DISCUSSION PAPER SERIES

No. 3606

CAN EQUITY ENHANCE EFFICIENCY? SOME LESSONS FROM CLIMATE NEGOTIATIONS

Francesco Bosello, Barbara Buchner, Carlo Carraro and Davide Raggi

INTERNATIONAL TRADE

Centre for Economic Policy Research

www.cepr.org

Available online at: **www.cepr.org/pubs/dps/DP3606.asp**

ISSN 0265-8003

CAN EQUITY ENHANCE EFFICIENCY? SOME LESSONS FROM CLIMATE NEGOTIATIONS

Francesco Bosello, Fondazione ENI Enrico Mattei
Barbara Buchner, Fondazione ENI Enrico Mattei
Carlo Carraro, Università di Venezia and CEPR
Davide Raggi, Fondazione ENI Enrico Mattei

Discussion Paper No. 3606
February 2003

Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 3606

February 2003

ABSTRACT

Can Equity Enhance Efficiency? Some Lessons from Climate Negotiations*

This Paper analyses the relationship between different equity rules and the incentives to sign and ratify a climate agreement. A widespread conjecture suggests that a more equitable distribution of the burden of reducing emissions would enhance the incentives for more countries – particularly big emitters – to accept an emission reduction scheme defined within an international climate agreement. This Paper shows that this conjecture is only partly supported by the empirical evidence that can be derived from the recent outcomes of climate negotiations. Even though an equitable sharing of the costs of controlling GHG emissions can provide better incentives to sign and ratify a climate agreement than the burden sharing implicit in the Kyoto agreement, a stable global agreement cannot be achieved. A possible strategy to achieve a global agreement without free-riding incentives is a policy mix in which global emission trading is coupled with a transfer mechanism designed to offset incentives to free ride.

JEL Classification: C70, H00, H30 and Q38
Keywords: agreements, climate, equity, incentives, negotiations, policy and transfers

Francesco Bosello
Fondazione Eni Enrico Mattei
Campo S. Maria Formosa,
Castello 5252
30122 Venezia
ITALY
Tel: (39 041) 271 1459
Fax: (39 041) 271 1461
Email: bosello@mbox.feem.it

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=145758

Barbara Buchner
Fondazione Eni Enrico Mattei
Campo S. Maria Formosa,
Castello 5252
30122 Venezia
ITALY
Email: buchner@feem.it

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=157121

Carlo Carraro
Dipartimento di Scienze Economiche
Università di Venezia
San Giobbe 873
30121 Venezia
ITALY
Tel: (39 041) 234 9166
Fax: (39 041) 234 9176
Email: ccarraro@unive.it

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=104121

Davide Raggi
Fondazione Eni Enrico Mattei
Campo S. Maria Formosa,
Castello 5252
30122 Venezia
ITALY
Email: raggi@feem.it

For further Discussion Papers by this author see:
www.cepr.org/pubs/new-dps/dplist.asp?authorid=158621

*This Paper has been prepared within the research activities of the CLIMNEG research network. The financial support of the European Commission, Directorate Research, is gratefully acknowledged. The authors are also grateful to Jean Charles Hourcade, Richard Tol and the participants at the Alessandria workshop on ‘Game Practice and the Environment’ for useful comments. Igor Cersosimo and Jill Weinreich provided useful assistance. The usual disclaimer applies.

Submitted 18 September 2002

Can Equity Enhance Efficiency?

Some Lessons from Climate Negotiations

1. Introduction

In the last decades, the importance of international and global environmental problems, such as acid rains, the depletion of the ozone layer and the greenhouse effect, has increased continually. In the absence of a supra-natural authority which enforces environmental policies and regulations, emission reductions can only be achieved via voluntary initiatives and international cooperation. Given the global nature of the above environmental problems, an effective international agreement which implements these emission reductions has to involve as many countries as possible, or at least a number of countries which account for a large share of total emissions. This is particularly true for global warming whose effects and subsequently required mitigation policies are pushed to an unprecedented spatial and time scale.

Unfortunately, broad participation is difficult to achieve (Carraro and Siniscalco, 1993). Given that emission control is costly and a “clean” atmosphere is a public good, countries hardly have incentives to sign an agreement on GHG emission control (the well known free-riding problem). Moreover, structural differences among countries (polluters most often do not suffer the highest damages) imply the difficulty to share the burden of emission reductions in a way that makes it convenient for most countries to sign the agreement (in some countries, abatement costs may not be smaller than the benefits from avoided damages).

These considerations lead to the conclusion that a global agreement on climate change policy (i.e. an agreement signed by all world countries) is generally unrealistic and that emission reduction policies should focus on two interrelated objectives (IPCC 2001, Working Group 3, Chapter 10): (i) on the one hand, a cost-effective reduction of emissions; (ii) on the other hand, ways of providing the incentives for more countries to sign the agreement.

A recent strand of literature analyses the incentives underlying the emergence of international environmental cooperation and the formation of climate coalitions within the general framework of non-cooperative games. This literature highlights that “self-enforcing agreements”, i.e. agreements based on profitable and stable coalitions, may emerge at the equilibrium (see e.g., Carraro and Siniscalco, 1993 and Barrett, 1994). However, in most studies, the size of stable coalitions remains limited for any functional specification of countries’ welfare functions (Hoel, 1992; Barrett, 1994; Carraro and Siniscalco, 1993; Heal, 1994). Hence, the need to develop strategies which enhance the incentives to sign a climate agreement by making it profitable to most relevant countries and by offsetting their incentives to free-ride.

One of the currently proposed ideas in the debate on climate change policy is that more equitable agreements could be a way of increasing consensus and thus having more signatories of the climate treaty. This idea is at the heart of many of the conclusions, based on the present state of knowledge on the economics of climate change, contained in the recent 2001 IPCC Summary for Policymakers from Working Group 3. However, albeit intuitive, there is no substantial analysis that a more equitable distribution of the burden of reducing GHG emissions would induce more countries to sign and ratify the Kyoto Protocol or another climate agreement. The goal of this paper is exactly to address this issue and to assess whether increased equity enhances the likelihood that more countries - and the relevant countries above all - accept to sign and ratify a climate agreement.

Notice that, were the above conjecture true, we could conclude that equity enhances efficiency, because a larger number of relevant signatories (possibly the big emitters) obviously implies a larger amount of emission abatement.

The first step of our analysis is a careful examination of the self-enforcing properties of the Kyoto agreement. To achieve this goal, we use a revealed preference approach, i.e. we start from the actual outcome of the Kyoto negotiations to identify countries' weights in the function defining the optimal cooperative solution. This enables us to assess whether the Kyoto agreement is stable (i.e. no country has an incentive to free ride, i.e. not ratifying and/or implementing the Protocol)[1]. Section 3 analyses the profitability and stability of the Kyoto agreement in two extreme situations. First, when all emission reductions are undertaken domestically without using the so-called Kyoto flexibility mechanisms. Then, when emission reductions can also be undertaken using an emission trading scheme which involves all signatory countries without constraints (no ceilings). It has indeed been argued (see e.g., Eyckmans, 2001) that the possibility of emission trading, by increasing the cost-effectiveness of the agreement, also increases its stability (i.e. incentives to free-ride are lower and more countries sign). Therefore, we will also assess this conjecture in the case of the Kyoto agreement.

In section 4, we carry out the same type of profitability and stability analysis by introducing equity. Three "equitable" burden-sharing criteria -- which are different from the one implicit in the emission abatement targets agreed to in Kyoto -- are considered. These are: (i) the equalisation of average abatement costs; (ii) the equalisation of per capita abatement costs; and (iii) the equalisation of abatement costs on the GDP ratio.[2] For each of these criteria, the profitable and stable coalitions (within all possible coalition structures) are computed in order to verify whether more equity enhances the incentives for self-enforcing agreements to emerge.

