Stability of Climate Coalitions in a Cartel Formation Game

Michael Finus, Ekko van Ierland and
Rob Dellink

NOTA DI LAVORO 61.2003

JUNE 2003
CLIM – Climate Change Modelling and Policy

Michael Finus, *Department of Economics, Hagen University, Germany*
Ekko van Ierland, *Wageningen University, Department of Social Sciences, The Netherlands*
Rob Dellink, *Wageningen University, Department of Social Sciences, The Netherlands*

Stability of Climate Coalitions in a Cartel Formation Game

Summary

We empirically test stability of climate change coalitions with the STAbility of Coalitions model (STACO). The model comprises twelve world regions and captures important dynamic aspects of the climate change problem. We apply the stability concept of internal and external stability to a cartel formation game. It is shown that only if benefits from global abatement are sufficiently high, stable coalitions emerge, though they only marginally improve upon the Nash equilibrium. We explain this phenomenon by analyzing the individual incentive structure of all regions and relate our results to the predictions of theory.

Keywords: International environmental agreements, Kyoto-Protocol, Cartel formation game, Non-cooperative game theory

JEL: C72, H41, Q25

The authors acknowledge the support of Juan-Carlos Altamirano-Cabrera, Eligius Hendrix, Niels Olieman, Pepijn van Oort, Arjan Ruijs and Hans-Peter Weikard in the analysis.

Address for correspondence:

Ekko van Ierland
Wageningen University
Department of Social Sciences
Environmental Economics and Natural Resources Group
Hollandseweg 1
6706 KN Wageningen
The Netherlands
E-mail: Ekko.vanIerland@alg.shhk.wau.nl

1. Introduction

Game theoretical analyses of the formation of international environmental agreements (IEAs) have stressed the difficulties in designing self-enforcing treaties because of free-riding. Two approaches can be distinguished:[1] cooperative and non-cooperative game theory. The *cooperative approach* has focused on transfer schemes that ensure stability of the efficient grand coalition implementing a socially optimal emission or abatement vector (e.g., Chander/Tulkens 1995, 1997 and Germain et al. 2000). The tool of the analysis is the *characteristic function* that assigns a worth to coalitions. The worth is the aggregate payoff to a coalition that it can secure for itself irrespective of the behavior of countries outside the coalition. Stability has been checked by invoking the concept of the core: the grand coalition is stable, that is, lies in the core, if no subgroup of countries has an incentive to form another coalition, assuming that remaining countries break up into singletons playing either a minimax, maximin or Nash equilibrium strategy.

The advantage of the cooperative approach is that theoretical results have been derived under general conditions. Moreover, the amount of empirical studies is relatively large and most rely on a sound empirical module (e.g., Eyckmans and Tulkens 1999, Germain et al. 1998 and Kaitala et al. 1995). The importance of this approach lies in stressing the role of the allocation of the gains from cooperation for stability and in showing how free-riding can be mitigated by a "cleverly" designed transfer scheme. However, by the nature of a normatively oriented approach, cooperative game theory contributes only to a limited extent to rationalizing inefficient IEAs, which, of course, most treaties are. Moreover, we are convinced that some conceptual drawbacks are implied by the characteristic function. First, assuming that countries pursue their self-interest as rational players, it seems natural to conclude that they will base their decision of membership on *individual payoffs* and not on the *aggregate payoff* to their coalition even if transfers are available. Second, the stability test rests on very strong assumptions about the implicit punishment after free-riding of a group of countries. Third, externalities between countries and coalitions are only insufficiently captured since the characteristic function treats all players outside a coalition as a residual that acts as a benchmark for deviations with punishment (Bloch 1997).

---

[1] The following discussion is exclusively restricted to coalition formation in the context of IEAs. For an overview, see Finus (2001 and 2003a). A more general discussion of cooperative and non-cooperative coalition theory is provided in Bloch (1997).

In contrast, the *non-cooperative approach* has focused on explaining the problems of forming large and effective coalitions. The tool of the analysis is the *valuation function* that assigns an individual payoff to each country for each possible partition of countries (i.e., coalition structure). For each coalition structure, payoffs follow from the assumption that coalition members jointly maximize the aggregate payoff to their coalition but behave non-cooperatively towards outsiders (see section 2 for details). Equilibrium coalition structures are determined by applying the concept of internal and external stability. *Internal stability* means that no coalition member has an incentive to leave its coalition to become a singleton and *external stability* that no singleton has an incentive to join a coalition. Key results that emerge from this literature (e.g., Barrett 1994 and 1997, Bauer 1992, Carraro/Siniscalco 1993, Hoel 1992, Hoel/Schneider 1997 Jeppesen/Andersen 1998 and Rubio/Ulph 2001) are: a) only small coalitions are stable and b) whenever full cooperation (social optimum) would generate large global welfare gains compared to no cooperation (Nash equilibrium), stable coalitions achieve only little.

The advantage of the non-cooperative approach is that it helps to explain the problems of cooperation in international pollution control in the sense of a positive analysis. The reason is that it better captures spillovers across countries and coalitions, and that punishment after a deviation rests on a more plausible assumption: after a country leaves the agreement the residual signatories remain in it, though they revise their abatement strategies. A conceptual drawback of this approach is that most results rely on simulations and have been derived for very specific assumptions. Typical assumptions include a static payoff structure, symmetric players, and in the case of heterogeneous countries a particular form of heterogeneity. Moreover, there are only few empirical studies and most compromise either on the dynamics (e.g., Botteon/Carraro 1997 and 1998 and Tol 2001) or on the regional disaggregation of the climate problem (i.e., number of players; e.g., Bosello et al. 2001, Buchner et al., Eyckmans/Finus 2003).

The purpose of this paper is to fill this gap - at least partially, though, admittedly, our empirical module of the model is not a fully-fledged general equilibrium model. Nevertheless, we believe that our model improves upon previous work in two respects. First, our model captures important features of the dynamic nature of greenhouse gas concentration. Second, the analysis comprises twelve world regions that render the interaction between actors more interesting than studies that consider only few regions.

In the following, we lay out the game theoretical part of the model in section 2 and the empirical part in section 3. In section 4, we discuss ecological and welfare aspects of coalition formation of our base case and in section 5 we report on results of various sensitivity analyses. Section 6 summarizes the main findings and concludes with some remarks about future research issues.

2. Theoretical Background of the Model

Coalition formation is modeled as a *two-stage game*. In the *first stage,* countries or regions decide on their *membership* in a coalition; in the *second stage,* coalition members choose their *abatement strategies*. In the *first stage,* we assume that there are two membership strategies available to countries: strategy $\sigma_i = 0$ means "I do not want to sign the agreement" and $\sigma_i = 1$ means "I want to become a member of a climate treaty". Technically, this implies that countries that announce $\sigma_i = 0$ form a singleton coalition and those that announce $\sigma_i = 1$ become members of a non-trivial coalition (i.e., a coalition of at least two members). More formally, we have (Finus/Rundshagen 2001):

Definition 1: Stage 1 of the Cartel Formation Game

Let i denote a particular country, $i \in I = \{1,...,N\}$, and let a particular membership strategy of country i be the message σ_i and its strategy set be given by $\Sigma_i = \{0,1\}$, $\Sigma = \Sigma_1 \times \Sigma_2 \times ... \times \Sigma_N$, and denote c^i the coalition to which i finally belongs, then

$$c^i = \begin{cases} \{i\} \text{ if } \sigma_i = 0 \\ \{j / \sigma_j = 1\} \text{ if } \sigma_i = 1 \end{cases}.$$

A coalition structure $c = (c^1,...,c^M)$ is a partition of countries where a particular coalition is denoted by c^k, $k \in \{1,...,M\}$, $c^k \cap c^l = \varnothing \ \forall k \neq l$, $\bigcup c^i = I$ and $c \in C$ where C is the set of coalition structures.

In our empirical model, we consider twelve world regions that give rise to 4096 different *strategy vectors.* However, since a strategy vector where only one region announces $\sigma_i = 1$ and all other regions announce $\sigma_i = 0$ leads to the same coalition structure as if all regions announce $\sigma_i = 0$, C comprises "only" 4084 different *coalition structures*. Due to the restriction to two membership strategies (joining the coalition or acting as a singleton), notation can be simplified and we may write $c = (c^S, 1,...,1)$ instead of $c = (c^1,...,c^M)$. If $c^S = \{i\}$ this is called *"singleton coalition structure"* and if $c^S = I$ this is called *"grand coalition structure"*.

In the *second stage,* countries choose their abatement strategies based on the following payoff function:

$$[1] \qquad \pi_i(q) = \sum_{t=1}^{T} (1+r_i)^{-t} (B_{it}(q_t) - AC_{it}(q_{it}))$$

where T denotes the time horizon, t=1, ..., T, r_i is the discount rate of country i, B_{it} are benefits from global abatement $q_t = \sum_{i=1}^{N} q_{it}$, AC_{it} are abatement costs from individual abatement q_{it} and q is an abatement vector of dimension $N \times T$. Benefits from global abatement are derived from reduced environmental damages caused by greenhouse gas emissions. We make the standard assumption: $\forall\ i \in I,\ q_{it} \in [0, e_{it}^{BAU}]$ and at each time t: $B_{it}^{'} > 0$, $B_{it}^{''} \leq 0$, $AC_{it}^{'} > 0$ and $AC_{it}^{''} > 0$ where primes denote first and second derivatives and e_{it}^{BAU} is the emission level in the business-as-usual scenario.

In section 3, we will lay out in detail how global abatement relates to global emissions and greenhouse gas concentration and how this affects payoffs. At this stage, it suffices to note that we follow the standard assumption of the valuation function approach and presume that countries belonging to the same coalition maximize the aggregate payoff to their coalition (Bloch 1997). The equilibrium abatement strategy vector q^* for coalition structure c is derived as a Nash equilibrium between coalitions. In our context, this implies that non-signatories maximize their own payoff and signatories maximize the sum of payoffs of the members of the agreement. Hence, following the terminology of Chander/Tulkens (1995 and 1997) q^* may also be called partial Nash equilibrium between the members of the agreement and the remaining countries. More formally, we have:

Definition 2: Stage 2 of the Coalition Formation Game

Fix a coalition structure $c = (c^S, 1 \ldots, 1)$ *let* $\upsilon_i(c) = \pi_i(q^*)$ *and assume that signatories* $i \in I^S$ *jointly maximize the aggregate payoff to their coalition* c^S *and each non-signatory* $j \in I^{NS}$ *maximizes his own payoff (*$I^{NS} \cap I^S = \varnothing, I^{NS} \cup I^S = I$*). Let* q^S *denote the abatement strategy vector of signatories and* q_j^{NS} *the abatement strategy vector of a non-signatory j,* $q_i \in Q_i$*,* $Q = Q_1 \times \ldots \times Q_N$*, and assume that the equilibrium abatement vector* $(q^{S*}, q^{NS*}) = q^* = (q^{S*}, q^{I \setminus I^{S*}}) = (q_j^*, q^{I \setminus j^*})$ *satisfies:*

$\forall\ c^S \in C,\ \forall\ q^S \in Q^S: \sum_{i \in c^S} \pi_i(q^{S*}, q^{I \setminus I^{S*}}) \geq \sum_{i \in c^S} \pi_i(q^S, q^{I \setminus I^{S*}})$ *and*

$\forall j \in I^{NS},\ \forall\ q_j \in Q_j: \pi_j(q_j^*, q^{I \setminus j^*}) \geq \pi_j(q_j, q^{I \setminus j^*})$ *where* q^* *is assumed to be a unique interior equilibrium.*

Definition 2 implies that the valuation of country i, $\upsilon_i(c)$, can solely be identified by a coalition structure c. Signatories behave cooperatively within their coalition but non-cooperatively against non-signatories. Hence, abatement strategies within coalition c^S are efficiently chosen. Consequently, the singleton (grand coalition) coalition structure implies an equilibrium abatement strategy vector corresponding to the "classical" Nash equilibrium (social optimum). Thus, the highest global welfare will be obtained in the grand coalition structure, the lowest in the single coalition structure and any welfare level in between in any other coalition structure. For the calibration of the payoff functions - on which we report in section 3 - it turns out that q^* (for all coalition structures $c \in C$) is unique and lies well within the boundaries of the abatement space as defined above ($q_{it} \in [0, e_{it}^{BAU}]$).

