements. (also CORE DP 2008/61)

87. Raouf BOUCEKKINE, Jacek B. KRAWCZYK, Thomas VALLEE. Towards an understanding of tradeoffs between regional wealth, tightness of a common environmental constraint and the sharing rules. (also CORE DP 2008/55)

86. Thierry BRECHET, Tsvetomir TSACHEV, Vladimir VELIOV. Prices versus quantities in a vintage capital model. March 2009 (also CORE DP 2009/15).

85. David DE LA CROIX, Davide DOTTORI. Easter Island's collapse : a tale of a population race. *Journal of Economic Growth*, 13 :27-55, 2008.

84. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intertemporal transfers of emission quotas in climate policies. *Economic Modelling*, 26(1) : 126-143, 2009.

83. Thierry BRECHET, Stéphane LAMBRECHT. Family altruism with renewable resource and population growth. *Mathematical Population Studies*, 16 :60-78, 2009.

82. Thierry BRECHET, Alexis GERARD, Giordano MION. Une évaluation objective des nuisances subjectives de l'aéroport de Bruxelles-National. *Regards Economiques*, N° 66, Février 2009.

81. Thierry BRECHET, Johan EYCKMANS. Coalition theory and integrated assessment modeling : Lessons for climate governance. In E. Brousseau, P.A. Jouvet and T. Tom Dedeurwaerder (eds). Governing Global Environmental Commons: Institutions, Markets, Social Preferences and Political Games, Oxford University Press, 2009.

80. Parkash CHANDER and Henry TULKENS. Cooperation, stability, and self-enforcement in international environmental agreements : A conceptual discussion. In R. Guesnerie and H. Tulkens (eds). The Design of Climate Policy, CESifo Seminar Series, The MIT Press, 2008.

79. Mirabelle MUULS. The effect of investment on bargaining positions. Over-investment in the case of international agreements on climate change. September 2008

78. Pierre-André JOUVET, Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending : a political economy approach. *Environmental Economics and Policy Studies*, Vol 9 (3) : 177-191 2008.

77. Fabien PRIEUR. The environmental Kuznets curve in a world of irreversibility. *Economic Theory*, 2009.

76. Raouf BOUCEKKINE, Natali HRITONENKO and Yuri YATSENKO. Optimal firm behavior under environmental constraints. April 2008. (also CORE DP 2008/24).

75. Giorgia OGGIONI and Yves SMEERS. Evaluating the impact of average cost based contracts on the industrial sector in the European emission trading scheme. January 2008 (also CORE DP 2008/1).

74. Thierry BRECHET and Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement revisited. *Ecological Economics*, 65 : 262-265, 2008.

73. Ingmar SCHUMACHER and Benteng ZOU. Pollution perception : A challenge for intergenerational equity. *Journal of Environmental Economics and Management*, 55, 296-309, 2008.

72. Thierry BRECHET et Patrick VAN BRUSSELEN. Le pic pétrolier: un regard d'économiste. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 63-81, 2007.

71. Thierry BRECHET. L'énergie : mutations passées et mutations en cours. *Reflets et Perspectives de la vie économique*, Tome XLVI, n° 4, 5-11, 2007.

70. Marc GERMAIN, Alphonse MAGNUS and Vincent VAN STEENBERGHE. How to design and use the clean development mechanism under the Kyoto Protocol? A developing country perspective. *Environmental & Resource Economics*, 38(1) : 13-30, 2007.

69. Thierry BRECHET en Pierre PICARD. Economische instrumenten voor de regulering van de geluidshinder in de omgeving van luchthavens? *Brussels Studies*, nummer 12, 3 december 2007

68. Thierry BRECHET et Pierre PICARD. Des instruments économiques pour la régulation des nuisances sonores autour des aéroports? *Brussels Studies*, numéro 12, 3 décembre 2007, www.brusselsstudies.be.