[1] Of course, the recent US decision not to ratify the Kyoto Protocol already suggests that the Kyoto agreement is not stable. However, our analysis is carried out under a long term horizon and therefore is devoted to analyse long-term incentives to participate in a climate agreement. Short term decisions may therefore differ from the ones that are optimal according to our modelling framework. See Section 2 for a further discussion of this issue.

[2] In Section 4 we will discuss why these three criteria are often considered as "equitable" and we will compare these criteria with other equity principles.

The results achieved in section 4 are not encouraging. Indeed, most coalition structures are neither stable, nor strongly profitable. Therefore, in section 5 we develop a further alternative, specifically we complement the three "equitable" burden sharing criteria with ex-post transfer policies designed to offset countries' incentives to free-ride. Can these transfer policies help in achieving a global agreement or something close to it? Which equity criterion enhances the effectiveness of these transfer mechanisms?

The surprising answer to these questions will be discussed in the concluding section of this paper, which will also outline directions for further research.

2. Profitability and Stability of Climate Agreements

Two profitability criteria and two stability criteria will be used to assess the self-enforcing properties of climate agreements. The definitions of profitability and stability have been derived directly from Carraro and Siniscalco (1993) (see also Eyckmans, 2001 and Weyant, 1999 for recent applications to climate policy). We say that an agreement is *weakly profitable* if the sum of the individual payoffs of the signatories is larger than the sum of their payoffs when no agreement is signed. In this case, the agreement produces a surplus (overall benefits are larger than costs), but this surplus may not profit to all signatories, i.e. some countries may gain, others may lose. By contrast, an agreement is *strongly profitable* if the payoff of all signatories is larger when the agreement is signed and implemented than when no agreement is signed. Hence, each single participant obtains a net benefit from the agreement.

We say that an agreement is *internally stable* if there is no incentive to free-ride, i.e. the payoff of each signatory is larger than the payoff he/she would obtain by defecting from the group of signatories (those who remain are supposed to keep cooperating even after the defection). Finally, an agreement is *stable* if there is no incentive to free ride and no incentive to join the group of signatories, i.e. the payoff to those countries that are not signatories is larger than the one they would achieve by signing the agreement.

Notice that these four criteria are increasingly demanding. Stability implies internal stability which implies strong profitability which implies weak profitability (see Botteon and Carraro, 1997a). In particular, profitability is a necessary condition for stability. Also notice that a stable agreement is nothing more than a Nash equilibrium agreement (D'Aspremont *et al.*, 1983 and Carraro and Marchiori, 2002). See the Appendix for a formal presentation of the above definitions and results.

Following recent suggestions coming from the theoretical literature (Carraro, 1998), we do not only consider the possibility that countries agree on a single climate treaty, but we also allow countries to negotiate on different tables and to form different regional agreements (similarly to what happens in trade negotiations). Therefore, both single and multiple coalition structures will be analysed. In the case of multiple coalitions, the definition of stability is slightly more complex because agreements should also be intra-coalitionally stable (Yi, 1997). In other words, there should be no incentives to leave one coalition to join a different one.

Therefore, in this paper, we assess the profitability and stability of all possible coalition structures that can emerge on the basis of the three equity criteria mentioned above. As a consequence, we evaluate both the incentives to sign a Kyoto-type agreement (i.e. whether Annex I countries are willing to sign and ratify a climate agreement when the burden sharing is changed) and the incentives to sign any other climate agreements (for each given burden-sharing rule).

3. Incentives to Sign and Ratify the Kyoto Protocol

The goal of this section is to analyse the profitability and stability of the Kyoto agreement, both when all emission reductions are undertaken domestically without using the so-called Kyoto flexibility mechanisms, and when emission reductions can also be undertaken using an unconstrained emission trading scheme which involves all signatory countries.

The analysis is carried out using the original version of the RICE model (Nordhaus and Yang, 1996). The RICE model is a single sector optimal growth model that has been extended to incorporate the interactions between economic activities and climate. One such model has been developed for each macro region into which the world is divided (USA, Japan, Europe, China, Former Soviet Union, and Rest of the World). Within each region a central planner chooses the optimal paths of fixed investment and emission abatement that maximise the present value of per capita consumption. Output (net of climate change) is used for investment and consumption and is produced according to a constant returns Cobb-Douglas technology, which combines the inputs from capital and labour with the level of technology. Population (taken to be equal to full employment) and technology levels grow over time in an exogenous fashion, whereas capital accumulation is governed by the optimal rate of investment. There is a wedge between output gross and net of climate change effects, the size of which is dependent upon the amount of abatement (rate of emission reduction) as well as the change in global temperature. The model is completed by three equations representing emissions (which are related to output and abatement), carbon cycle (which relates concentrations to emissions), and climate module (which relates the change in temperature relative to 1990 levels to carbon concentrations) respectively.

As said, the paper focuses on long-term incentives to sign a climate agreement. Therefore, we need to define the outcome of climate negotiations beyond the first commitment period. In this paper, we adopt the so-called "Kyoto forever" hypothesis (see e.g., Manne and Richels, 1999), namely we assume that the abatement targets agreed upon in Kyoto are binding until the end of this century. In other words, all Annex I countries are assumed to meet the Kyoto constraints from 2010 onward.[3] This is already a standard practice

[3] The use of the "Kyoto forever" hypothesis is a strong assumption. However, the CO2 concentration levels implicit in this assumption (if RICE is a good description of the world) coincide with those in the A1B scenario used by the International Panel on Climate Change (IPCC, 2001) which can be considered the "median" scenario among those currently proposed.

adopted in most economic analyses of climate policy (although there exist studies were different assumptions are made; see, for example, the chapter by Ciscar and Soria in this book). We use the "Kyoto forever" hypothesis not because it represents a realistic scenario, but as a benchmark with respect to which policy alternatives can be compared. Nonetheless, the adoption of this scenario helps also to understand some underlying motivations of the Kyoto agreement:

- Although being a scenario with an overall weak objective (700 ppmv), all the emission reduction requirements are focused on the industrialised countries - the Annex I countries - since the other regions are allowed to follow their BAU paths until 2100. In this sense, there is a kind of equity built-in into the Kyoto-forever scenario.
- Being very penalising for Annex I if there are only domestic policies and measures allowed, the scenario becomes advantageous as soon as emissions trading is allowed. The reason is that in this case, by leaving the other countries outside of the coalition, the Annex I can buy emissions at a low cost. Highlighting the low permit price for Annex I, the scenario thus provides an explanation of why the Non-Annex I is excluded from emission reduction commitments. [4]

Given the RICE representation of the economic system in different world regions and the related impacts on climate, we solved the joint maximisation process through which countries determine the cooperative emission levels (and as a consequence the emission reduction targets). Our business as usual corresponds to the non-cooperative case in which countries set emission levels (and the other decision variables) by maximising their own welfare function given the policy decisions taken by the other countries.

To identify the implicit weights in the joint maximisation process which lead to the cooperative outcome, we used an "inverse optimisation approach" (see e.g., Carraro, 1988, 1989, 1997), that is we iteratively computed the weights in the joint welfare function until each region's optimal investment and abatement levels are such to yield the emission targets agreed in Kyoto. In this way, the solution of the maximisation process can replicate (a) the emission abatement levels for each Annex I country and (b) the share of the abatement costs born by Annex I and by Non-Annex I.

The weights implicit in the "Kyoto forever agreement" are shown in Table 1. Notice that the largest bargaining powers are associated with China and the Rest of the World. The reason for this result is that in the "Kyoto forever" scenario binding emission targets are imposed only on industrialised countries, whereas China and the Rest of the World are not committed to reduce their emissions. FSU, which is often considered as a "winner" of Kyoto negotiations because of "hot air", has a low bargaining power, because our analysis adopts a long-term perspective in which short-term "hot air" has little weight. These results also confirms that some forms of equity is already embodied in the "Kyoto forever" scenario.