From definition 2, it is evident that because the strategy in the second stage is fixed, the entire coalition formation game reduces to one single stage. This allows analyzing stability of coalition structures in terms of strategies in the first stage based on the valuation of countries. We call a coalition structure c^* stable if no signatory has an incentive to leave the agreement and no non-signatory has an incentive to join the agreement. Thus, we use the standard definition of internally and externally stable coalition structures (I&E-CS) applied to our context.

Definition 3: Internally and Externally Stable Coalition Structures (I&E-CS)

Denote the set of countries announcing $\sigma_i = 0$ *by* I^{NS} *and the set of countries announcing* $\sigma_i = 1$ *by* I^S *and let the valuation of country i in coalition structure c generated by announcement* σ *be given by* $\upsilon_i(c(\sigma))$*, then* c^* *generated by* σ^* *is called*

internally stable if $\forall i \in I^S: \quad \upsilon_i(c^*(\sigma_i^* = 1, \sigma_{-i}^*)) \geq \upsilon_i(c(\sigma_i = 0, \sigma_{-i}^*))$ *and*

externally stable if $\forall j \in I^{NS}: \ \upsilon_j(c^*(\sigma_j^* = 0, \sigma_{-j}^*)) > \upsilon_j(c(\sigma_j = 1, \sigma_{-j}^*))$.

Definition 3 implies that a signatory will not leave the agreement and a non-signatory will join the agreement in the case of indifference. This assumption constitutes the most favorable conditions for large stable coalitions. From Definition 3 it is evident why we - different from the main stream of the literature applying I&E-CS to analyze stability of IEAs - explicitly model the first stage of the coalition formation game as an announcement game. In our setting an equilibrium always exists which may not be the case for the standard definition. The reason is that the singleton coalition structure is stable if each country announces $\sigma_i = 0$. Then, the singleton coalition structure forms that is internally stable by definition and externally stable because no other coalition can be induced by a change of a single membership strategy. The last remark stresses that an I&E-CS is de facto a Nash equilibrium in the announcement game formalized in Definition 1. Finally note that in the context of our empirical model a necessary condition for an internally stable coalition structure is that the condition of individual rationality is met (see Appendix 1 for a proof). That is, all signatories must receive a higher payoff than in the singleton coalition structure. Hence, if this condition is violated for at least one signatory, we can immediately conclude that this coalition structure cannot be internally stable.

3. Empirical Background of the Model

3.1 Introduction

In this section, we describe the calibration of payoff function [1]. The philosophy behind the construction of our empirical model comprises two items. First, the model must be simple enough to be tractable for a game theoretical analysis. Nevertheless, it should reflect important results and features of general equilibrium models in terms of the development of global emissions and concentration over some period. Therefore, we base our calibration in this respect on the widely known DICE-model by Nordhaus (1994). Second, in order to make the model interesting for a game theoretic analysis, there should be a sufficient amount of different players. We consider twelve world regions. Since this requires disaggregate information on benefit and abatement cost functions we rely on damage cost estimates of Fankhauser (1995) and Tol (1997) and abatement cost estimates of Ellerman/Decaux (1998). From the nature of the two items, it is apparent that we have to seek a compromise. Hence, we set up an empirical model that we call *sta*bility of *co*alition model, henceforth abbreviated STACO. STACO captures important dynamic aspects of climate change but is de facto a finitely repeated game with stationary abatement strategies.

In the following, we proceed in five steps. First, we describe the relation between emissions and concentration. Second, we discuss damages implied by concentration. Third, we show how we derive benefit functions from damage cost functions. Fourth, we report about the calibration of the abatement cost functions. Fifth, we discuss the implications of the first four steps for our payoff function and computations of valuations for different coalition structures. All parameters are reported in the Appendix 2; a detailed description of the model is available from the authors upon request (Dellink et al. 2003).

3.2 Emissions and Concentration

In our analysis, we focus on carbon dioxide, but the exogenous level of other greenhouse gases is included in the calibration of the damage cost function (Nordhaus 1994). For the development of emissions and the stock of carbon dioxide in the business-as-usual-scenario (BAU), we base our calibration on the market scenario in DICE. This scenario assumes no emission reduction, though there is a feedback between the environment and the economy. In DICE, global emissions grow non-constantly over time. However, it turns out that a linear specification of uncontrolled global emissions (e_t) provides a good fit for the development of the stock of carbon dioxide:

$$[2] \quad e_{t+1} = e_t + d_E$$

where d_E denotes the uncontrolled annual growth of global emissions, $e_t = \sum_{i=1}^{N} e_{it}$. Our analysis starts in 2010 and covers a period of 100 years in order to capture the long-run effects of the global warming problem. Thus, with reference to equation [1], t=2011, ..., T=2110. For emissions in 2010, we choose the value of DICE, which amounts to 11.96 gigatons CO_2. We estimate [2] using OLS-regression. This gives $d_E = 0.153$.

The stock of carbon dioxide in the atmosphere at time t is expressed in the standard way by the following equation:

$$[3] \quad M_t\left(q_{2011},...,q_t\right) = M_{pre-ind} + (1-\delta)^{(t-2010)} \cdot \left(M_{2010} - M_{pre-ind}\right) + \sum_{s=2011}^{t} \left((1-\delta)^{t-s} \cdot \omega \cdot \left(e_s - q_s\right)\right)$$

That is, the stock at time t, M_t, depends on global abatement from time t=2011 onwards, q_{2011}, ..., q_t where $q_t = \sum_{i=1}^{N} q_{it}$. More specifically, the stock depends on three terms. The first term is the pre-industrial stock, $M_{pre-ind}$, which is 590 gigatons CO_2 according to DICE. This stock remains constant over time and may be interpreted as the "natural equilibrium". The second term is the stock in 2010 in excess of the pre-industrial stock that decays with a rate δ per annum. The "natural removal or decay rate" as well as the stock in 2010 are taken from DICE and are $\delta = 0.00866$ and $M_{2010} = 835$ gigatons CO_2, respectively. The third term constitutes that part of the stock that is due to global (BAU-) emissions e_s, which grow according to [2], minus global abatement after 2010, q_s. The airborne fraction of total net emissions (BAU-emissions minus abatement) that remains in the atmosphere is 64 percent ($\omega = 0.64$) according to DICE, which decays with rate $\delta = 0.00866$ per annum. In the BAU-scenario with no abatement, the uncontrolled stock according to [3] in 2110 is 1585 gigatons whereas the corresponding value taken from DICE is 1576 gigatons. This stresses that our approximation in [2] works well.

If we denote the uncontrolled stock at time t by $M_t(0)$, then [3] can be rewritten:

$$[4] \quad M_t\left(q_{2011},...,q_t\right) = M_t(0) - \sum_{s=2011}^{t} (1-\delta)^{t-s} \cdot \omega \cdot q_s \,.$$

which simplifies if we assume q_{it} (and hence also q_t) constant over time. For the stock of CO_2 in 2110 this leads to:

$$[5] \qquad M_{2110}(q) = M_{2110}(0) - \left[\sum_{t=2011}^{2110} (1-\delta)^{2110-t} \cdot \omega \right] \cdot \frac{q}{100}$$

where $q = \sum_{t=2011}^{2110} q_t$, the term in brackets is a constant equal to 42.9 and $M_{2110}(0)$=1585 gigatons CO_2 as reported above.

3.3 Global Damage Cost Function

In DICE global damages depend on world temperature increase, ΔT_t, global GDP, Y_t, and parameter γ_D that measures the impact on GDP due to an increase in temperature of 3 degrees Celsius compared to the pre-industrial level.

$$[6] \qquad D_t = \gamma_D \cdot \left[\frac{\Delta T_t}{3} \right]^2 \cdot Y_t$$

However, in order to establish a direct link between concentration and damages, we follow Germain and Van Steenberghe (2001), who use the following approximation of the full climate module:

$$[7] \qquad \Delta T_t = \eta \cdot \ln\left(\frac{M_t}{M_{pre-ind}} \right)$$

where η is a parameter. Substituting [7] into [6], gives:

$$[8] \qquad D_t = \left(\frac{\gamma_D}{9} \right) \cdot \left[\eta \cdot \ln\left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot Y_t$$

In DICE, it is assumed that a doubling of the carbon dioxide concentration ($2 \cdot M_{pre-ind}$) leads to an increase in temperature of 3 degrees.[2] Thus from [7], $\eta = 3/\ln(2)$, and γ_D can be interpreted as damages in percentages of GDP for a doubling of concentration:

$$[9] \qquad D_t = \left[\frac{1}{\ln(2)} \cdot \ln\left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot (\gamma_D \cdot Y_t)$$

Though this damage function is non-linear, it can be approximated by a linear function in the relevant range of our study, that is, between the stock in 2010 (1.4 times pre-industrial level) and the estimated uncontrolled level in 2110 (3.5 times pre-industrial level):

---

[2] This is based on an exogenous additional impact of other greenhouse gases on radiative forcing (see Nordhaus 1994).

[10] $$D_t = \left[\gamma_1 + \gamma_2 \cdot \left(\frac{M_t}{M_{pre-ind}}\right)\right] \cdot \left(\gamma_D \cdot Y_t\right)$$

where γ_1 and γ_2 are calculated via OLS-regression. Further manipulation that considers the fact that (i) a doubling of concentration occurs between 2055 and 2065 in DICE and also in our approximation, (ii) the undiscounted GDP in this period is 70284 billion US$ and (iii) $M_{pre-ind} = 590$ gigatons CO_2, we derive:[3]

[11] $$D_t = \gamma_D \cdot \left(\varphi_1 + \varphi_2 \cdot M_t\right)$$

where $\varphi_1 = \gamma_1 \cdot Y_{2061} = -140146$ billion US$ and $\varphi_2 = \gamma_2 \cdot (1/M_{pre-ind}) \cdot Y_{2061} = 178.331$ billion US$ per Gton.

3.4 Derivation of Global and Regional Benefit Functions

Since we prefer to compute payoffs in terms of net benefits and not in terms of total costs, we express benefits in the form of reduced damages due to abatement. Due to the assumption of stationary abatement strategies, we can express benefits in year t as a function of total abatement over the entire period, $q = \sum_{t=2011}^{2110} q_t$. Noting that [11] reads $D_t\left(M_t\left(q\right)\right) = \gamma_D \cdot \left(\varphi_1 + \varphi_2 \cdot M_t\left(q\right)\right)$ if abatement is explicitly accounted for, we derive for benefits from global abatement in year t, $B_t(q)$:

[12] $$\begin{aligned} B_t\left(q\right) &= D_t\left(M_t\left(0\right)\right) - D_t\left(M_t\left(q\right)\right) \\ &= \gamma_D \cdot \left[\varphi_1 + \varphi_2 \cdot M_t\left(0\right)\right] - \gamma_D \cdot \left[\varphi_1 + \varphi_2 \cdot M_t\left(q\right)\right] \\ &= \gamma_D \cdot \varphi_2 \cdot \left(M_t\left(0\right) - M_t\left(q\right)\right) \end{aligned}$$

which indicates that the intercept φ_1 has no effect on the benefit function. Summing over all periods, discounting benefits with a discount rate of 2 percent, inserting $\varphi_2 = 178.331$ from above gives total benefits $TB(q) = \gamma_D \cdot 1385.1 \cdot q$ and marginal total benefits $MTB(q) = \gamma_D \cdot 1385$. Nordhaus (1994) assumes for the scale parameter γ_D a value of 0.0133, that is, damages amount to 1.33 percent of GDP. However, it is known that the DICE value is relatively low. Therefore, we use the more recent estimate of Tol (1997) who estimates damage costs of 2.7 percent of GDP for a doubling of concentration and hence $\gamma_D = 0.027$. This leads to $TB(q) = 37.40 \cdot q$, implying discounted marginal global benefits of 37.40 US$ per ton CO_2 ($MTB(q) = 37.4$). This figure is in line with results by Plambeck and Hope (1996) who

---

[3] All market values are expressed in billion US$ of 1985 using the deflator provided by NASA (2002). This applies to damages, benefits and abatement costs.

report that their best estimates of marginal global benefits in a regional scenario fall within the range of 10 to 48 US$ per ton CO_2.