67. Thierry BRECHET and Pierre PICARD. Can economic instruments regulate noise pollution in locations near airports? *Brussels Studies*, issue 12, 2007 december the 3rd , www.brusselsstudies.be

66. Pierre-André JOUVET, Pierre PESTIEAU and Gregory PONTHIERE. Longevity and Environmental quality in an OLG model. September 2007 (also available as CORE DP 2007/69).

65. Raouf BOUCEKKINE and Marc GERMAIN. Impacts of emission eduction policies in a multi-regional multi-sectoral small open economy with endogenous growth. February 2007 (also available CORE DP 2007/11).

64. Parkash CHANDER and Subhashini MUTHUKRISHNAN. Green consumerism and collective action. June 2007 (also available as CORE DP 2007/58).

63. Jakub GROWIEC and Ingmar SCHUMACHER. Technological opportunity, long-run growth and convergence. July 2007 (also available as CORE DP 2007/57).

62. Maria Eugenia SANIN and Skerdilajda ZANAJ. Environmental innovation under Cournot competition. June 2007. (also available as CORE DP 2007/50)

61. Thierry BRECHET and Stéphane LAMBRECHT. Family altruism with a renewable resource and population growth. October 2006 (also available as CORE DP 2006/35).

60. Thierry BRECHET, François GERARD and Henry TULKENS. Climate Coalitions: a theoretical and computational appraisal. February 2007 (also available as CORE DP 2007/3).

59. Thierry BRECHET. L'environnement dans tous ses états. *Regards Economiques*, n° 50, 26-32, Avril 2007.

58. Thierry BRECHET and Susana PERALTA. The race for polluting permitsThierry. March 2007 (also available as CORE DP 2007/27).

57. Giorgia OGGIONI, Ina RUMIANTSEVA and Yves SMEERS. Introduction of CO_2 emission certificates in a simplified model of the Benelux electricity network with small and industrial consumers. Reprint from *Proceedings of the International Conference on Clean Electrical Power*, Capri, Italy, May 21-23, 2007.

56. Agustin PEREZ-BARAHONA. The problem of non-renewable energy resource in the production of physical capital. January 2007 (also available as CORE DP 2007/8).

55. Thierry BRECHET, Benoît LUSSIS. The contribution of the clean development mechanism to national climate policies. *Journal of Policy Modelling*, 28(9), 981-994, December 2006.

54. Ingmar SCHUMACHER. Endogenous discounting via wealth, twin-peaks and the role of technology. November 2006 (also available as CORE DP 2006/104).

53. Ingmar SCHUMACHER. On optimality, endogenous discounting and wealth accumulation. October 2006 (also available as CORE DP 2006/103).

52. Jakub GROWIEC, Ingmar SCHUMACHER. On technical change in the elasticities of resource inputs. November 2006. (also available as CORE DP 2006/63).

51. Maria Eugenia SANIN. Market Design in Wholesale Electricity Markets. October 2006 (also available as CORE DP 2006/100).

50. Luisito BERTINELLI, Eric STROBL and Benteng ZOU. Polluting technologies and sustainable economic development. June 2006 (also available as CORE DP 2006/52).

49. Marc GERMAIN, Alphonse MAGNUS. Prices versus quantities: Stock pollution control with repeated choice of the instrument. October 2005. *Journal of Computational and Applied Mathematics*, 197 (2006) 437-445.

48. Agustin PEREZ-BARAHONA. Capital accumulation and exhaustible energy resources: a special functions case. September 2006 (also available as CORE DP 2007/9).

47. Philippe TULKENS, Henry TULKENS. The White House and the Kyoto Protocol: Double standards on uncertainties and their consequences. May 2006 (also TERI School of Advanced Studies WP Series #1).

46. Thierry BRECHET, Pierre-André JOUVET. Environmental innovation and the cost of pollution abatement. January 2006 (also available as CORE DP 2006/40).

45. Fabien PRIEUR. The implication of irreversible pollution on the relation between growth and the environment: The degenerate Kuznets curve. February 2006.

44. Thierry BRECHET, Marc GERMAIN, Philippe MONTFORT. Allocation des efforts de dépollution dans des économies avec spécialisation internationale. *Revue Economique*, 57(2), Mars 2006.