[4] These remarks should also be useful to clarify that the wording "Kyoto agreement" used so far refers to the long term version of the Kyoto agreement called "Kyoto forever" scenario or "Kyoto forever agreement".

Given the weights of Table 1, we could move to the second step of our analysis, namely the analysis of the self-enforcing features of the "Kyoto forever agreement". In order to assess the profitability and stability of this "agreement", we had to compare the payoffs which Annex I countries achieve when they cooperate, to the payoffs when no cooperation takes place and/or when a different agreement is signed (this second comparison is crucial in assessing the free-riding incentives and therefore the stability of the "Kyoto forever agreement". See the Appendix).

Table 1. Weights revealed by the "Kyoto forever agreement"

	Weights
USA	0,10655
JPN	0,03707
EU	0,03848
CHN	0,51732
FSU	0,02289
ROW	0,27769

To achieve this goal, we computed the costs and benefits of all possible climate agreements (i.e. coalition structures. See Carraro and Marchiori, 2002). These costs and benefits can be obtained by solving the game between the six regions of RICE using a numerical iterative algorithm. In the non-cooperative case (our business-as-usual), the equilibrium concept used to solve the game is the usual Nash equilibrium. By contrast, when a coalition forms, it is assumed that countries which sign the agreement maximise their joint welfare and play Nash against the free-riding countries. The resulting equilibrium is equivalent to the γ-equilibrium proposed in Chander and Tulkens (1995, 1997).[5]

The results of our optimisation experiments, where 203 different coalition structures have been examined, can be summarised as follows:

(i) The "Kyoto forever agreement" is neither weakly nor strongly profitable. The reason is that the total surplus provided by the agreement from now to 2100 is slightly negative. Moreover, all Annex I

[5] The γ-equilibrium of the game between the four Annex I countries and the two non-Annex I countries of RICE is computed as follows. Annex I countries maximise an aggregate utility function which is the weighted sum of their individual utility functions, where the weights have been computed using the procedure described above, whereas Non-Annex I countries maximise their own utility function, taking as given what the other countries do (see Appendix). In the same way, we also computed all possible γ-equilibria of the game, whatever the size of the coalition and the identity of its members.

regions would lose from signing the agreement (See Table 2). This result is not surprising as cooperation may not be beneficial in the presence of free-riders (see e.g., Carraro and Siniscalco, 1993; Chander and Tulkens, 1997; Carraro and Marchiori, 2002).[6] When emission trading is allowed for, given the cost-effectiveness properties of unconstrained emission trading, losses are lower (this result confirms the theoretical analysis in Chander *et al.* (1999) but the "Kyoto forever agreement" still remains neither weakly nor strongly profitable (see Table 2 again).[7] The reason is that the emission levels attained by Non-Annex I countries in the long-run are too high. Hence, signatory countries pay the cost of emission abatement without getting any benefits. Notice that, in the presence of emission trading, the winner would be Japan, whereas the US, the EU and the FSU would keep losing from signing the agreement. The reason is that Japan greatly benefits from emission trading because it is the country with the highest marginal abatement costs**.**

Table 2. Winners and losers under the "Kyoto forever agreement".

Relative net gains (benefits from avoided damages minus abatement costs in the case of "Kyoto forever" vs. the case of no-cooperation)				
	United States of America	**Japan**	**Europe**	**Former Soviet Union**
"Kyoto forever" with domestic abatement only	- 0,021%	- 0,015%	- 0,009%	- 0,020%
"Kyoto forever" with emission trading	- 0,020%	+ 0,008%	- 0,004%	- 0,003%

(ii) In addition, the "Kyoto forever agreement" is neither stable, nor internally stable. Hence, at least one country has an incentive to free-ride on the other Annex I's abatement effort. Both when emission reductions are only domestic and when emission trading is allowed, Russia and the US have the largest incentive to free-ride (see Table 3). In the absence of a market for emission permits, those two countries are closely followed by Japan. However, being the country that benefits most from emissions trading, Japan is also the one without any incentives to free-ride after the implementation of the trading scheme.

[6] The same result has been found in other fields of economics, i.e. monetary economics (see Rogoff, 1987)

[7] Our conclusion differs from the one in Weyant (1999) and in Eyckmans and Cornillie (2000) where is shown that the "Kyoto forever agreement" is weakly profitable (but not strongly profitable unless a transfer scheme is introduced).

Table 3. Incentives to free ride on the "Kyoto forever agreement".

Relative net gains (benefits from avoided damages minus abatement costs in the case of "Kyoto forever" vs. the case of individual free-riding)				
	United States of America	**Japan**	**Europe**	**Former Soviet Union**
"Kyoto forever" with domestic abatement only	- 0,021%	- 0,015%	- 0,010%	- 0,032%
"Kyoto forever" with emission trading	- 0,018%	+ 0,007%	- 0,005%	- 0,020%

(iii) The burden-sharing distribution implicit in the "Kyoto forever agreement" and represented by the weights of Table 1 can lead to some weakly profitable agreements (see Table 4) even though the "Kyoto forever agreement" itself is not weakly profitable, as seen above. However, no coalition structure (i.e. no agreement) is either strongly profitable, or stable. The situation improves in the presence of emission trading. Indeed, the share of both weakly and strongly profitable and internally stable coalitions increases when emission trading is allowed. Moreover, one coalition structure (over the 203 possible coalition structures) becomes both internally and externally stable.

Table 4. Share of profitable and stable coalitions with the "Kyoto forever" burden sharing.

	Weakly Profitable	**Strongly Profitable**	**Internally Stable**	**Stable**
"Kyoto forever" with domestic abatement only	0,5%	0	0	0
"Kyoto forever" with emission trading	43,3%	5,9%	5,9%	1 over 203

(iv) The possibility of forming multiple coalitions, rather than negotiating on a single agreement, is of no help. Indeed, no coalition structure with multiple coalitions is stable using the "Kyoto forever" burden sharing rule. The only stable coalition structure, i.e. a Nash equilibrium of the game in which countries decide whether or not to join the coalition under the "Kyoto forever" burden sharing rule,

> is formed by a coalition of four countries and by two free-riders. However, the four countries are not the Annex I countries, but Japan, China, FSU and the Rest of the World. The reason for this result lies in the incentives for cooperation provided by emission trading which favour those countries with the largest differences in marginal abatement costs: in our case, Japan on the one hand, and China, FSU, ROW on the other. The incentive for developing countries to participate in the agreement is further increased by the high damages they would suffer from the impacts of climate changes.

If one believes in the features of the RICE model, the above results cast some doubts on the equity properties of the burden sharing criterion which is implicit in the "Kyoto forever" scenario. Indeed, it may be argued that a more equitable distribution of the burden of controlling GHG emissions would induce all or almost all countries to sign and ratify a climate agreement. The validity of this conjecture will be explored in the next section.

4. Equity Criteria and the Structure of Equilibrium Agreements

In this section, the analysis of the profitability and stability of alternative coalition structures is carried out by using three burden sharing criteria which are different from the one implicit in the emission abatement targets of the "Kyoto forever" scenario. The goal is to check whether more equity induces more countries to sign a climate agreement, thus enhancing efficiency.