Table 1: Benefit and Abatement Cost Parameters

Regions	Emissions in 2010 (Gton)	Share of global benefits s_i Calibration I	Share of global benefits s_i Calibration II	Abatement cost parameter β_i	Abatement cost parameter α_i
1 USA	2.42	0.226	0.124	0.0005	0.00398
2 JPN	0.56	0.173	0.114	0.0155	0.18160
3 EU	1.4	0.236	0.064	0.0024	0.01503
4 OOE	0.62	0.035	0.017	0.0083	0
5 EET	0.51	0.013	0.013	0.0079	0.00486
6 FSU	1	0.068	0.035	0.0023	0.00042
7 EEX	1.22	0.030	0.030	0.0032	0.03029
8 CHN	2.36	0.062	0.062	0.00007	0.00239
9 IND	0.63	0.050	0.171	0.0015	0.00787
10 DAE	0.41	0.025	0.085	0.0047	0.03774
11 BRA	0.13	0.015	0.052	0.5612	0.84974
12 ROW	0.7	0.068	0.233	0.0021	0.00805
WORLD	11.96	$\sum s_i = 1$	$\sum s_i = 1$		

In a final step, we have to allocate global benefits from reduced environmental damages to the various world regions based on the assumption that $TB_i(q) = s_i \cdot TB(q)$ (and hence $MTB_i(q) = s_i \cdot MTB(q)$) where s_i is the share of region i. We consider 12 regions: USA (USA), Japan (JPN), European Union (EEC), other OECD countries (OOE), Eastern European countries (EET), former Soviet Union (FSU), energy exporting countries (EEX), China (CHN), India (IND), dynamic Asian economies (DAE), Brazil (BRA) and "rest of the world" (ROW).[4] The allocation is a difficult task since no source of damage cost estimates is available that exactly matches with our regions. However, two sources come relatively close to our regional specification: Fankhauser (1995) and Tol (1997). Hence, we adjust their estimates for our purposes.[5] This gives rise to two calibrations displayed in the third and fourth

---

[4] EEC comprises the 15 countries of the European Union as of 1995. Other OECD countries (OOE) includes among other countries Canada, Australia and New Zealand. Eastern European countries (EET) includes for instance Hungary, Poland, and Czech Republic. Energy Exporting Countries (EEX) includes for example the Middle East Countries, Mexico, Venezuela and Indonesia. Dynamic Asian economies (DAE) comprises South Korea, Philippines, Thailand and Singapore. Rest of the World (ROW) includes for instance South Africa, Morocco and many countries in Latin America and Asia. For details, see Babiker et al. (2001).

[5] Because of space limitations, the interested reader is referred to our empirical background paper that is available upon request from the authors. There we lay out in detail how we derive Calibration I and II from Fankhauser (1995) and Tol (1997).

column in Table 1 above, respectively, that we call Calibration I and Calibration II. Calibration I is mainly based on Fankhauser´s estimates whereas Calibration II on Tol´s computations. Calibration I implies relatively high shares for OECD countries whereas Calibration II implies lower shares for these countries but higher shares for IND, DAE, BRA and ROW.

3.5 Derivation of Abatement Cost Functions

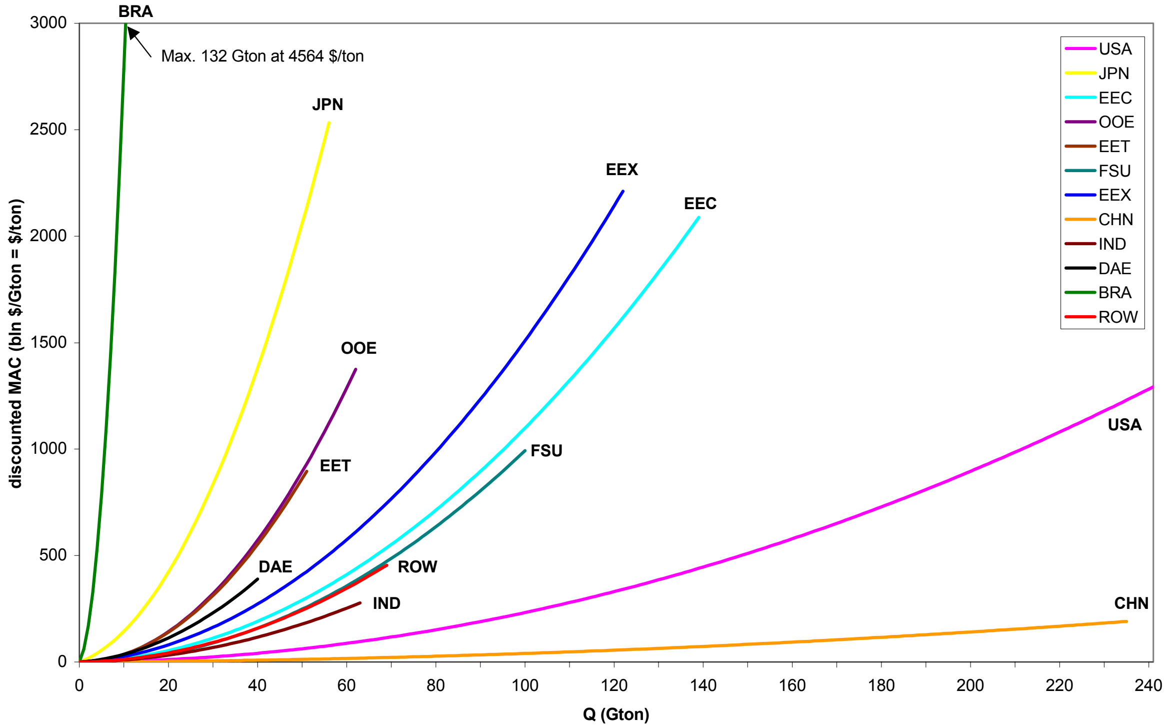
For the specification of the abatement cost function, we rely on estimates of the EPPA model that are reported in Ellerman and Decaux (1998). They assume an annual abatement cost function of the following form:

$$[13] \quad AC_{it}(q_{it}) = \tfrac{1}{3}\cdot\alpha_i\cdot(q_{it})^3 + \tfrac{1}{2}\cdot\beta_i\cdot(q_{it})^2$$

We can use their estimates but have to adjust their figures in four respects. First, we have to account for the fact that their abatement cost estimates are in million US$ per megaton greenhouse gas reduction whereas our unit of measurement is billion US$ per gigaton. Second, we replace q_{it} by $q_i/100$ in [13] because we assume stationary strategies ($q_{i,2011} = ... = q_{i,2110}$). Third, they estimate a negative value for the parameter α_i for OOE. Since this would cause problems for computations, we set α_i=0 in this case and re-estimate β_i for OOE. All estimates are displayed in the last two columns in Table 1. Fourth, in our model abatement means emission reduction with respect to BAU-emissions. Thus, we allocate total initial emissions of 11.96 gigatons (see section 3.2) to the 12 regions, using the shares of Ellerman and Decaux (1998). This gives the numbers in the second column in Table 1. This implies that we assume not only global emissions to grow linearly with d_E (see equation [2]) but also regional emissions, however, according to their shares in global emissions ($s_i \cdot d_E$).

In order to derive total abatement costs of region i, $TAC_i(q_i)$, we sum [13] over t=2011, ..., 2110 and discount with discount rate r, $TAC_i(q_i) = \sum_{t=2011}^{2110}(1+r)^{-(t-2010)}AC_{it}(q_i)$. This implies that we assume the same abatement cost structure throughout, neglecting possible exogenous or endogenous cost efficiency effects. Noting that because of stationary strategies, we can write $TAC_i(q_i) = AC_{it}(q_i)\cdot\sum_{t=2011}^{2110}(1+r)^{-(t-2010)}$ and discounting abatement costs with the same uniform discount rate of 2 percent as in the case of benefits, we get $TAC_i(q_i) = 43.1\cdot AC_{it}(q_i)$ and marginal total abatement costs of $MTAC_i(q_i) = 43.1\cdot MAC_{it}(q_i)$ which are drawn in Figure 1.

Figure 1: Marginal Total Abatement Cost Functions



From the graph, it is evident that marginal abatement costs never intersect and that CHN and USA have the flattest curves while BRA as well as JPN have the steepest. That is, as a tendency, those regions with high BAU-emissions face low marginal abatement costs and those with low emissions face high marginal abatement costs.

3.6 Payoff Function

Using the information of section 3.4 and 3.5 gives the following payoff function:

$$[14] \qquad \pi_i = TB_i(q) - TAC_i(q_i)$$

The empirical computation of valuations (see Definition 2) implies that countries choose their abatement strategies based on [14]. In equilibrium, $\sum_{i \in c^i} MTB_i(q) = MTAC_i(q_i)$. Since our specification of $TB_i(q)$ implies a linear function and hence constant marginal benefits, signatories and non-signatories have dominant abatement strategies. That is, optimal abatement strategies of a region or group of regions are independent of those of other regions (see Appendix 1). This implies that if regions form a coalition and thereby increasing their abatement efforts this is not offset by a reduction of abatement efforts of outsiders. In other words, in our model no leakage effects occur. According to theory (Carraro/Siniscalco 1998 and Finus 2003a), this is the most favorable condition for forming stable coalitions. Nevertheless, as will be apparent from subsequent sections, cooperation proves very difficult.

4. Results: Base Case

4.1 Introduction

From the previous discussion it became evident that in particular the estimation of benefits from global abatement is associated with some uncertainty. This concerns the level of damages represented by the parameter γ_D and the shares of global benefits of individual regions, s_i. Hence, we conduct in the following various sensitivity analyses. In order to structure the analysis, we call shares according to Calibration I and a value of $\gamma_D = 0.027$, as assumed in section 3.4, the base case. This case is discussed in this section. Any deviation of this assumption is summarized under "sensitivity analyses" and treated in section 5. The first set of sensitivity analyses assumes Calibration I but lower or higher values for γ_D (ranging from 50% to 300% of the original value). The second set assumes $\gamma_D = 0.027$, but considers regional benefit shares of Calibration II.

In order to gain insight in the fundamental features of our model, we discuss first three benchmark scenarios. 1) The *singleton coalition structure* with no cooperation (subsection 4.2). 2) The *grand coalition structure* with full cooperation (subsection 4.3). 3) The *Kyoto coalition structure* that constitutes partial cooperation (subsection 4.4). Here we assume that the members of the original Kyoto Protocol form a coalition, which includes USA, JPN, EEC, OOE, EET and FSU. Subsequently, we report on results of our stability check (subsection 4.5).

4.2 Singleton Coalition Structure

Table 2 reports results if each region forms its own coalition that corresponds to the "classical" Nash equilibrium with no cooperation. Hence, marginal abatement costs are equal to marginal benefits for each country. Annual global emission reduction amounts to only 4.6 percent that implies a stock of carbon dioxide of 1,561 gigatons of CO_2 in 2110. This is about 2.5 times the pre-industrial level. The fact that benefits are rather high compared to costs from abatement explains that even in the absence of any cooperation total emission reductions exceed that in the BAU-scenario (no abatement) by 55 gigatons.

Table 2: Singleton Coalition Structure (Nash Equilibrium)

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Benefits minus abatement costs	Marginal abatement costs	Marginal benefits
	Gton (over 100 years)	percentage of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	Bln US$ over 100 years	US$/ton	US$/ton
USA	16	6.7	53	468	415	8.5	8.5
JPN	1	1.4	2	357	354	6.5	6.5
EEC	7	4.7	24	488	464	8.8	8.8
OOE	2	3.1	1	71	71	1.3	1.3
EET	1	1.8	0	27	27	0.5	0.5
FSU	5	4.9	4	140	135	2.5	2.5
EEX	1	0.7	0	62	62	1.1	1.1
CHN	15	6.6	16	128	112	2.3	2.3
IND	3	5.3	3	103	101	1.9	1.9
DAE	1	1.3	0	52	51	0.9	0.9
BRA	0	0.1	0	32	32	0.6	0.6
ROW	4	5.3	4	141	137	2.5	2.5
World	55	4.6	109	2,069	1,960		

Global stock of carbon dioxide by 2110 = 1,561 Gton

At the level of individual regions, it is evident that annual emission reductions vary widely. The reason is large differences in marginal abatement cost curves (see Figure 1 and Table 1, section 3) and marginal benefits from abatement (see Table 1, section 3) between regions. For instance, USA has a relatively flat marginal abatement cost curve but high marginal benefits from abatement. Thus, even in the absence of cooperation, USA has an incentive to annually reduce emissions by 6.7 percentage. A similar argument applies to CHN that has an even flatter marginal abatement cost curve, though lower marginal benefits from abatement compared to USA. In contrast, regions like BRA, DAE, EEX have virtually no incentive at all to conduct emission reductions by itself because of steep marginal abatement cost curves and low marginal benefits from abatement. Overall, it is evident that marginal benefits and costs remain at a moderate level.