43. Ingmar SCHUMACHER and Benteng ZOU. Habit in Pollution, A Challenge for Intergenerational Equity. March 2006 (also available as CORE DP 2006/6).

42. Jean-Charles HOURCADE, P.R. SHUKLA and Sandrine MATHY. Cutting the Climate-Development Gordian Knot – Economic options in a politically constrained world. September 2005.

41. Urs LUTERBACHER. Climate Change, the Kyoto Protocol, and Transatlantic Relations. November 2005.

40. Parkash CHANDER and Henry TULKENS. Cooperation, Stability and Self-Enforcement in International Environmental Agreements: A Conceptual Discussion. July 2005.

39. Paul-Marie BOULANGER et Thierry BRECHET. Le Mécanisme pour un Développement Propre tiendra-t-il ses promesses ? *Reflets et Perspectives de la Vie Economique*, Tome XLIV – 2005 – N° 3, 5-27.

38. Paul-Marie BOULANGER and Thierry BRECHET. Models for policy-making in sustainable development: The state of the art and perspectives for research. *Ecological Economics*, 55, 337-350, 2005.

37. Johan EYCKMANS an Henry TULKENS. Optimal and Stable International Climate Agreements. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

36. Thierry BRECHET and Benoît LUSSIS. The Clean Development Mechanism in Belgian Climate Policy. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

35. Vincent VAN STEENBERGHE. The impact of banking on permits prices and compliance costs. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

34. Johan EYCKMANS, Denise VAN REGEMORTER and Vincent VAN STEENBERGHE. Kyoto-permit prices and compliance costs: an analysis with MacGEM. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

33. Johan EYCKMANS, Bert WILLEMS and Jean-Pascal VAN YPERSELE. Climate Change: Challenges for the World. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

32. Marc GERMAIN, Stef PROOST and Bert SAVEYN. The Belgian Burden Sharing. October 2005. Reprint from "*Economic Aspects of Climate Change Policy : A European and Belgian Perspective*", a joint product of CES-K.U.Leuven and CORE-UCL, edited by Bert Willems, Johan Eyckmans and Stef Proost, published by ACCO, 3000 Leuven (Belgium)

31. Ingmar SCHUMACHER. Reviewing Social Discounting within Intergenerational Moral Intuition. June 2005.

30. Stéphane LAMBRECHT. The effects of a demographic shock in an OLG economy with pay-as-you-go pensions and property rights on the environment: the case of selfish households. January 2005.

29. Stéphane LAMBRECHT. Maintaining environmental quality for overlapping generations: Some Reflections on the US Sky Trust Initiative. May 2005.

28. Thierry BRECHET, Benoît LUSSIS. The contribution of the Clean Development Mechanism to national climate policies. April 2005.

27. Thierry BRECHET, Stéphane LAMBRECHT, Fabien PRIEUR. Intergenerational transfers of pollution rights and growth. May 2005 (also availabe as CORE DP 2005/42).

26. Maryse LABRIET, Richard LOULOU. From non-cooperative CO_2 abatement strategies to the optimal world cooperation: Results from the integrated MARKAL model. April 2005.

25. Marc GERMAIN, Vincent VAN STEENBERGHE, Alphonse MAGNUS. Optimal Policy with Tradable and Bankable Pollution Permits : Taking the Market Microstructure into Account.*Journal of Public Economy Theory*, 6(5), 2004, 737-757.

24. Marc GERMAIN, Stefano LOVO, Vincent VAN STEENBEGHE. De l'impact de la microstructure d'un marché de permis de polluer sur la politique environnementale. *Annales d'Economie et de Statistique*, n° 74 – 2004, 177-208.

23. Marc GERMAIN, Alphonse MAGNUS, Vincent VAN STEENBERGHE. Should developing countries participate in the Clean Development Mechanism under the Kyoto Protocol ? The low-hanging fruits and baseline issues. December 2004.

22. Thierry BRECHET et Paul-Marie BOULANGER. Le Mécanisme pour un Développement Propre, ou comment faire d'une pierre deux coups. *Regards Economiques*, Ires n° 27, janvier 2005.