The background of the equity debate in mitigating the risks of global climate change can be found in the 1992 U.N. Framework Convention on Climate Change. Article 3 states that the Parties have to engage in the protection of the climate system with "common but differentiated responsibilities". This phrase characterises the real beginning of the search for equity proposals, both in the international and intergenerational range. Since the debate about the adequacy of scope and timing of emission reduction commitments is still ongoing, it becomes more and more obvious that the definition of "fairness" or "equity" in the context of climate change control is not a straightforward task. Different pre-conditions and characteristics of the countries, strong and diverse self-interests, incentives to free ride as well as the special features of climate change, render the approval and acceptance of equity criteria difficult. There exist a number of proposals regarding what could constitute equity in GHG mitigation. Corresponding to the wide variety of equity principles, a range of possible burden-sharing rules emerged[8].

Equity proposals usually can be classified by distinguishing whether the applied equity criterion has been chosen according to the initial allocation of emissions ("allocation-based equity criteria"), according to the

[8] For further details see for example Cazorla and Toman (2000), Tol (2001), Rose and Stevens (1993), Rose *et al.* (1998) and Schmidt and Koschel (1998).

final outcome of the implementation of the policy instruments ("outcome-based equity criteria") or according to the process by which the criterion has been chosen ("process-based equity criteria").[9]

Tables 5-7 below summarise the main features of these three different groups of equity proposals and describe the way in which they are usually implemented. The tables are based on suggestions provided in the literature, among others by Cazorla and Toman (2000), Tol (2001), Rose and Stevens (1993), Rose *et al.*(1998) and Schmidt and Koschel (1998).

Table 5. Allocation-based equity criteria

Equity principle	Definition	Implied burden-sharing rule
Egalitarian	All people have an equal right to pollute and to be protected from pollution.	Equal emissions reductions (abatement costs) per capita (in proportion to population or historic responsibilities). Implementation criterion: **Equal per capita abatement costs**
Ability to pay	Abatement costs should vary directly with economic circumstances and national well-being.	Equal emissions reductions (abatement costs) per unit GDP Implementation criterion: **Equal abatement costs per unit of GDP**
Sovereignty[10]	All nations have an equal right to pollute and to be protected from pollution.	Grandfathering (equal emissions reductions or abatement costs in proportion to emissions) Implementation criterion: **Equal average abatement costs**

Source: Adapted from Cazorla and Toman (2000), Tol (2001), Rose and Stevens (1993), Rose *et al.*(1998) and Schmidt and Koschel (1998).

---

[9] For further explanations regarding this distinction see, among others, Rose *et al.* (1998) and Schmidt and Koschel (1998).

[10] Closely related to the equity principle of sovereignty is the "Polluter Pays Principle" which also says that the abatement burden has to be allocated corresponding to emissions (which may include historical emissions). As in the case of sovereignty, equal emissions reductions (abatement costs) in proportion to emission levels are required. Since this principle almost coincides with the principle of sovereignty, only rarely a distinction is made between them in the literature (see, for example, Cazorla and Toman (2000). Due to the similarities we also decided not to take it explicitly into account but to deal with it implicitly through the sovereignty equity concept.

Table 6. Outcome-based equity criteria

Equity principle	Definition	Implied burden-sharing rule
Horizontal	All nations have the right to be treated equally both concerning emission rights and burden sharing responsibilities.	Welfare changes across nations such that welfare costs or net abatement costs as a proportion of GDP or of population are the same in each country. Implementation criterion: **Equal welfare costs per unit of GDP or per capita**
Vertical	Welfare gains should vary inversely with national economic well-being; welfare losses should vary directly with GDP. The greater the ability to pay, the greater the economic burden.	Emissions reductions such that net abatement costs grow with GDP. Implementation criterion: **Equal abatement costs per unit of GDP**
Compensation (Pareto rule)	"Winners" should compensate "losers" so that both are better off after mitigation.	Distribute abatement costs so that no nation suffers a net loss of welfare. Implementation criterion: **Strong profitability**

Source: Adapted from Cazorla and Toman (2000), Tol (2001), Rose and Stevens (1993), Rose *et al*. (1998) and Schmidt and Koschel (1998).

Notice that "allocation-based equity criteria" are implemented with reference to the abatement cost function. They are the dominating concepts used and examined in the literature (Cf. Eyckmans and Cornillie, 2000; Schmidt and Koschel, 1998), because they can be easily applied even without specifying the welfare function for each country. Nevertheless, a number of other equity formulations are possible and emerged, mainly related to a re-distribution of total welfare. For example, Tol (2001) analyses the impacts of three equity concepts based on welfare distribution. The first one relates to Kant with a "Rawlsian touch" ("Do not do to others what you do not want to be done to you", whereby the "others" are the least well-off regions, thus "act as if the impact on the worst-off country is your own"). The second one can be seen as a principle based on Varian's no-envy criterion (for all regions, at all times, the sum of costs of emissions reductions and the costs of climate change should be equal; income distribution should be at the same level where it would have been without climate policy). The third one maximises a global welfare function which explicitly includes an inequality aversion.

The reasons why most empirical studies focus on cost-related equity concepts are their simple implementation and the possibility of comparing the results across studies. Indeed, criteria based on welfare distribution depend on the specification of the welfare function. Existing specifications largely differ across models. In some models, the welfare function is not even defined. By contrast, the specification of abatement costs, and in particular of marginal abatement costs, is subject to much lower variability across models.

Table 7. Process-based equity criteria

Equity principle	Definition	Implied burden-sharing rule
Rawls' max-min	The welfare of the worst-off nation should be maximised, thus maximise the net benefit to the poorest nations.	Distribute largest proportion of net welfare change to poorest nations; majority of emissions reductions (abatement costs) imposed on wealthier nations.
Market justice	The market is "fair", thus make greater use of markets.	Distribute emissions reductions to highest bidder; lowest net abatement costs by using flexible mechanisms (ET).
Consensus	The international negotiation process is fair, thus seek a political solution promoting stability.	Distribute abatement costs (power weighted) so the majority of nations are satisfied.
Sovereign bargaining	Principles of fairness emerge endogenously as a result of multistage negotiations.	Distribute abatement costs according to equity principles that result from international bargaining and negotiation over time.
Kantian allocation rule[11]	Each country chooses an abatement level at least as large as the uniform abatement level it would like all countries to undertake.	Differentiate emissions reductions by country's preferred world abatement, possibly in tiers or groups.

Source: Adapted from Cazorla and Toman (2000), Tol (2001), Rose and Stevens (1993), Rose *et al*. (1998) and Schmidt and Koschel (1998).

For these same reasons, in this paper we also focus on cost-related equity concepts. However, we do not limit our analysis to *ex-ante* "allocation-based equity criteria" (Egalitarian, Ability-to-pay and Sovereignty), but we rather require that these criteria also hold *ex-post*. In other words, we compute profitable and stable coalition structures under the constraint that either one of the following equity criteria holds:

(1) Equal average abatement costs

(2) Equal per capita abatement costs

(3) Equal abatement costs per unit of GDP

Therefore, the equity criteria adopted in this paper are "outcome based". As in the previous section, for each equity criterion, all 203 possible coalition structures have been computed and countries' payoffs compared in order to assess the profitability and stability of each coalition structure. The total amount of abatement in the

[11] According to Rose *et al*. (1998) this rule can be considered roughly equal to the principle of sovereignty plus elements of the principle of consensus.

alternative cases, i.e. in the climate agreements based on the three equity rules, is the same as under the "Kyoto forever" hypothesis [12].

The results of our optimisation experiments are presented in Tables 8, 9, 10 and 11. They can be summarised as follows:

(i) All three outcome-based equity criteria increase the probability that a climate agreement yields a surplus. Indeed, the share of weakly profitable coalition structures is much larger with the three new equity criteria than with the burden-sharing rule implicit in the "Kyoto forever agreement" (see Table 8). Nevertheless, the possibility of regional agreements does not improve the results: no multiple coalition structure is weakly profitable.