4.3 Grand Coalition Structure

Table 3 displays results for the grand coalition structure that corresponds to the "classical" global or social optimum with full cooperation. Thus, marginal abatement costs are equal across countries and amount to 37.4 US$/ton - a value that is in the range of many other empirical studies (e.g., Weyant 1999). At the aggregate level, annual emission reduction amounts to 21.4 percent, exceeding those in the singleton coalition structure by a substantial amount. Nevertheless, the effect on concentrations in 2110 is only moderate - a feature reminiscent also to most computable general equilibrium models: it amounts to a reduction of only 5.5 percentage compared to the singleton coalition structure. The reason is that the airborne fraction of CO_2-emissions that remains in the atmosphere is only 64 percent and the annual natural removal rate of 0.86 percent levels off differences between both scenarios over a period of 100 years. However, the total payoff (benefits minus abatement costs) in the grand coalition structure is 6031 billion US$, which implies a gain from cooperation of 208 percent compared to the singleton coalition structure. This stresses the importance of cooperation in the case of global warming.

Table 3: Grand Coalition Structure (Social Optimum)

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Benefits minus abatement costs	Marginal abatement costs	Marginal benefits	Incentive to leave coalition
	Gton (over 100 years)	percentage of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	US$/ton	US$/ton	bln US$ over 100 years
USA	38	15.7	513	2,169	1,656	37.4	8.5	23.6
JPN	4	6.5	63	1,653	1,590	37.4	6.5	-123.8
EEC	16	11.5	229	2,262	2,033	37.4	8.8	-180.1
OOE	10	16.5	127	331	203	37.4	1.3	109.6
EET	10	19.6	130	125	**-6**	37.4	0.5	124.9
FSU	19	19.3	242	647	405	37.4	2.5	178.1
EEX	12	10.2	188	288	99	37.4	1.1	169.9
CHN	96	40.6	1,348	594	**-754**	37.4	2.3	1133.2
IND	22	33.8	295	479	184	37.4	1.9	245.8
DAE	10	25.1	155	239	84	37.4	0.9	142.1
BRA	1	5.5	12	147	135	37.4	0.6	10.0
ROW	19	26.5	250	652	401	37.4	2.5	185.1
World	256	21.4	3,553	9,584	6,031			-

Global stock of carbon dioxide by 2110 = 1,475 Gton

At the level of individual regions, it is evident that CHN, USA and IND have to contribute substantial more than other regions to a globally optimal solution due to their flat marginal abatement cost curves. For EET and CHN a globally optimal solution would not be individually rational since these regions would loose compared to the Nash equilibrium as it is indicated by bold faced figures in column 6, Table 3. Those regions have to contribute much to cooperation but benefit only little in the form of reduced damages. Thus, we can immediately conclude that the grand coalition is not a stable coalition structure. Moreover, a more detailed analysis conducted in the last column of Table 3 reveals that all regions, except JPN and EEC, have an incentive to leave the grand coalition. Considering the absolute amount of the gains from leaving the grand coalition indicates that most regions face a strong free-rider incentive. Only JPN and EEC have no interest in leaving the grand coalition. However, not only these two regions have the highest interest in full cooperation but - as will be apparent below - also in partial cooperation. A detailed explanation of the underlying fundamentals will be provided below where we report on our stability analysis (subsection 4.5).

4.4 Kyoto Coalition Structure

Table 4 displays results for the Kyoto coalition structure. Hence, according to the assumption of the valuation function, the first six regions (indicated italics in Table 4) jointly maximize the aggregate payoff to their coalition and therefore marginal abatement costs of these regions are equal. Even though half of the regions form a coalition, annual abatement is substantially lower than in the global optimum but almost twice as high as in the Nash equilibrium. Also, the global gain from cooperation is with 3140 bln US$ 60 percent higher than in the Nash equilibrium.

Table 4: Kyoto Coalition Structure

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Benefits minus abatement costs	Marginal abatement costs	Marginal benefits	Incentive to change member-ship strategy
	Gton (over 100 years)	percentage of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	US$/ton	US$/ton	bln US$ over 100 years
USA	32	13.4	332	906	574	28.0	8.5	65.3
JPN	3	5.2	38	691	653	28.0	6.5	-46.9
EEC	14	9.7	147	945	798	28.0	8.8	-52.8
OOE	9	14.3	83	138	**55**	28.0	1.3	70.5
EET	9	16.9	85	52	**-33**	28.0	0.5	80.3
FSU	17	16.7	157	270	**113**	28.0	2.5	114.6
EEX	1	0.7	0	120	120	1.1	1.1	-113.5
CHN	15	6.6	16	248	232	2.3	2.3	-794.9
IND	3	5.3	3	200	197	1.9	1.9	-172.7
DAE	1	1.3	0	100	99	0.9	0.9	-93.9
BRA	0	0.1	0	61	61	0.6	0.6	-6.5
ROW	4	5.3	4	272	268	2.5	2.5	-137.8
World	107	8.9	865	4,005	3,140			

Global stock of carbon dioxide by 2110 = 1,539 Gton

However, also the Kyoto coalition structure is not stable. Three regions, OOE, EET and FSU, would be worse off in this coalition than in the Nash equilibrium (as indicated by bold faced numbers in Table 4, column 5). Moreover, not only these regions but also the USA have an incentive to leave the coalition, as it is evident from the last column in Table 4.[6] This result together with our finding that the USA will already conduct relative high abatement without any cooperation (see Table 2) helps to explain the decision of President Bush to withdraw from the Kyoto Protocol and his announcement to pursue, nevertheless, an "active" national climate policy.

---

[6] The finding that the Kyoto coalition is neither individually rational nor internal stable is also confirmed by Bosello et al. (2001).

Not surprising, all six outsiders are better off than in the Nash equilibrium since they benefit from the abatement efforts of the Kyoto coalition. The fact that none of the outsiders has an incentive to join the coalition is more surprising, which follows from the negative number in the last column in Table 4. The reason is that if already six regions have formed a coalition, joining would imply a substantial increase of abatement efforts for a potential entrant but only a marginal additional benefit from reduced emissions.

4.5 Stability Analysis

We checked all 4084 coalition structures for internal and external stability with an algorithm programmed with the software package Matlab. We found no non-trivial coalition structure that is internally and externally stable at the same time.[7] Whereas more than 1000 coalition structures are externally stable, only 14 coalition structures are internally stable. Thus, the main problem for cooperation is internal stability because of strong free-rider incentives to leave a coalition. In order to shed light on this fundamental problem for cooperation, we compute first a free-rider incentive index and then have a closer look at internally stable coalition structures that are displayed in Table 5.

The aim of the free-rider incentive index is to capture the general incentive to participate in cooperation and to explain membership of internally stable coalition structures. The assumptions of the valuation function (see Definition 2) suggest to construct an index related to the benefits and costs of joint abatement. Therefore, we define the index as annual percentage emission reduction in the social optimum in region i (column 3, Table 3) divided by marginal benefits from abatement in the Nash equilibrium in region i (last column in table 2). The numerator captures the incentive of a country to join a coalition in terms of its contribution to joint abatement. The higher this value, the more has a region to contribute to joint abatement, and hence the lower is the incentive to cooperate. The denominator captures the incentive of a country to join a coalition in terms of its individual benefits from joint abatement. The higher the value, the more does a region benefit from joint abatement and hence the higher is the incentive to cooperate. Taken together, by construction of this index, a low value indicates a low free-rider incentive and a high value a high free-rider incentive. Of course, this index can only be a crude measure of the "average incentive structure" given that there are 4084 different coalition structures. In order to ease comparison, we express free-

---

[7] A non-trivial coalition structure includes a coalition with at least two members. In the following, we concentrate in the stability analysis on these coalition structures since the singleton coalition structure is stable by definition. See section 2.

rider incentives in relative terms and set the highest free-rider incentive to 100 percent. This gives the following values:

USA: 4.71%, JPN: 2.55%, EEC: 3.33%, OOE: 32.37%, EET: 100%, FSU: 19.69%, EEX: 23.65%, CHN: 45.03%, IND: 45.38%, DAE: 71.15%, BRA: 23.38%, ROW: 27.04%

It is evident that EET has the highest free-rider incentive, followed by DAE, IND and CHN. In contrast, JPN has the lowest free-rider incentive followed by EEC and USA. However, not only the absolute value of the free-rider incentive matters but also the relative distance between values, as it is evident from Table 5.

Table 5: Internally Stable Coalitions

Coalitions	Free-rider Incentive Index
OOE, EEX	32.4/23.7
EEX, CHN	23.7/45.0
OOE, IND	32.4/45.4
EEX, IND	23.7/45.4
OOE, DAE	32.4/71.1
EEX, DAE	23.7/71.1
CHN, DAE	45.0/71.1
IND, DAE	45.4/71.1
FSU, BRA	19.7/23.4
OOE, IND, BRA	32.4/45.4/23.4
FSU, ROW	19.7/27.0
BRA, ROW	23.4/27.0
FSU, BRA, ROW	19.7/23.4/27.0

Though JPN, EEC and USA have a low free-rider incentive, they are not members of an internally stable coalition. All three countries have an incentive in cooperation because of relatively high marginal benefits. Moreover, they have a strong incentive to form a coalition for instance with CHN because of her flat marginal abatement cost curve. However, such a coalition would not be internally stable because it violates the interests of CHN. Also, EET is no member of an internally stable coalition because its free-rider index is far above average. Thus, only countries with a similar incentive structure form internally stable coalitions.

5. Results: Sensitivity Analyses

A typical feature of empirical work is that results depend on parameter values, which are subject to some uncertainty. Given the large number of parameters that enter our model, some selection is necessary for sensitivity analyses. As indicated in section 3, we believe that the highest uncertainty concerns benefits from global abatement in terms of absolute and regional values. Hence, we conduct two sets of sensitivity analyses. The first set continues to assume shares in global benefits of the base case (Calibration I) but uniformly lowers or raises the level of benefits from global abatement. That is, we change the base value of $\gamma_D = 0.027$. The second set assumes different shares of benefits, namely those listed in Table 1, section 3, under the heading of Calibration II.

5.1 First Set of Sensitivity Analyses (Calibration I)

We start by lowering global benefits by 50 percent compared to the base case that implies $\gamma_D = 0.0135$ instead of $\gamma_D = 0.027$, which is almost the value of Nordhaus (1994). We find no stable (non-trivial) coalition structure in this case as indicated in Table 6. Subsequently, we raise benefits gradually. This leads to a stable coalition between JPN and EEC at a level of 120 percent. Interestingly, in this case, internally stable coalition structures are exactly those listed in Table 5, except that JPN and EEC also form an internally stable coalition, which is also externally stable. Recalling our discussion in section 4, this is not surprising. First, in the grand and the Kyoto coalition structures these were the only two regions that had no incentive to leave their coalition (see Tables 3 and 4). Second, JPN and EEC had the lowest free-rider incentive with a similar value (see subsection 4.5).[8] However, the coalition of JPN and EEC only marginally improves upon the singleton coalition structure as is evident from Table 6. Not only that a coalition of only two regions implies that there are ten free-riders, a coalition of two regions with a low free-rider incentive index chooses only very moderate abatement targets (because marginal abatement costs are relatively high compared to marginal benefits).

We also compute scenarios where we raise benefits to 200 and 300 percent, respectively, but no major changes occur. Though absolute values of the numbers in Table 6 increase, relative differences remain almost the same. In addition, only a coalition of JPN and EEC is stable for these cases that only marginally improves upon the non-cooperative case but falls substantially short of the full cooperative case.