21. Sergio CURRARINI & Henry TULKENS. Stable international agreements on transfrontier pollution with ratification constraints. In C. Carrarro and V. Fragnelli (eds.), *Game Practice and the Environment*. Cheltenham, Edward Elgar Publishing, 2004, 9-36. (also available as CORE Reprint 1715).

20. Agustin PEREZ-BARAHONA & Benteng ZOU. A comparative study of energy saving technical progress in a vintage capital model. December 2004.

19. Agustin PEREZ-BARAHONA & Benteng ZOU. Energy saving technological progress in a vintage capital model. December 2004.

18. Matthieu GLACHANT. Voluntary agreements under endogenous legislative threats and imperfect enforcement. November 2004.

17. Thierry BRECHET, Stéphane LAMBRECHT. Puzzling over sustainability: an equilibrium analysis. November 2004.

16. Vincent VAN STEENBERGHE. Core-stable and equitable allocations of greenhouse gas emission permits. October 2004. (also available as CORE DP 2004/75).

15. Pierre-André JOUVET Philippe MICHEL, Pierre PESTIEAU. Public and private environmental spending. A political economy approach. September 2004. (also available as CORE DP 2004/68).

14. Thierry BRECHET, Marc GERMAIN, Vincent VAN STEENBERGHE. The clean development mechanism under the Kyoto protocol and the 'low-hanging fruits' issue. July 2004. (also available as CORE DP 2004/81).

13. Thierry BRECHET, Philippe MICHEL. Environmental performance and equilibrium. July 2004. (also available as CORE DP 2004/72).

12. Luisito BERTINELLI, Eric STROBL. The Environmental Kuznets Curve semi-parametrically revisited. July 2004. (also available as CORE DP 2004/51).

11. Axel GOSSERIES, Vincent VAN STEENBERGHE. Pourquoi des marchés de permis de polluer ? Les enjeux économiques et éthiques de Kyoto. April 2004. (also available as IRES discussion paper n° 2004-21).

10. Vincent VAN STEENBERGHE. CO_2 Abatement costs and permits price : Exploring the impact of banking and the role of future commitments. December 2003. (also available as CORE DP 2003/98).

9. Katheline SCHUBERT. Eléments sur l'actualisation et l'environnement. March 2004.

8. Marc GERMAIN. Modélisations de marchés de permis de pollution. July 2003.

7. Marc GERMAIN. Le Mécanisme de Développement Propre : Impacts du principe d'additionalité et du choix de la baseline. January 2003.

6. Thierry BRECHET et Marc GERMAIN. Les affres de la modélisation. May 2002.

5. Marc GERMAIN and Vincent VAN STEENBERGHE. Constraining equitable allocations of tradable CO_2 emission quotas by acceptability, *Environmental and Resource Economics*, (26) 3, 2003.

4. Marc GERMAIN, Philippe TOINT, Henry TULKENS and Aart DE ZEEUW. Transfers to sustain dynamic core-theoretic cooperation in international stock pollutant control, *Journal of Economic Dynamics & Control*, (28) 1, 2003.

3. Thierry BRECHET, Marc GERMAIN et Philippe MONTFORT. Spécialisation internationale et partage de la charge en matière de réduction de la pollution. (also available as IRES discussion paper n°2003-19).

2. Olivier GODARD. Le risque climatique planétaire et la question de l'équité internationale dans l'attribution de quotas d'émission échangeable. May 2003.

1. Thierry BRECHET. Entreprise et environnement : des défis complémentaires ? March 2002. Revue Louvain.

Environmental Economics & Management Memorandum

Chair Lhoist Berghmans in Environmental Economics and Management
Center for Operations Research & Econometrics (CORE)
Université catholique de Louvain (UCL)
Voie du Roman Pays 34
B-1348 Louvain-la-Neuve, Belgium

Hard copies are available upon request : env@core.ucl.ac.be
Papers are available in pdf format on line : http://www.uclouvain.be/en-21264.html