(ii) The situation is less positive when the more restrictive criterion of strong profitability is used. Indeed, even the three equity criteria proposed above fail to guarantee a large number of strongly profitable coalition structures. Nonetheless, two of the proposed equity criteria imply that the share of strongly profitable coalition structures is larger than with the burden-sharing rule implicit in the "Kyoto forever" scenario (see Table 9). When the goal is strong profitability, multiple coalitions again do not provide an incentive structure better than the one provided by single coalitions.

(iii) In addition, no coalition structure with multiple coalitions is internally stable (see Table 10). Hence, the only coalition structures which could be stable are the ones in which a single coalition forms. However, the share of single coalitions which are both strongly profitable and internally stable further decreases for all burden-sharing criteria (see Table 10 again). Again, only two equity criteria (equal per capita abatement costs and equal abatement costs per unit of GDP) show better results than the burden-sharing rule implicit in the "Kyoto forever agreement".

(iv) As a consequence, only very few coalition structures are likely to be stable, i.e. without any incentives to leave or to enter the coalition. As shown by Table 11, only one coalition is both profitable and stable, namely it emerges as an equilibrium of the game in which countries non-cooperatively decide whether or not to join the coalition. This equilibrium coalition structure is formed by a coalition of three countries and by three free-riders. It can be obtained only if ex-ante all countries agree that abatement efforts must be such to equalise abatement costs per capita. This coalition is formed by Japan, the Former Soviet Union and ROW.

[12] This condition is necessary in order to compare the various types of climate agreements with the "Kyoto forever" scenario. However, as a consequence the analysis always assumes the same level of stringency and does not verify whether different emission goals, e.g. more or less GHG mitigation, could induce different outcomes with respect to coalitional performance.

Table 8. Weak Profitability. Share of weakly profitable coalitions for each burden-sharing criterion.

	Single coalitions	Multiple coalitions	Total percentage of coalitions
"Kyoto forever" implicit burden sharing	1,7%	0	0,5%
Equal average abatement costs	29,3%	0	8,4%
Equal per capita abatement costs	32,8%	0	9,4%
Equal abatement costs per unit of GDP	32,8%	0	9,4%

Table 9. Strong Profitability. Share of strongly profitable coalitions for each burden-sharing criterion.

	Single coalitions	Multiple coalitions	Total percentage of coalitions
"Kyoto forever" implicit burden sharing	0	0	0
Equal average abatement costs	0	0	0
Equal per capita abatement costs	6,9%	0	2,0%
Equal abatement costs per unit of GDP	1,7%	0	0,5%

Table 10. Internal Stability. Share of internally stable coalitions for each burden-sharing criterion.

	Single coalitions	Multiple coalitions	Total percentage of coalitions
"Kyoto forever" implicit burden sharing	0	0	0
Equal average abatement costs	0	0	0
Equal per capita abatement costs	3,4%	0	1,0%
Equal abatement costs per unit of GDP	1,7%	0	0,5%

Table 11. Stability. Number of stable coalitions for each burden-sharing criterion.

	Single coalitions	Multiple coalitions	Total number of coalitions
"Kyoto forever" implicit burden sharing	0	0	0
Equal average abatement costs	0	0	0
Equal per capita abatement costs	1	0	1
Equal abatement costs per unit of GDP	0	0	0

Summing up, *the adoption of more equitable burden-sharing rules enhances the profitability of a climate agreement but not its stability, i.e. equity improves the distribution of costs and benefits but does not seem to be effective in offsetting the incentives to free-ride.*

Two possible ways of addressing the problem are available. First, policy strategies could be designed to further redistribute the surplus provided by the cooperative behaviour within a coalition. This would increase the number of strongly profitable coalitions and hence the probabilities to identify a stable coalition structure. Transfer schemes designed to make a climate agreement profitable to all countries have been proposed for example in Chander and Tulkens (1997) and applied to climate models in Weyant (1999) or Eyckmans (2001).[13] A more detailed analysis of how equity criteria can be used to achieve strong profitability (*fairness* in their wording) is contained in Hourcade and Gilotte (2001).

Second, policy strategies could be designed to redistribute the surplus achieved by internally stable coalitions with the goal to induce other countries to enter the coalition. This idea is proposed and analysed in Carraro and Siniscalco (1993) where is shown that, with symmetric countries, transfer mechanisms can be used to broaden the coalition only if all countries in the initial, internally stable coalition are committed to cooperation once the transfer scheme is adopted. However, in Botteon and Carraro (1997a) a counter-example is provided in which asymmetric countries could use the surplus of cooperation achieved by a stable coalition to move to the grand coalition through appropriate transfers and without any form of commitment.

In the next section, we will explore this second possibility. The first one - transfers to increase the number of strongly profitable coalitions – was previously analysed in other papers (above all in Weyant, 1999, or in Eyckmans and Tulkens, 1999, where a version of the RICE model is also used).

5. Equity, Transfers and Global Agreements

The conditions for transfers to achieve the goal of expanding a coalition are presented in the Appendix. Here we would like to stress that, at the equilibrium:

- Transfers are self-financed, i.e. countries are allowed to transfer only the surplus yielded by their cooperation. Hence, we analyse how weakly and strongly profitable coalitions can be broadened through a transfer mechanism.
- The transfer mechanism is Pareto optimal, i.e. all countries gain from using transfers to broaden the coalition.

Given this latter restriction, the broadened coalition is also weakly or strongly profitable. However, self-financing implies that there may not be enough resources to offset the free-riding incentives of all countries which are not in the initial, internally stable coalition. Finally, notice that even countries in the initial stable

[13] Notice that all these transfer schemes reflect the application of the compensation criterion described in Table 6.

coalition may have an incentive to free-ride when other countries join. Hence, the transfer mechanism must also be such to offset these latter incentives to free-ride.

Table 12 presents our results. The first column shows the initial, internally stable coalitions for each of the three burden-sharing criteria analysed in the previous section. The second column shows the largest internally stable coalition that can be achieved through a transfer mechanism starting from the corresponding initial, internally stable coalition.

Table 12. Internally stable coalitions before and after the use of transfers

Internally stable coalitions without and with transfers		
	Internally stable coalitions before transfers	**Internally stable coalitions after transfers**
Equalisation of average abatement costs	0	0
Equalisation of abatement costs/GDP	USA + CHN	USA + CHN + ROW
Equalisation of per capita abatement costs	EU + CHN + ROW JPN + FSU + ROW	USA + EU + CHN + ROW USA + JPN + EU + FSU + ROW

Our results can be summarised as follows:

(i) No transfer mechanism and no ex-ante burden sharing criterion (of the three that we considered) yields an incentive structure or enough resources to achieve the grand coalition, i.e. a global agreement on climate change. At least one region free rides on the agreement.

(ii) The burden-sharing criteria that are most effective in guaranteeing the achievement of a large coalition without free-riding incentive are the equalisation of per capita abatement costs and the equalisation of abatement costs per unit of GDP. For example, with the former, a coalition formed by Japan, FSU and ROW can offset the free-riding incentives of EU and US. With the latter, a coalition formed by China and US can induce ROW to sign the climate agreement. Notice that the US needs a compensating transfer to enter a coalition which forms according to the criterion of equal per-capita abatement costs, whereas they belong to the initially stable coalitions if the burden-sharing criterion is equal abatement costs per unit of GDP. This is quite intuitive: the US has high per capita emissions, but relatively small emissions per unit of GDP.