---

[8] The values computed in subsection 4.5 change only marginally when increasing damages to a level of 120 percent since also annual percentages of emission reduction increase in a similar range. In fact, the difference in values of the free-rider incentive index of JPN and EEC becomes even smaller.

Table 6: Sensitivity Analysis for Calibration I*

Benefits	Scenarios	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Benefits minus abatement costs
		Gton (over 100 years)	percentage of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years
Benefits 50 %	No cooperation	34	2.9	36	644	608
	Full cooperation	172	14.4	1,225	3,211	1,986
Benefits 100 %	No cooperation	55	4.6	109	2,069	1,960
	Full cooperation	256	21.4	3,553	9,584	6,031
Benefits 120 %	No cooperation	62	5.2	145	2,801	2,655
	Coalition JPN, EEC	67	5.6	203	2,988	2,784
	Full cooperation	284	23.8	4693	12,746	8,053
Benefits 200 %	No cooperation	87	7.3	324	6,485	6,161
	Coalition JPN, EEC	92	7.7	455	6,908	6,453
	Full cooperation	377	31.5	10,204	28,205	18,000
Benefits 300 %	No cooperation	112	9.3	609	12,519	11,910
	Coalition JPN, EEC	119	9.9	857	13,323	12,466
	Full cooperation	470	39.3	18,856	52,759	33,903

* No cooperation=singleton coalition structure, stable by definition; full cooperation=grand coalition, not stable for all scenarios; coalition of JPN and EEC is only stable for benefits 120, 200 and 300 %; benefits 100 % = base case.

All results are perfectly in line with theory (see Finus 2001 and 2003a for an overview and the literature cited there). First, if there are stable coalitions they will be rather small. Second, coalitions will be of equal or smaller size in the case of heterogeneous regions than in the case of symmetric regions. In our empirical context with heterogeneous incentives, only a coalition of at most two regions is stable. In contrast, assuming symmetric parameter values for our specification of the payoff function, we find that the maximum stable coalition structure comprises three regions. Third, whenever the relative difference between no cooperation and full cooperation is large, stable coalitions (partial cooperation) achieve only little. For all scenarios, the global payoff in the Nash equilibrium is roughly one third of that in the social optimum - a large difference - and a stable coalition closes this gap only by a very small amount. Interestingly, the ratio between Nash equilibrium and social optimum in terms of global payoff rises slightly from 30.6 percent in the 50% benefit scenario to 32.9 percent in the 120% benefit scenario, reaching 35.9 percent in the 300% benefit scenario. Thus, when the difference between no and full cooperation is particularly pronounced no stable (non-trivial) coalition exists. Only if this difference becomes small enough, partial cooperation is stable.

5.2 Second Set of Sensitivity Analyses (Calibration II)

Here we assume the level of global benefits at 100 percent as in the base case but consider different regional shares of benefits, as listed in Table 1 under Calibration II. For this run, we find the results displayed in Table 7.

Table 7: Sensitivity Analysis for Calibration II*

Scenarios	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Benefits minus abatement costs
	Gton (over 100 years)	percentage of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years
No cooperation	54	4.5	93	2,013	1,920
Coalition JPN, BRA, ROW	58	4.9	141	2,178	2,037
Kyoto coalition	89	7.5	346	3,345	2,999
Full cooperation	256	21.4	3,553	9,584	6,031

* No cooperation=singleton coalition structure, stable by definition; full cooperation=grand coalition, not stable; Kyoto coalition not stable; coalition of JPN, BRA and ROW is only stable non-trivial coalition structure.

From Table 7 (together with further background information) three important conclusions emerge that confirm previous findings. First, the difference between no cooperation and full cooperation is large. However, the grand coalition is not stable. Second, the Kyoto coalition structure is clearly inferior to full cooperation but would improve quite considerably upon no cooperation. However, this coalition is also not stable since all participants except JPN would have an incentive to leave this coalition. Third, the only stable coalition is formed by JPN, BRA and ROW that only marginally improves upon the Nash equilibrium.[9] Computing the free-rider incentive for Calibration II in the spirit outlined in section 4 reveals that this result can easily be rationalized. These three regions have by far the lowest free-rider incentive and a similar index value. This explains not only membership in this coalition but also why this coalition does not contribute much in solving the global warming problem. The result also stresses that the conjecture, those regions, which form a coalition, are the ‘good guys’ and those, which stay outside a coalition, are the ‘bad guys’, would be premature. From a game theoretic perspective, we can only conclude that regions forming a coalition have a low and similar free-rider incentive. For instance, in this example, the signatories JPN and BRA reduce emissions on average by 3 and 2.6 percent, respectively, whereas the outsiders USA and IND reduce emissions by 4.6 percent and 12 percent, respectively.

---

[9] Again, this result is very robust to raising the level of global benefits. Results are available upon request from the authors.

Taken together, we may conclude that in our model stability and membership in stable coalition structures are very robust in terms of the level of *global benefits* from abatement but results are sensitive to *regional shares* of benefits. Moreover, there is a close relation between the predictions of theory and our empirical results that hold for all scenarios.

6. Summary and Conclusions

In this paper, we studied stability of climate change coalitions in a cartel formation game, applying the concept of internally and externally stable coalition structures. We considered a game with twelve world regions that gives rise to 4084 different coalition structures. Payoffs were derived from an empirical model, called STACO, with a time horizon of 100 years, covering the period between 2010 and 2110. STACO aims at capturing all important dynamic aspects of the global warming problem but assumes stationary abatement strategies for game theoretic tractability. From our many results, we would like to mention six. *First*, the gains from cooperation that are at stake in the case of global warming are large in our model. This is not only true for the absolute amount of global net benefits in the global optimum but also when this number is put in perspective to net benefits in the Nash equilibrium. *Second*, neither the grand coalition nor the Kyoto coalition is stable for all parameter scenarios that we considered. Moreover, it turned out that the US conducts a considerable amount of abatement already in the Nash equilibrium and has an incentive to leave the grand and the Kyoto coalition. This result provided some rationale for the withdrawal of this country from the Kyoto Protocol. However, we found that the Kyoto coalition would imply a non-neglectable improvement compared to the Nash equilibrium, though it is clearly inferior to the global optimum. *Third*, only if benefits from global abatement reach a sufficiently high level do stable non-trivial coalitions emerge. This stresses that stable cooperation can only be expected if the impact of greenhouse gases receives sufficient attention by governments. *Fourth*, if there are stable coalitions, then they are small and only marginally improve upon the Nash equilibrium in terms of global welfare, global emissions and concentration. This may explain why progress in the case of global warming has been slow in the past. *Fifth*, membership in stable coalitions could be rationalized by computing a free-rider incentive index. It turned out that only regions with a low and similar free-rider incentive would form stable coalitions. We concluded that those coalitions are stable because members conduct only small additional emission reductions compared to the Nash equilibrium and because members have a sufficiently homogenous cost-benefit structure. This result explains why only industrialized countries have joined the Kyoto Protocol so far and that without transfer payments this will most likely not change in the near future. *Sixth*, results are very robust in terms of the level of benefits from global abatement but are sensitive in terms of the regional distribution of benefits.

For *future research*, we would like to mention three extensions. *First*, we would like to include transfers in the stability analysis as for instance in Bosello et a. (2001) and Buchner/ Carraro (2003). This comprises direct monetary transfers as suggested by the meeting of parties to the Kyoto Protocol in Marrakech. The proposal allows developing countries to draw on financial resources from an environmental fund, as this is for instance also the case in the Montreal Protocol. However, transfers may also comprise indirect measures as for instance permit trading (Article 17), clean development mechanism (Article 12) and joint implementation (Articles 3 and 4). We suspect that all kind of transfers will lead to more cooperation since they help to balance different interests. *Second*, the assumption of the valuation function approach of joint welfare maximization implies not only that cost efficient but also ambitious abatement targets are implemented within coalitions. This is one important reason for instability of large coalitions because of high free-rider incentives and an unequal distribution of the gains from cooperation. Thus, overall, more may be achieved if members settle for less ambitious abatement targets and/or if abatement burdens are allocated more equally. If the effect on participation is strong enough, this may well compensate for inefficiencies as emerges from theoretical work by Endres/Finus (2002), Finus/Rundshagen (1998) and Finus (2003b). *Third*, the definition of external stability implies that regions can join coalitions at their free will. From a public choice perspective, however, one may suspect that current members of a treaty decide on accession by majority or unanimity vote. We suspect that this leads to more stability and cooperation.

References

Babiker, M.H., Reilly, J.M., Mayer, M., Eckaus, R.S., Wing, I.S. and R.C. Hyman (2001), The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Revisions, Sensitivities, and Comparison Results, Report No. 71, MIT, Cambridge.

Barrett, S. (1994), Self-Enforcing International Environmental Agreements. "Oxford Economic Papers", vol. 46, pp. 804-878.

Barrett, S. (1997), Heterogeneous International Agreements. In: C. Carraro (ed.), International Environmental Negotiations: Strategic Policy Issues. Edward Elgar, Cheltenham, pp. 9-25.

Bauer, A. (1992), International Cooperation over Greenhouse Gas Abatement. Mimeo, Seminar für empirische Wirtschaftsforschung, University of Munich, Munich.

Bloch, F. (1997), Non-Cooperative Models of Coalition Formation in Games with Spillovers. In: Carraro, C. and D. Siniscalco (eds.), New Directions in the Economic Theory of the Environment. Cambridge University Press, Cambridge, ch. 10, pp. 311-352.

Bosello, F., Buchner, B., Carraro, C. and D. Raggi. (2001), Can Equity Enhance Efficiency? Some Lessons from Climate Negotiations. FEEM-Working Paper No. 49.2001, forthcoming in C. Carraro and V. Fragnelli (eds.), Game Practice and the Environment, Edward Elgar, Cheltenham, UK.

Botteon, M. and C. Carraro (1997), Burden-Sharing and Coalition Stability in Environmental Negotiations with Asymmetric Countries. In: Carraro, C. (ed.), International Environmental Negotiations: Strategic Policy Issues. Edward Elgar, Cheltenham et al., ch. 3, pp. 26-55.

Botteon, M. and C. Carraro (1998), Strategies for Environmental Negotiations: Issue Linkage with Heterogeneous Countries. In: Hanley, N. and H. Folmer (eds.), Game Theory and the Global Environment. Edward Elgar, Cheltenham ., ch. 9, pp. 180-200.

Buchner, B. and C. Carraro (2003), Emission Trading Regimes and Incentives to Participate in International Climate Agreements. CATEP Policy Brief No. 3, 2003.

Buchner, B., C. Carraro, I. Cersosimo and C. Marchiori. (2002), Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation. CEPR Discussion Paper 3299.

Carraro, C. and D. Siniscalco (1993), Strategies for the International Protection of the Environment. "Journal of Public Economics", vol. 52, pp. 309-328.

Carraro, C. and D. Siniscalco (1998), International Environmental Agreements: Incentives and Political Economy. "European Economic Review", vol. 42, pp. 561-572.

Chander, P. and H. Tulkens (1995), A Core-Theoretic Solution for the Design of Cooperative Agreements on Transfrontier Pollution. "International Tax and Public Finance", vol. 2, pp. 279-293.

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

Dellink, R.B., M. Finus, E.C. van Ierland and J.-C. Altamirano (2003), Empirical Background Paper of the STACO Model, Draft, University of Wageningen.

Ellerman, A.D. and A. Decaux (1998), MIT Report #40. Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves.

http://web.mit.edu/globalchange/www/ rpt40.html.

Endres, A. and M. Finus (2002), Quotas May Beat Taxes in a Global Emission Game. "International Journal of Tax and Public Finance" vol. 9, pp. 687-707.

Eyckmans, J. and M. Finus (2003), Coalition Formation in a Global Warming Game: How the Design of Protocols Affects the Success of Environmental Treaty-Making. CLIMNEG Working Papers, No. 56, 2003.

Eyckmans, J. and H. Tulkens (1999), Simulating with RICE Coalitionally Stable Burden Sharing Agreements for the Climate Change Problem. CES ifo Working Papers Series, No. 228, Munich.

Fankhauser, S. (1995), Valuing Climate Change, Earthscan, London.

Finus, M. (2001), Game Theory and International Environmental Cooperation. Edward Elgar, Cheltenham.