Nonetheless, a stable global agreement cannot be achieved. Hence, we wonder whether the introduction of emission trading, regardless of the ex-ante burden-sharing criterion, can provide enough resources which, once transferred to free-riding countries, can induce them to sign the climate agreement. The answer to this question is provided by the following two propositions, which summarise our numerical results:

Proposition 1*: Regardless of the ex-ante burden sharing criterion (equity), and regardless of the initial, internally stable coalition, the equalisation of marginal abatement costs, coupled with an appropriately designed ex-post transfer mechanism, can lead to a grand coalition, i.e. a global climate agreement signed by all countries or regions, which is stable.*

In other words, through emission trading and transfers, *all* internally stable coalitions can be broadened to achieve a stable grand coalition. By using a twofold transfer mechanism, one designed to transform a weakly profitable coalition into a strongly profitable one (i.e. as in Gilotte, 2001), and a second one designed to make it internally stable, we achieve an even stronger conclusion:

Proposition 2*: The result of Proposition 1 holds for all initial weakly profitable coalitions.*[14]

The list of all weakly and strongly profitable coalitions is provided in Table 13. Starting from any of these coalition structures, and applying an unconstrained trading scheme jointly with appropriate transfer mechanisms, it is possible to achieve a stable grand coalition.

There is a main weakness in the above conclusions, which depends on the specification of the RICE model. Most resources to fund the transfer mechanism which helps in achieving the grand coalition do not come from the US or the EU, but from Japan, China and Rest of the World. The example shown in Table 14 can help us to show why.

---

[14] The results of Propositions 1 and 2 are implicitly shown also in Chander and Tulkens (1995) but for a different definition of stability (usually named coalition unanimity. Cf. Tulkens, 1998, and Yi, 1997). In particular, their definition of stability coincides with our definition of profitability.

Table 13. Weakly and strongly profitable coalitions

Coalitions that can be broadened into the grand coalition by means of transfers	
JPN+EU+CHN+FSU+ROW	Weakly profitable
EU+CHN+FSU+ROW	Weakly profitable
EU+FSU+ROW	Weakly profitable
EU+ROW	Weakly profitable
EU+CHN+ROW	Weakly profitable
EU+CHN	Weakly profitable
EU+CHN+FSU	Weakly profitable
JPN+EU+FSU+ROW	weakly profitable
JPN+EU+ROW	weakly profitable
JPN+EU+CHN+ROW	weakly profitable
JPN+EU+CHN	weakly profitable
JPN+EU+CHN+FSU	weakly profitable
USA+EU+CHN+FSU+ROW	weakly profitable
USA+CHN+FSU+ROW	weakly profitable
USA+FSU+ROW	weakly profitable
USA+ROW	weakly profitable
USA+CHN+ROW	weakly profitable
USA+CHN	weakly profitable
USA+CHN+FSU	weakly profitable
USA+EU+FSU+ROW	weakly profitable
USA+EU+ROW	weakly profitable
USA+EU+CHN+ROW	weakly profitable
USA+JPN+CHN+FSU+ROW	weakly profitable
USA+JPN+FSU+ROW	weakly profitable
USA+JPN+ROW	weakly profitable
USA+JPN+CHN+ROW	weakly profitable
USA+JPN+CHN	weakly profitable
USA+JPN+CHN+FSU	weakly profitable
USA+JPN+EU+FSU+ROW	weakly profitable
USA+JPN+EU+ROW	weakly profitable
USA+JPN+EU+CHN+ROW	weakly profitable
CHN+FSU	strongly profitable
FSU+ROW	strongly profitable
CHN+ROW	strongly profitable
JPN+CHN+ROW	strongly profitable
JPN+CHN	strongly profitable
JPN+ROW	strongly profitable
CHN+FSU+ROW	strongly profitable
JPN+CHN+FSU	strongly profitable
JPN+FSU+ROW	strongly profitable
JPN+CHN+FSU+ROW	strongly profitable

Table 14. Incentive structure and transfer mechanisms to achieve a global agreement when EU and ROW form the initial internally stable coalition (in welfare units).

Step 1	USA	JPN	**EU**	CHN	FSU	**ROW**
Profitability $P_i(s) – P_i(\varnothing)$			-0.124			5.488
Internal stability $Q_i(s \backslash i) – P_i(s)$			0.126			-5.488
External stability $P_i(s \cup i) – Q_i(s)$	-0.223	0.152		0.504	0.17	
Step 2	USA	**JPN**	**EU**	**CHN**	**FSU**	**ROW**
Profitability $P_i(s) – P_i(\varnothing)$		0.155	-0.117	0.322	0.195	5.793
Internal stability $Q_i(s \backslash i) – P_i(s)$		-0.146	0.139	-0.3	-0.188	-5.523
External stability $P_i(s \cup i) – Q_i(s)$	-0.227					
Step 3	**USA**	**JPN**	**EU**	**CHN**	**FSU**	**ROW**
Profitability $P_i(s) – P_i(\varnothing)$	-0.21	0.174	-0.075	0.186	0.19	5.742
Internal stability $Q_i(s \backslash i) – P_i(s)$	0.227	-0.158	0.113	-0.149	-0.18	-5.36

Let us assume that EU and ROW form the initially stable coalition. A different initially stable coalition would lead to similar conclusions. Step 1 analyses the profitability and stability of the coalition formed by EU and ROW using the definitions provided in section 2. It is easy to see that the coalition is weakly profitable. The surplus can thus be used to make it both strongly profitable and internally stable. However, it would not be externally stable. Japan, China and FSU would like to join. If the three countries enter the coalition, one of the previous participating countries (the EU) would like to exit the coalition. Hence, transfers can be used to stabilise the coalition formed by Japan, EU, China, FSU and ROW (Step 2). Further transfers are necessary to induce the US to enter the coalition (Step 3). This is certainly feasible, because the benefit achieved by ROW in the grand coalition is large and can easily be used to compensate the free-riding incentive of EU and US (0.227 and 0.113 respectively). However, what is odd is that the EU and the US should receive transfers rather than transferring resources. Of course, we could design a transfer mechanism where resources flow from developed to developing countries. However, we would like to stress that, given the structure of RICE, most gains from a climate agreement go to FSU, China and ROW, which implies that these countries have more resources to induce the other ones to participate in the global agreement.

The realism of this result is obviously open to debate. However, we do not believe that this result undermines the general conclusions achieved above; it simply calls for additional analyses of the incentive structure of climate agreements undertaken using models different from RICE.

6. Conclusions

Previous sections have analysed the incentive structure of different types of climate agreements using the RICE model as the device of representing the interactions between economic and climate variables. First, we focused on the "Kyoto forever agreement", of which we analysed profitability and stability. The conclusion is that almost all Annex I countries lose by signing the agreement and that more than one of these countries have an incentive to free-ride, i.e. the net benefit from letting the other countries to reduce emissions is larger than the net benefit from reducing emissions. Of course, net benefits take into account the avoided damages from climate change at least as far as they are represented in RICE.

Second, we analysed the conjecture that a more equitable *ex-post* distribution of the burden of reducing emissions could enhance the incentives for more countries - particularly big emitters - to accept an emission reduction scheme defined within an international climate agreement. Our optimisation experiments only partly support this conjecture. Even though equitable burden sharing rules provide better incentives to sign and ratify a climate agreement than the burden-sharing rule which is implicit in the "Kyoto forever" scenario, a stable agreement cannot generally be achieved, i.e. equity seems to enhance the profitability of climate agreements but it does not offset the incentives to free-ride.

Third, we verify whether there exists a transfer mechanism that could help broadening an initial stable, but partial, coalition achieved by agreeing on an equitable burden-sharing scheme. Our results suggest that transfers can indeed help broadening a given coalition. However, the grand coalition could not be achieved at least with the three equity rules considered in this paper (equal average abatement costs, equal per capita abatement costs and equal abatement costs per unit of GDP).

The only strategy which we showed could achieve a stable global agreement is a policy mix in which global emission trading is coupled with a transfer mechanism designed to offset ex-post incentives to free ride. This policy mix can achieve a stable global agreement whatever the initial weakly profitable coalition.

As a consequence, our results seem to suggest that an excessive focus on equity rules is not fruitful. It is more effective to minimise overall abatement costs via emission trading and then use the resulting surplus to provide incentives for free-riding countries to join the initial coalition.

The above results are obviously very preliminary. Firstly, we compared only three equity rules Other criteria could produce different results, even though the equity rules applied in this paper encompass most of the empirical rules likely to be proposed. Secondly, and most importantly, all results crucially depend on the specification of the RICE model and on its way off assessing costs and benefits of emission abatement. It is well-known that the RICE model is a very useful but simplified representation of the economic system and that its environmental components are very limited. Therefore, it would be important to check whether our results are robust with respect to different model specifications. In particular, results are sensitive to the specification of the damage function and to the long-run dynamics of the model. A lower damage from climate change perceived in developing countries would reduce the benefits of GHG emission control policies in these countries and therefore their incentives to join a coalition and to contribute to transfer schemes.

References

Barrett, S. 1994. Self-enforcing International Environmental Agreements, *Oxford Economic Papers*, 46, 878-894.

Barrett, S. 1997. Towards a Theory of International Environmental Co-operation, in C. Carraro and D. Siniscalco, eds., *New Directions in the Economic Theory of the Environment*, Cambridge University Press: Cambridge.

Botteon, M. and C. Carraro. 1997a. Burden-Sharing and Coalition Stability in Environmental Negotiations with Asymmetric Countries, in C. Carraro, ed., *International Environmental Agreements: Strategic Policy Issues*, E. Elgar, Cheltenham.

Botteon, M. and C. Carraro. 1997b. Strategies for Environmental Negotiations: Issue Linkage with Heterogeneous Countries, in H. Folmer and N. Hanley, eds., *Game Theory and the Environment*, E. Elgar, Cheltenham.

Carraro, C. 1988. The Implicit Objective Function of Italian Macroeconomic Policy, *Economic Modelling*, n.3, 261-276.

Carraro, C. 1989. The Tastes of European Central Bankers, in M. De Cecco and A. Giovannini, eds., *A European Central Bank? Perspectives on Monetary Unification after Ten Years of the EMS*, Cambridge University Press, Cambridge.

Carraro, C. 1997. Modelling International Policy Games: Lessons from European Monetary Coordination, *Empirica*, 23, 163-177.

Carraro, C. 1998. Beyond Kyoto: A Game-Theoretic Perspective, in Proceedings of the OCED Workshop on "Climate Change and Economic Modelling: Background Analysis for the Kyoto Protocol", Paris.

Carraro, C., C. Marchiori. 2002. Stable Coalitions, in C. Carraro, ed., *The Endogenous Formation of Economic Coalitions*, Edward Elgar: Cheltenham.

Carraro, C. and D. Siniscalco. 1993. Strategies for the International Protection of the Environment, *Journal of Public Economics*, 52, 309-328.

Cazorla, M. and M. Toman. 2000. International Equity and Climate Change Policy, *RFF Climate Issue Brief* No. 27, Washington.

Chander, P. and H. Tulkens. 1995. A Core-Theoretic Solution for the Design of Cooperative Agreements on Transfrontier Pollution, *International Tax and Public Finance* 2 (2), 279-294.

Chander, P. and H. Tulkens. 1997. The Core of an Economy with Multilateral Environmental Externalities, *International Journal of Game Theory*, 26, 379-401.

Chander, P., H. Tulkens, J.P. Van Ypersele and S. Willems. 1999. The Kyoto Protocol: An Economic and Game Theoretic Interpretation, CLIMNEG Working Paper n. 12, CORE, UCL, Louvain.

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

D'Aspremont, C.A. and J.J. Gabszewicz. 1986. On the Stability of Collusion, in G.F. Matthewson and J.E. Stiglitz, eds., *New Developments in the Analysis of Market Structure*, Mac Millan Press, New York, 243-264.

Donsimoni, M.-P., N. S. Economides and H. M. Polemarchakis. 1986. Stable Cartels. *International Economic Review* 27 (2), 317-327.

Eyckmans, J. 2001. On the Farsighted Stability of the Kyoto Protocol, Some Simulation Results, ETE Working Paper No. 2001-03, Katholieke Universiteit Leuven, University of Leuven.

Eyckmans, J. and J. Cornillie. 2000. Efficiency and Equity in the EU Bubble. ETE Working Paper No. 2000-02, Katholieke Universiteit Leuven, University of Leuven.

Eyckmans, J. and H. Tulkens. 1999. Simulating with RICE Coalitionally Stable Burden Sharing Agreements for the Climate Change Problem. *FEEM Working Paper* 71-99.

Heal, G. 1994. The Formation of Environmental coalitions, in C. Carraro, ed., *Trade, Innovation, Environment*, Kluwer Academic Publishers: Dordrecht.

Hoel, M. 1991. Global Environmental Problems: The Effects of Unilateral Actions Taken by One Country, *Journal of Environmental Economics and Management*, 20, 1, 55-70.

Hoel, M. 1992. International Environmental Conventions: The Case of Uniform Reductions of Emissions, *Environment and Resource Economics*, 2, 141-159.

Hourcade, J.C. and L. Gilotte. 2001. From Equity Principles to Allocation Rules, Report to the European Commission, CIRED.

Gilotte, L. 2001. Testing Allocation Rules, Report to the European Commission, CIRED.

IPCC. 2001. Third Assessment Report and Summary for Policymakers. Cambridge University Press: Cambridge.

Manne, A. and R. Richels. 1999. The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives? in J. Weyant, ed., The Cost of the Kyoto Protocol: A Multi-Model Evaluation. Special Issue of the *Energy Journal*.

Nordhaus, W.D. and Z. Yang. 1996. A Regional General-Equilibrium Model of Alternative Climate-Change Strategies. *American Economic Review*, Vol. 86, No. 4.

Rogoff, K. 1987. Reputational Constraints on Monetary Policy. *Carnegie-Rochester Conference Series on Public Policy*, 26, 141-182.

Rose, A., B. Stevens, J. Edmonds and M. Wise. 1998. International Equity and Differentiation in Global Warming Policy: An Application to Tradable Emission Permits, *Environment and Resource Economics,* 12(1): 25-51.

Rose, A. and B. Stevens. 1993. The Efficiency and Equity of Marketable Permits for CO2 Emissions, *Resource and Energy Economics*, 15(1): 117-46.

Schmidt, T.F.N. and H. Koschel. 1998. Climate Change Policy and Burden Sharing in the European Union – Applying Alternative Equity Rules to a CGE-framework. ZEW Discussion Paper No. 98-12.

Tol, R.S.J. 2001. Equitable Cost-Benefit Analysis of Climate Change Policies, *Ecological Economics,* 36 (2001): 71-85.

Tulkens, H. 1998. Cooperation versus Free-riding in International Environmental Affairs: Two Approaches, in H. Folmer and N. Hanley, eds., *Game Theory and the Environment*, E. Elgar.

Weyant, J. (ed.). 1999. The Cost of the Kyoto Protocol: A Multi-Model Evaluation, *Energy Journal*, Special Issue.

Yang, Z. 2000. Forming Coalitions in International Agreements on Global Climate Change, University of Pennsylvania.

Yi, S. 1997. Stable Coalition Structures with Externalities, *Games and Economic Behaviour*, 20, 201-223.

APPENDIX

An economic model of international agreements on CO_2 emission reduction

Consider n countries ($n \geq 2$) that interact in a common environment and bargain over emission control of a specific pollutant. Let $W_i(x_1 \ldots x_n)$ be a country's welfare function, where x_i, i=1,2,...,n, denotes a vector containing country i's emissions and all other economic variables affecting abatement costs and the environmental damage perceived in each country. The function $W_i(.)$, i=1,2,...,n, captures countries' interaction in a global environment, as welfare depends on all countries' emissions as well as on other trans-national variables (i.e. trade policy variables). Let $P_i(s)$ denote the value of country i's welfare when it decides to join the coalition s, whereas $Q_i(s)$ is the value of its welfare when country i does not join the coalition s. Let us assume that only one coalition can be formed. Conditions which hold when multiple coalitions form can be found in Yang (2000) and Carraro and Marchiori (2002).