Finus, M. (2003a), Stability and Design of International Environmental Agreements: The Case of Transboundary Pollution. Forthcoming in Folmer, H. and T. Tietenberg (eds), International Yearbook of Environmental and Resource Economics, 2003/4, Edward Elgar, Cheltenham, UK.

Finus, M. (2003b), Less Maybe More in International Pollution Control. Preliminary Draft, University of Hagen.

Finus, M. and B. Rundshagen (1998), Toward a Positive Theory of Coalition Formation and Endogenous Instrumental Choice in Global Pollution Control. "Public Choice", vol. 96, pp. 145-186.

Finus, M. and B. Rundshagen (2001), Endogenous Coalition Formation in Global Pollution Control. A Partition Function Approach. Working Paper No. 307, University of Hagen. Revised version forthcoming in Carraro, C. (ed.), Endogenous Formation of Economic Coalitions, Edward Elgar, Cheltenham, UK.

Finus, M. and B. Rundshagen (2003), How the Rules of Coalition Formation Affect Stability of International Environmental Agreements. Preliminary Draft, University of Hagen.

Germain, M. and V. van Steenberghe (2001), Constraining Equitable Allocations of Tradable Greenhouse Gases Emission Quotas by Acceptability. Discussion Paper 2001/5, CORE-Université Catholique de Louvain, Louvain-la-Neuve.

Germain, M., P. L. Toint, H. Tulkens and A. de Zeeuw (2000), Transfers to Sustain Core-Theoretic Cooperation in International Stock Pollutant Control. Revised version of CORE Discussion Paper No. 9832, Center for Operations Research and Econometrics, Université Catholique de Louvain, Louvain.

Hoel, M. (1992), International Environment Conventions: The Case of Uniform Reductions of Emissions. "Environmental and Resource Economics", vol. 2, pp. 141-159.

Hoel, M. and K. Schneider (1997), Incentives to Participate in an International Environmental Agreement. "Environmental and Resource Economics", vol. 9, pp. 153-170.

Jeppesen, T. and P. Andersen (1998), Commitment and Fairness in Environmental Games. In: Hanley, N. and H. Folmer (eds.), Game Theory and the Environment. ch. 4, pp. 65-83, Edward Elgar, Cheltenham et al.

Kaitala, V., K.-G. Mäler and H. Tulkens (1995), The Acid Rain Game as a Resource Allocation Process with an Application to the International Cooperation among Finland, Russia and Estonia. "Scandinavian Journal of Economics", vol. 97, pp. 325-343.

Nordhaus, W.D. (1994), Managing the Global Commons. MIT Press, Cambridge, MA.

NASA (2002), GDP Inflation Calculator Based on "Budget of the United States Government, Fiscal Year 2001", Historical Tables, Table 10.1, Gross Domestic Product and Deflators Used in the Historical Tables: 1940-2005, http://www.jsc.nasa.gov/bu2/inflateGDP.html.

Plambeck, E.L. and C. Hope (1996), An Updated Valuation of the Impacts of Global Warming. In Nakicenovic, N., W. D. Nordhaus, R. Richels, and F. Toth (eds.), Proceeding of the Workshop on Climate Change: Integrating Science, Economics and Policy. IIASA, Laxenburg, Austria, December 1996.

Rubio, S. and A. Ulph (2001), A Simple Dynamic Model of International Environmental Agreements with a Stock Pollutant. Preliminary Version, University of Southampton.

Tol, R.S.J. (1997), A Decision-analytic Treatise of the Enhanced Greenhouse Effect. PhD. Thesis, Vrije Universiteit, Amsterdam.

Tol, R. (2001), Climate Coalitions in an Integrated Assessment Model. "Computational Economics", vol. 18, pp. 159-172.

Weyant, J. (ed.) (1999), The Costs of the Kyoto Protocol: a Multi-model Evaluation. "The Energy Journal", special issue.

Appendix 1

In section 2, we claim that a necessary condition for internal stability in our model is that each signatory receives more than in the singleton coalition structure. That is, we claim $\upsilon_i(c) \geq \upsilon_i(c') \geq \upsilon_i(c'')$ where $c = (c^S, 1, ..., 1)$, $c' = (c^S \setminus \{i\}, 1, ..., 1)$ and $c'' = (1, 1, ..., 1)$, assuming that region i is a member of coalition c^S in coalition structure c but not in coalition structures c′ and c′′. Of course, the first inequality sign is only a restatement of the condition of internal stability and hence we only have to prove the second inequality sign. We do so by showing that if some regions form coalition $c^S \setminus \{i\}$, region i will be better off than in the singleton coalition structure (Finus/Rundshagen 2003).

In our model (see section 3, in particular subsection 3.6) total benefits of region i, $TB_i(q)$, are a linear function of total abatement, $q = \sum q_i$, that may be written as $TB_i(q) = b_i \cdot q$ where b_i is a parameter of region i. Total abatement costs, $TAC_i(q_i)$, are a strictly convex function of individual abatement q_i. Hence, the first order condition of coalition $c^S \setminus \{i\}$ read $\sum_{j \in c^S \setminus \{i\}} MTB_j(q) = MTAC_j(q_j)$ or $\sum_{j \in c^S \setminus \{i\}} b_j = MTAC_j(q_j)$ and that of region i $MTB_i(q) = MTAC_i(q_i)$ or $b_i = MTAC_i(q_i)$. Consequently, optimal abatement of all regions is independent of abatement of other regions. Hence, $q_i^*(c') = q_i^*(c'')$ but $q^*(c') \geq q^*(c'')$ because $\sum_{j \in c^S \setminus \{i\}} b_j \geq b_j$ for all $\left|c^S\right| \geq 2$. Thus, region i faces the same abatement costs in c′ than in c′′ but higher benefits and therefore $\upsilon_i(c') \geq \upsilon_i(c'')$ follows.

Appendix 2

Parameter Values

Symbol	Description	Value	Unit	Source
e_{2010}	global emissions in 2010	11.96	Gton CO_2	Nordhaus (1994)
$e_{i,2010}$	regional emissions in year 2010	see Table 1 in section 3	Gton CO_2	own calculation based on Ellerman and Decaux (1998)
d_E	annual growth in global and regional emissions in BAU-scenario	0.153	Gton CO_2	own calculation based on Nordhaus (1994)
$M_{pre\text{-}ind}$	pre-industrial level of CO_2-stock	590	Gton CO_2	Nordhaus (1994)
M_{2010}	stock of CO_2 in 2010	835	Gton CO_2	Nordhaus (1994)
δ	natural annual removal or decay rate of CO_2-stock	0.00866	-	Nordhaus (1994)
ω	airborne fraction of emissions that remain in the atmosphere	0.64		Nordhaus (1994)
R	annual uniform discount rate	0.02	-	assumption
s_i	share of region i in global benefits	see Table 1 in section 3	-	own calculation based on Fankhauser (1995) and Tol (1997)
α_i	abatement cost parameter of region i	see Table 2	-	own calculation based on Ellerman and Decaux (1998)
β_i	abatement cost parameter of region i	see Table 2	-	own calculation based on Ellerman and Decaux (1998)
φ_1	intercept of damage function	-140146	Billion US$	own calculation
φ_2	slope of damage and benefit function	178.331	Billion US$ per Gton	own calculation
γ_D	scale parameter of damage and benefit function	0.027	-	Tol (1997)

NOTE DI LAVORO DELLA FONDAZIONE ENI ENRICO MATTEI
Fondazione Eni Enrico Mattei Working Paper Series
Our working papers are available on the Internet at the following addresses:

http://www.feem.it/Feem/Pub/Publications/WPapers/default.html
http://papers.ssrn.com

SUST	1.2002	*K. TANO, M.D. FAMINOW, M. KAMUANGA and B. SWALLOW*: Using Conjoint Analysis to Estimate Farmers' Preferences for Cattle Traits in West Africa
ETA	2.2002	*Efrem CASTELNUOVO and Paolo SURICO*: What Does Monetary Policy Reveal about Central Bank's Preferences?
WAT	3.2002	*Duncan KNOWLER and Edward BARBIER*: The Economics of a "Mixed Blessing" Effect: A Case Study of the Black Sea
CLIM	4.2002	*Andreas LÖSCHEL*: Technological Change in Economic Models of Environmental Policy: A Survey
VOL	5.2002	*Carlo CARRARO and Carmen MARCHIORI*: Stable Coalitions
CLIM	6.2002	*Marzio GALEOTTI, Alessandro LANZA and Matteo MANERA*: Rockets and Feathers Revisited: An International Comparison on European Gasoline Markets
ETA	7.2002	*Effrosyni DIAMANTOUDI and Eftichios S. SARTZETAKIS*: Stable International Environmental Agreements: An Analytical Approach
KNOW	8.2002	*Alain DESDOIGTS*: Neoclassical Convergence Versus Technological Catch-up: A Contribution for Reaching a Consensus
NRM	9.2002	*Giuseppe DI VITA:* Renewable Resources and Waste Recycling
KNOW	10.2002	*Giorgio BRUNELLO*: Is Training More Frequent when Wage Compression is Higher? Evidence from 11 European Countries
ETA	11.2002	*Mordecai KURZ, Hehui JIN and Maurizio MOTOLESE*: Endogenous Fluctuations and the Role of Monetary Policy
KNOW	12.2002	*Reyer GERLAGH and Marjan W. HOFKES:* Escaping Lock-in: The Scope for a Transition towards Sustainable Growth?
NRM	13.2002	*Michele MORETTO and Paolo ROSATO*: The Use of Common Property Resources: A Dynamic Model
CLIM	14.2002	*Philippe QUIRION*: Macroeconomic Effects of an Energy Saving Policy in the Public Sector
CLIM	15.2002	*Roberto ROSON*: Dynamic and Distributional Effects of Environmental Revenue Recycling Schemes: Simulations with a General Equilibrium Model of the Italian Economy
CLIM	16.2002	*Francesco RICCI* (l): Environmental Policy Growth when Inputs are Differentiated in Pollution Intensity
ETA	17.2002	*Alberto PETRUCCI*: Devaluation (Levels versus Rates) and Balance of Payments in a Cash-in-Advance Economy
Coalition Theory Network	18.2002	*László Á. KÓCZY* (liv*):* The Core in the Presence of Externalities
Coalition Theory Network	19.2002	*Steven J. BRAMS, Michael A. JONES and D. Marc KILGOUR* (liv): Single-Peakedness and Disconnected Coalitions
Coalition Theory Network	20.2002	*Guillaume HAERINGER* (liv): On the Stability of Cooperation Structures
NRM	21.2002	*Fausto CAVALLARO and Luigi CIRAOLO:* Economic and Environmental Sustainability: A Dynamic Approach in Insular Systems
CLIM	22.2002	*Barbara BUCHNER, Carlo CARRARO, Igor CERSOSIMO and Carmen MARCHIORI*: Back to Kyoto? US Participation and the Linkage between R&D and Climate Cooperation
CLIM	23.2002	*Andreas LÖSCHEL and ZhongXIANG ZHANG:* The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakech
ETA	24.2002	*Marzio GALEOTTI, Louis J. MACCINI and Fabio SCHIANTARELLI*: Inventories, Employment and Hours
CLIM	25.2002	*Hannes EGLI:* Are Cross-Country Studies of the Environmental Kuznets Curve Misleading? New Evidence from Time Series Data for Germany
ETA	26.2002	*Adam B. JAFFE, Richard G. NEWELL and Robert N. STAVINS*: Environmental Policy and Technological Change
SUST	27.2002	*Joseph C. COOPER and Giovanni SIGNORELLO*: Farmer Premiums for the Voluntary Adoption of Conservation Plans
SUST	28.2002	*The ANSEA Network*: Towards An Analytical Strategic Environmental Assessment
KNOW	29.2002	*Paolo SURICO*: Geographic Concentration and Increasing Returns: a Survey of Evidence
ETA	30.2002	*Robert N. STAVINS:* Lessons from the American Experiment with Market-Based Environmental Policies