As the focus of this section is to analyse the stability of coalitions, the only argument of the value of the welfare function is the identity and number of cooperating countries. However, it is implicit that all other relevant variables in RICE, including emissions and policy decisions in other countries, enter country i's welfare function. Hence $P_i(\emptyset)$, i=1,2,...,n, is a country's non-cooperative payoff (the non-cooperative Nash equilibrium payoff), whereas $P_i(S)$ is country i's payoff when all countries decide to cooperate (the grand-coalition S is formed).

Notice that when a country joins the environmental coalition, it determines its optimal emission level by maximising a function reflecting the agreed-upon burden sharing rule (i.e. in the case of the Nash-bargaining rule, emissions are determined by maximising the product of the deviation of cooperative countries' emissions from the non cooperative level). When a country does not join the coalition, it sets emissions by maximising its own welfare function given the emissions levels of all other countries (emissions are therefore defined by its own best-reply function). This behavioural assumption defines the concept of γ-equilibrium (Chander and Tulkens, 1997).

Two conditions must be met for an environmental coalition to be self-enforcing (see e.g., Carraro and Siniscalco, 1993 and Barrett, 1994). First, the coalition must be profitable, i.e. each country $i \in s$ gains from joining the coalition, with respect to its position when no countries cooperate.

Formally, a coalition s is **profitable** if:

(1) $$P_i(s) \geq P_i(\emptyset), \forall i \in s.$$

Second, no country must have an incentive to free-ride, i.e. the coalition s must be stable. More precisely, a country i chooses the cooperative strategy if $P_i(s)$, the country's payoff for belonging to the coalition s, is larger than $Q_i(s \backslash i)$, the country's payoff when it exists the coalition, and lets the other countries sign the cooperative agreement. Hence, $Q_i(s\backslash i) - P_i(s)$, $i \in s$, is a country's incentive to defect from a coalition s, whereas $P_i(s \cup i) - Q_i(s)$, $i \notin s$, is the incentive for a non-cooperating country to join the coalition s.

Thus, a coalition s is **stable** iff there is no incentive to free-ride, i.e.

(2) $$Q_i(s\backslash i) - P_i(s) < 0 \qquad \text{for each country i belonging to } s;$$

and there is no incentive to broaden the coalition, i.e.

(3) $$P_i(s \cup i) - Q_i(s) < 0 \qquad \text{for each country i which does not belong to } s.$$ [15]

It has been shown that under fairly general conditions stable coalitions exist (see Donsimoni *et al.*, 1986). However, this does not satisfactorily address the problem of protecting international commons, because, as it has been demonstrated both in the oligopoly and in the environmental literature (see, for example, D'Aspremont *et al.*, 1983; D'Aspremont and Gabszewicz, 1986; Hoel, 1992; Barrett, 1994, 1997; Carraro and Siniscalco, 1993), stable coalitions are generally formed by $j \leq n$ players, where j is a small number, regardless of n.[16] If stable coalitions are small, and countries are symmetric, the impact of their emission reductions on total emissions is likely to be negligible. However, the above-mentioned results mostly concern models in which countries are supposed to be symmetric, i.e. they share the same welfare function. More encouraging results can be achieved in the presence of asymmetric countries (Barrett, 1997; Botteon and Carraro, 1997a, 1997b).

The existence of small stable coalitions leads to the following question: can the cooperating countries expand the coalition through self-financed welfare transfers to the remaining players?

The answer provided by the literature and by the practice of international agreements focuses on transfers as means to bribe non signatory countries. Notice that we are not referring to the possibility of using transfers or side-payments to make the agreement profitable to all countries. This latter issue is discussed e.g., in Chander and Tulkens (1997), Eyckmans and Cornillie (2000) and Weyant (1999). Here we start from the necessary condition that the agreement is profitable, and we look at the possibility that transfers increase the stability of the agreement.

In this context, which is discussed in detail in Carraro and Siniscalco (1993), a non-trivial analysis of transfers requires to impose constraints on the amount of resources to be transferred: were the transfers unconstrained, all non-signatories could be bribed, but the mechanism would not be credible. Therefore, we assume that: (i) transfers must be self-financed, i.e. the total transfer T must be lower than the gain that the

[15] This definition corresponds to that of cartel stability presented in the oligopoly literature D'Aspremont and Gabszewicz (1986). A similar definition is also used in Barrett (1994). However, this definition assumes that deviating countries cannot form (or do not find it profitable to form) another coalition, i.e. group deviations are not allowed for. This restriction, even if widely accepted, is quite important as shown in Carraro and Marchiori (2002).

[16] More satisfactory results are presented in Heal (1994), where a fixed cost of forming the coalition is introduced.

committed countries obtain from expanding the coalition; (ii) the move to a larger coalition must be **Pareto-improving**, i.e. all countries must increase their welfare vis-à-vis the situation preceding the coalition expansion, and vis-à-vis non-cooperation (the larger coalition must also be profitable).

Under these conditions, however, the theoretical literature has provided a negative result. If countries are symmetric, self-financed transfers cannot induce free-riders to sign the environmental agreement, unless some degrees of commitment constrain the strategic choices of cooperating countries.[17] However, in the case of asymmetric countries, transfers can be used to expand the initially stable coalition even in the absence of any forms of commitment Botteon and Carraro (1997a).

Let us start by analysing which conditions have to be satisfied in order to induce an additional country to enter a stable coalition. Suppose the coalition s is stable. If its members are committed to cooperation, their joint additional benefit when country j enters the coalition is:

(4) $$\Sigma_{i\in s}[P_i(s\cup j) - P_i(s)] > 0$$

The incentive for country j to free ride from the $s\cup j$ coalition is:

(5) $$Q_j(s) - P_j(s\cup j) > 0$$

because the coalition $s\cup j$ is not stable. Hence, the coalition $s\cup j$ can be stabilised by a system of transfers if:

(6) $$\Sigma_{i\in s}[P_i(s\cup j) - P_i(s)] > Q_j(s) - P_j(s\cup j)$$

and:

(i) there exists a sharing rule such that $P_i(s\cup j) - P_i(s) > 0$ for all $i\in s$.

(ii) countries belonging to the coalition s are committed to cooperation.

If this latter condition is not satisfied, in the symmetric case transfers cannot expand a stable coalition (Carraro and Siniscalco, 1993). However, in the asymmetric case, transfers may succeed in expanding the stable coalitions s even without any forms of commitment. In the asymmetric case, all countries may have a cost of belonging to the coalition much lower than the cost of exiting it.[18] Formally, $Q_i(s\cup j\backslash i) - P_i(s\cup j)$ may be negative for all $i\in s$. If this is the case, the coalition $s\cup j$ can be stabilised by a system of transfers if:

(7) $$\Sigma_{i\in s}[P_i(s\cup j) - Q_i(s\cup j\backslash i)] > Q_j(s) - P_j(s\cup j)$$

Notice that this latter condition is more restrictive than condition (6) because: $P_i(s) < Q_i(s\cup j\backslash i)$, $i\in s$.

[17] Carraro and Siniscalco (1993) prove the following proposition: if no (symmetric) countries can commit to the cooperative strategy, no self-financed transfer from the j cooperating countries to the other non-cooperating countries can successfully enlarge the original coalition.

[18] This is not possible in the symmetric case because the marginal country equates the payoff it receives when it belongs to the coalition with the payoff it would achieve by leaving the coalition.