NRM	31.2002	*Carlo GIUPPONI and Paolo ROSATO:* Multi-Criteria Analysis and Decision-Support for Water Management at the Catchment Scale: An Application to Diffuse Pollution Control in the Venice Lagoon
NRM	32.2002	*Robert N. STAVINS*: National Environmental Policy During the Clinton Years
KNOW	33.2002	*A. SOUBEYRAN and H. STAHN* : Do Investments in Specialized Knowledge Lead to Composite Good Industries?
KNOW	34.2002	*G. BRUNELLO, M.L. PARISI and Daniela SONEDDA:* Labor Taxes, Wage Setting and the Relative Wage Effect
CLIM	35.2002	*C. BOEMARE and P. QUIRION* (lv): Implementing Greenhouse Gas Trading in Europe: Lessons from Economic Theory and International Experiences
CLIM	36.2002	*T.TIETENBERG* (lv): The Tradable Permits Approach to Protecting the Commons: What Have We Learned?
CLIM	37.2002	*K. REHDANZ and R.J.S. TOL* (lv): On National and International Trade in Greenhouse Gas Emission Permits
CLIM	38.2002	*C. FISCHER* (lv): Multinational Taxation and International Emissions Trading
SUST	39.2002	*G. SIGNORELLO and G. PAPPALARDO:* Farm Animal Biodiversity Conservation Activities in Europe under the Framework of Agenda 2000
NRM	40.2002	*S .M. CAVANAGH, W. M. HANEMANN and R. N. STAVINS:* Muffled Price Signals: Household Water Demand under Increasing-Block Prices
NRM	41.2002	*A. J. PLANTINGA, R. N. LUBOWSKI and R. N. STAVINS:* The Effects of Potential Land Development on Agricultural Land Prices
CLIM	42.2002	*C. OHL* (lvi): Inducing Environmental Co-operation by the Design of Emission Permits
CLIM	43.2002	*J. EYCKMANS, D. VAN REGEMORTER and V. VAN STEENBERGHE* (lvi): Is Kyoto Fatally Flawed? An Analysis with MacGEM
CLIM	44.2002	*A. ANTOCI and S. BORGHESI* (lvi): Working Too Much in a Polluted World: A North-South Evolutionary Model
ETA	45.2002	*P. G. FREDRIKSSON, Johan A. LIST and Daniel MILLIMET* (lvi): Chasing the Smokestack: Strategic Policymaking with Multiple Instruments
ETA	46.2002	*Z. YU* (lvi): A Theory of Strategic Vertical DFI and the Missing Pollution-Haven Effect
SUST	47.2002	*Y. H. FARZIN*: Can an Exhaustible Resource Economy Be Sustainable?
SUST	48.2002	*Y. H. FARZIN*: Sustainability and Hamiltonian Value
KNOW	49.2002	*C. PIGA and M. VIVARELLI*: Cooperation in R&D and Sample Selection
Coalition Theory Network	50.2002	*M. SERTEL and A. SLINKO* (liv): Ranking Committees, Words or Multisets
Coalition Theory Network	51.2002	*Sergio CURRARINI* (liv): Stable Organizations with Externalities
ETA	52.2002	*Robert N. STAVINS*: Experience with Market-Based Policy Instruments
ETA	53.2002	*C.C. JAEGER, M. LEIMBACH, C. CARRARO, K. HASSELMANN, J.C. HOURCADE, A. KEELER and R. KLEIN* (liii): Integrated Assessment Modeling: Modules for Cooperation
CLIM	54.2002	*Scott BARRETT* (liii)*:* Towards a Better Climate Treaty
ETA	55.2002	*Richard G. NEWELL and Robert N. STAVINS*: Cost Heterogeneity and the Potential Savings from Market-Based Policies
SUST	56.2002	*Paolo ROSATO and Edi DEFRANCESCO*: Individual Travel Cost Method and Flow Fixed Costs
SUST	57.2002	*Vladimir KOTOV and Elena NIKITINA* (lvii): Reorganisation of Environmental Policy in Russia: The Decade of Success and Failures in Implementation of Perspective Quests
SUST	58.2002	*Vladimir KOTOV* (lvii): Policy in Transition: New Framework for Russia's Climate Policy
SUST	59.2002	*Fanny MISSFELDT and Arturo VILLAVICENCO* (lvii): How Can Economies in Transition Pursue Emissions Trading or Joint Implementation?
VOL	60.2002	*Giovanni DI BARTOLOMEO, Jacob ENGWERDA, Joseph PLASMANS and Bas VAN AARLE:* Staying Together or Breaking Apart: Policy-Makers' Endogenous Coalitions Formation in the European Economic and Monetary Union
ETA	61.2002	*Robert N. STAVINS, Alexander F.WAGNER and Gernot WAGNER*: Interpreting Sustainability in Economic Terms: Dynamic Efficiency Plus Intergenerational Equity
PRIV	62.2002	*Carlo CAPUANO*: Demand Growth, Entry and Collusion Sustainability
PRIV	63.2002	*Federico MUNARI and Raffaele ORIANI*: Privatization and R&D Performance: An Empirical Analysis Based on Tobin's Q
PRIV	64.2002	*Federico MUNARI and Maurizio SOBRERO*: The Effects of Privatization on R&D Investments and Patent Productivity
SUST	65.2002	*Orley ASHENFELTER and Michael GREENSTONE*: Using Mandated Speed Limits to Measure the Value of a Statistical Life
ETA	66.2002	*Paolo SURICO:* US Monetary Policy Rules: the Case for Asymmetric Preferences
PRIV	67.2002	*Rinaldo BRAU and Massimo FLORIO*: Privatisations as Price Reforms: Evaluating Consumers' Welfare Changes in the U.K.
CLIM	68.2002	*Barbara K. BUCHNER and Roberto ROSON*: Conflicting Perspectives in Trade and Environmental Negotiations
CLIM	69.2002	*Philippe QUIRION*: Complying with the Kyoto Protocol under Uncertainty: Taxes or Tradable Permits?
SUST	70.2002	*Anna ALBERINI, Patrizia RIGANTI and Alberto LONGO*: Can People Value the Aesthetic and Use Services of Urban Sites? Evidence from a Survey of Belfast Residents
SUST	71.2002	*Marco PERCOCO:* Discounting Environmental Effects in Project Appraisal

NRM	72.2002	*Philippe BONTEMS and Pascal FAVARD*: Input Use and Capacity Constraint under Uncertainty: The Case of Irrigation
PRIV	73.2002	*Mohammed OMRAN:* The Performance of State-Owned Enterprises and Newly Privatized Firms: Empirical Evidence from Egypt
PRIV	74.2002	*Mike BURKART, Fausto PANUNZI and Andrei SHLEIFER:* Family Firms
PRIV	75.2002	*Emmanuelle AURIOL, Pierre M. PICARD:* Privatizations in Developing Countries and the Government Budget Constraint
PRIV	76.2002	*Nichole M. CASTATER***:** Privatization as a Means to Societal Transformation: An Empirical Study of Privatization in Central and Eastern Europe and the Former Soviet Union
PRIV	77.2002	*Christoph LÜLSFESMANN*: Benevolent Government, Managerial Incentives, and the Virtues of Privatization
PRIV	78.2002	*Kate BISHOP, Igor FILATOTCHEV and Tomasz MICKIEWICZ*: Endogenous Ownership Structure: Factors Affecting the Post-Privatisation Equity in Largest Hungarian Firms
PRIV	79.2002	*Theodora WELCH and Rick MOLZ*: How Does Trade Sale Privatization Work? Evidence from the Fixed-Line Telecommunications Sector in Developing Economies
PRIV	80.2002	*Alberto R. PETRUCCI*: Government Debt, Agent Heterogeneity and Wealth Displacement in a Small Open Economy
CLIM	81.2002	*Timothy SWANSON and Robin MASON* (lvi): The Impact of International Environmental Agreements: The Case of the Montreal Protocol
PRIV	82.2002	*George R.G. CLARKE and Lixin Colin XU:* Privatization, Competition and Corruption: How Characteristics of Bribe Takers and Payers Affect Bribe Payments to Utilities
PRIV	83.2002	*Massimo FLORIO and Katiuscia MANZONI*: The Abnormal Returns of UK Privatisations: From Underpricing to Outperformance
NRM	84.2002	*Nelson LOURENÇO, Carlos RUSSO MACHADO, Maria do ROSÁRIO JORGE and Luís RODRIGUES*: An Integrated Approach to Understand Territory Dynamics. The Coastal Alentejo (Portugal)
CLIM	85.2002	*Peter ZAPFEL and Matti VAINIO* (lv): Pathways to European Greenhouse Gas Emissions Trading History and Misconceptions
CLIM	86.2002	*Pierre COURTOIS*: Influence Processes in Climate Change Negotiations: Modelling the Rounds
ETA	87.2002	*Vito FRAGNELLI and Maria Erminia MARINA* (lviii): Environmental Pollution Risk and Insurance
ETA	88.2002	*Laurent FRANCKX* (lviii): Environmental Enforcement with Endogenous Ambient Monitoring
ETA	89.2002	*Timo GOESCHL and Timothy M. SWANSON* (lviii): Lost Horizons. The noncooperative management of an evolutionary biological system.
ETA	90.2002	*Hans KEIDING* (lviii): Environmental Effects of Consumption: An Approach Using DEA and Cost Sharing
ETA	91.2002	*Wietze LISE* (lviii): A Game Model of People's Participation in Forest Management in Northern India
CLIM	92.2002	*Jens HORBACH*: Structural Change and Environmental Kuznets Curves
ETA	93.2002	*Martin P. GROSSKOPF:* Towards a More Appropriate Method for Determining the Optimal Scale of Production Units
VOL	94.2002	*Scott BARRETT and Robert STAVINS*: Increasing Participation and Compliance in International Climate Change Agreements
CLIM	95.2002	*Banu BAYRAMOGLU LISE and Wietze LISE:* Climate Change, Environmental NGOs and Public Awareness in the Netherlands: Perceptions and Reality
CLIM	96.2002	*Matthieu GLACHANT*: The Political Economy of Emission Tax Design in Environmental Policy
KNOW	97.2002	*Kenn ARIGA and Giorgio BRUNELLO*: Are the More Educated Receiving More Training? Evidence from Thailand
ETA	98.2002	*Gianfranco FORTE and Matteo MANERA*: Forecasting Volatility in European Stock Markets with Non-linear GARCH Models
ETA	99.2002	*Geoffrey HEAL*: Bundling Biodiversity
ETA	100.2002	*Geoffrey HEAL, Brian WALKER, Simon LEVIN, Kenneth ARROW, Partha DASGUPTA, Gretchen DAILY, Paul EHRLICH, Karl-Goran MALER, Nils KAUTSKY, Jane LUBCHENCO, Steve SCHNEIDER and David STARRETT*: Genetic Diversity and Interdependent Crop Choices in Agriculture
ETA	101.2002	*Geoffrey HEAL:* Biodiversity and Globalization
VOL	102.2002	*Andreas LANGE*: Heterogeneous International Agreements – If per capita emission levels matter
ETA	103.2002	*Pierre-André JOUVET and Walid OUESLATI*: Tax Reform and Public Spending Trade-offs in an Endogenous Growth Model with Environmental Externality
ETA	104.2002	*Anna BOTTASSO and Alessandro SEMBENELLI*: Does Ownership Affect Firms' Efficiency? Panel Data Evidence on Italy
PRIV	105.2002	*Bernardo BORTOLOTTI, Frank DE JONG, Giovanna NICODANO and Ibolya SCHINDELE*: Privatization and Stock Market Liquidity
ETA	106.2002	*Haruo IMAI and Mayumi HORIE* (lviii): Pre-Negotiation for an International Emission Reduction Game
PRIV	107.2002	*Sudeshna GHOSH BANERJEE and Michael C. MUNGER*: Move to Markets? An Empirical Analysis of Privatisation in Developing Countries
PRIV	108.2002	*Guillaume GIRMENS and Michel GUILLARD*: Privatization and Investment: Crowding-Out Effect vs Financial Diversification
PRIV	109.2002	*Alberto CHONG and Florencio LÓPEZ-DE-SILANES*: Privatization and Labor Force Restructuring Around the World
PRIV	110.2002	*Nandini GUPTA*: Partial Privatization and Firm Performance
PRIV	111.2002	*François DEGEORGE, Dirk JENTER, Alberto MOEL and Peter TUFANO*: Selling Company Shares to Reluctant Employees: France Telecom's Experience

PRIV	112.2002	*Isaac OTCHERE*: Intra-Industry Effects of Privatization Announcements: Evidence from Developed and Developing Countries
PRIV	113.2002	*Yannis KATSOULAKOS and Elissavet LIKOYANNI*: Fiscal and Other Macroeconomic Effects of Privatization
PRIV	114.2002	*Guillaume GIRMENS:* Privatization, International Asset Trade and Financial Markets
PRIV	115.2002	*D. Teja FLOTHO:* A Note on Consumption Correlations and European Financial Integration
PRIV	116.2002	*Ibolya SCHINDELE and Enrico C. PEROTTI*: Pricing Initial Public Offerings in Premature Capital Markets: The Case of Hungary
PRIV	1.2003	*Gabriella CHIESA and Giovanna NICODANO*: Privatization and Financial Market Development: Theoretical Issues
PRIV	2.2003	*Ibolya SCHINDELE*: Theory of Privatization in Eastern Europe: Literature Review
PRIV	3.2003	*Wietze LISE, Claudia KEMFERT and Richard S.J. TOL*: Strategic Action in the Liberalised German Electricity Market
CLIM	4.2003	*Laura MARSILIANI and Thomas I. RENSTRÖM*: Environmental Policy and Capital Movements: The Role of Government Commitment
KNOW	5.2003	*Reyer GERLAGH*: Induced Technological Change under Technological Competition
ETA	6.2003	*Efrem CASTELNUOVO*: Squeezing the Interest Rate Smoothing Weight with a Hybrid Expectations Model
SIEV	7.2003	*Anna ALBERINI, Alberto LONGO, Stefania TONIN, Francesco TROMBETTA and Margherita TURVANI:* The Role of Liability, Regulation and Economic Incentives in Brownfield Remediation and Redevelopment: Evidence from Surveys of Developers
NRM	8.2003	*Elissaios PAPYRAKIS and Reyer GERLAGH*: Natural Resources: A Blessing or a Curse?
CLIM	9.2003	*A. CAPARRÓS, J.-C. PEREAU and T. TAZDAÏT*: North-South Climate Change Negotiations: a Sequential Game with Asymmetric Information
KNOW	10.2003	*Giorgio BRUNELLO and Daniele CHECCHI*: School Quality and Family Background in Italy
CLIM	11.2003	*Efrem CASTELNUOVO and Marzio GALEOTTI*: Learning By Doing vs Learning By Researching in a Model of Climate Change Policy Analysis
KNOW	12.2003	*Carole MAIGNAN, Gianmarco OTTAVIANO and Dino PINELLI (eds.)*: Economic Growth, Innovation, Cultural Diversity: What are we all talking about? A critical survey of the state-of-the-art
KNOW	13.2003	*Carole MAIGNAN, Gianmarco OTTAVIANO, Dino PINELLI and Francesco RULLANI* (lix): Bio-Ecological Diversity vs. Socio-Economic Diversity. A Comparison of Existing Measures
KNOW	14.2003	*Maddy JANSSENS and Chris STEYAERT* (lix): Theories of Diversity within Organisation Studies: Debates and Future Trajectories
KNOW	15.2003	*Tuzin BAYCAN LEVENT, Enno MASUREL and Peter NIJKAMP* (lix): Diversity in Entrepreneurship: Ethnic and Female Roles in Urban Economic Life
KNOW	16.2003	*Alexandra BITUSIKOVA* (lix): Post-Communist City on its Way from Grey to Colourful: The Case Study from Slovakia
KNOW	17.2003	*Billy E. VAUGHN and Katarina MLEKOV* (lix): A Stage Model of Developing an Inclusive Community
KNOW	18.2003	*Selma van LONDEN and Arie de RUIJTER* (lix): Managing Diversity in a Glocalizing World
Coalition Theory Network	19.2003	*Sergio CURRARINI:* On the Stability of Hierarchies in Games with Externalities
PRIV	20.2003	*Giacomo CALZOLARI and Alessandro PAVAN* (lx): Monopoly with Resale
PRIV	21.2003	*Claudio MEZZETTI* (lx): Auction Design with Interdependent Valuations: The Generalized Revelation Principle, Efficiency, Full Surplus Extraction and Information Acquisition
PRIV	22.2003	*Marco LiCalzi and Alessandro PAVAN* (lx): Tilting the Supply Schedule to Enhance Competition in Uniform-Price Auctions
PRIV	23.2003	*David ETTINGER* (lx): Bidding among Friends and Enemies
PRIV	24.2003	*Hannu VARTIAINEN* (lx): Auction Design without Commitment
PRIV	25.2003	*Matti KELOHARJU, Kjell G. NYBORG and Kristian RYDQVIST* (lx): Strategic Behavior and Underpricing in Uniform Price Auctions: Evidence from Finnish Treasury Auctions
PRIV	26.2003	*Christine A. PARLOUR and Uday RAJAN* (lx): Rationing in IPOs
PRIV	27.2003	*Kjell G. NYBORG and Ilya A. STREBULAEV* (lx): Multiple Unit Auctions and Short Squeezes
PRIV	28.2003	*Anders LUNANDER and Jan-Eric NILSSON* (lx): Taking the Lab to the Field: Experimental Tests of Alternative Mechanisms to Procure Multiple Contracts
PRIV	29.2003	*TangaMcDANIEL and Karsten NEUHOFF* (lx): Use of Long-term Auctions for Network Investment
PRIV	30.2003	*Emiel MAASLAND and Sander ONDERSTAL* (lx): Auctions with Financial Externalities
ETA	31.2003	*Michael FINUS and Bianca RUNDSHAGEN:* A Non-cooperative Foundation of Core-Stability in Positive Externality NTU-Coalition Games
KNOW	32.2003	*Michele MORETTO*: Competition and Irreversible Investments under Uncertainty
PRIV	33.2003	*Philippe QUIRION:* Relative Quotas: Correct Answer to Uncertainty or Case of Regulatory Capture?
KNOW	34.2003	*Giuseppe MEDA, Claudio PIGA and Donald SIEGEL*: On the Relationship between R&D and Productivity: A Treatment Effect Analysis
ETA	35.2003	*Alessandra DEL BOCA, Marzio GALEOTTI and Paola ROTA:* Non-convexities in the Adjustment of Different Capital Inputs: A Firm-level Investigation

GG	36.2003	*Matthieu GLACHANT*: Voluntary Agreements under Endogenous Legislative Threats
PRIV	37.2003	*Narjess BOUBAKRI, Jean-Claude COSSET and Omrane GUEDHAMI*: Postprivatization Corporate Governance: the Role of Ownership Structure and Investor Protection
CLIM	38.2003	*Rolf GOLOMBEK and Michael HOEL*: Climate Policy under Technology Spillovers
KNOW	39.2003	*Slim BEN YOUSSEF*: Transboundary Pollution, R&D Spillovers and International Trade
CTN	40.2003	*Carlo CARRARO and Carmen MARCHIORI*: Endogenous Strategic Issue Linkage in International Negotiations
KNOW	41.2003	*Sonia OREFFICE*: Abortion and Female Power in the Household: Evidence from Labor Supply
KNOW	42.2003	*Timo GOESCHL and Timothy SWANSON*: On Biology and Technology: The Economics of Managing Biotechnologies
ETA	43.2003	*Giorgio BUSETTI and Matteo MANERA*: STAR-GARCH Models for Stock Market Interactions in the Pacific Basin Region, Japan and US
CLIM	44.2003	*Katrin MILLOCK and Céline NAUGES*: The French Tax on Air Pollution: Some Preliminary Results on its Effectiveness
PRIV	45.2003	*Bernardo BORTOLOTTI and Paolo PINOTTI*: The Political Economy of Privatization
SIEV	46.2003	*Elbert DIJKGRAAF and Herman R.J. VOLLEBERGH*: Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods
ETA	47.2003	*Jens HORBACH*: Employment and Innovations in the Environmental Sector: Determinants and Econometrical Results for Germany
CLIM	48.2003	*Lori SNYDER, Nolan MILLER and Robert STAVINS:* The Effects of Environmental Regulation on Technology Diffusion: The Case of Chlorine Manufacturing
CLIM	49.2003	*Lori SNYDER, Robert STAVINS and Alexander F. WAGNER*: Private Options to Use Public Goods. Exploiting Revealed Preferences to Estimate Environmental Benefits
CTN	50.2003	*László Á. KÓCZY and Luc LAUWERS* (lxi): The Minimal Dominant Set is a Non-Empty Core-Extension
CTN	51.2003	*Matthew O. JACKSON* (lxi)*:*Allocation Rules for Network Games
CTN	52.2003	*Ana MAULEON and Vincent VANNETELBOSCH* (lxi): Farsightedness and Cautiousness in Coalition Formation
CTN	53.2003	*Fernando VEGA-REDONDO* (lxi): Building Up Social Capital in a Changing World: a network approach
CTN	54.2003	*Matthew HAAG and Roger LAGUNOFF* (lxi): On the Size and Structure of Group Cooperation
CTN	55.2003	*Taiji FURUSAWA and Hideo KONISHI* (lxi): Free Trade Networks
CTN	56.2003	*Halis Murat YILDIZ* (lxi): National Versus International Mergers and Trade Liberalization
CTN	57.2003	*Santiago RUBIO and Alistair ULPH* (lxi): An Infinite-Horizon Model of Dynamic Membership of International Environmental Agreements
KNOW	58.2003	*Carole MAIGNAN, Dino PINELLI and Gianmarco I.P. OTTAVIANO*: ICT, Clusters and Regional Cohesion: A Summary of Theoretical and Empirical Research
KNOW	59.2003	*Giorgio BELLETTINI and Gianmarco I.P. OTTAVIANO:* Special Interests and Technological Change
ETA	60.2003	*Ronnie SCHÖB:* The Double Dividend Hypothesis of Environmental Taxes: A Survey
CLIM	61.2003	*Michael FINUS, Ekko van IERLAND and Robert DELLINK*: Stability of Climate Coalitions in a Cartel Formation Game

(l) This paper was presented at the Workshop "Growth, Environmental Policies and Sustainability" organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001

(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on "Property Rights, Institutions and Management of Environmental and Natural Resources", organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001

(lii) This paper was presented at the International Conference on "Economic Valuation of Environmental Goods", organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001

(liii) This paper was circulated at the International Conference on "Climate Policy – Do We Need a New Approach?", jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002

(lv) This paper was presented at the First Workshop of the Concerted Action on Tradable Emission Permits (CATEP) organised by the Fondazione Eni Enrico Mattei, Venice, Italy, December 3-4, 2001

(lvi) This paper was presented at the ESF EURESCO Conference on Environmental Policy in a Global Economy "The International Dimension of Environmental Policy", organised with the collaboration of the Fondazione Eni Enrico Mattei , Acquafredda di Maratea, October 6-11, 2001

(lvii) This paper was presented at the First Workshop of "CFEWE – Carbon Flows between Eastern and Western Europe", organised by the Fondazione Eni Enrico Mattei and Zentrum fur Europaische Integrationsforschung (ZEI), Milan, July 5-6, 2001 (lviii) This paper was presented at the Workshop on “Game Practice and the Environment”, jointly organised by Università del Piemonte Orientale and Fondazione Eni Enrico Mattei, Alessandria, April 12-13, 2002

(lix) This paper was presented at the ENGIME Workshop on “Mapping Diversity”, Leuven, May 16-17, 2002

(lx) This paper was presented at the EuroConference on “Auctions and Market Design: Theory, Evidence and Applications”, organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002

(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003

2002 SERIES

CLIM	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
VOL	*Voluntary and International Agreements* (Editor: Carlo Carraro)
SUST	*Sustainability Indicators and Environmental Valuation* (Editor: Carlo Carraro)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Dino Pinelli)
MGMT	*Corporate Sustainable Management* (Editor: Andrea Marsanich)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)

2003 SERIES

CLIM	*Climate Change Modelling and Policy* (Editor: Marzio Galeotti)
GG	*Global Governance* (Editor: Carlo Carraro)
SIEV	*Sustainability Indicators and Environmental Valuation* (Editor: Anna Alberini)
NRM	*Natural Resources Management* (Editor: Carlo Giupponi)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Gianmarco Ottaviano)
IEM	*International Energy Markets* (Editor: Anil Markandya)
CSRM	*Corporate Social Responsibility and Management* (Editor: Sabina Ratti)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)
CTN	*Coalition Theory Network*