THE COUPLING OF CLIMATE AND ECONOMIC DYNAMICS

THE COUPLING OF CLIMATE AND ECONOMIC DYNAMICS
Essays on Integrated Assessment

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This book is dedicated to our grand-grand children, not yet born but who will see the impact of climate change.

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Jean-Charles Hourcade
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Foreword

This volume is the result of a comprehensive research effort undertaken under the aegis of the NCCR-"Climate", a Swiss strategic research network launched in 2002 to foster interdisciplinary work on the various facets of the climate change issue. This research has been aimed at the representation in a variety of integrated assessment models of the complex interactions between economic and climate subsystems. It has been made possible by a strong collaborative work within the NCCR-"Climate" and with internationally acclaimed researchers in the field. This diversity of sources is reflected in the topics and the panel of authors who have contributed the fourteen chapters of the book. Our journey will begin with a broad perspective on the *Linking of climate and economic dynamics*, followed by a survey of *Recent achievements and unresolved problems* in the coupling of these two dynamics in Integrated Assessment Models (IAM). The three next chapters present modelling tools used to realize a *Hard coupling between fully fledged economic and climate models*, to represent mathematically the *Concept of viability and its relevance to integrated assessment*, and to deal with *Abrupt stochastic damage function to analyze climate policy benefits*, respectively. Two chapters are dedicated to *Climate Policy Cooperation Games* and the *Issue linking approach*, where a game theoretic analysis combines with integrated assessment models to define the dividends of cooperation. Two chapters are devoted to the modelling of energy options in multi-region world energy-technology-environment models. The first one presents a *15-region world model* which is used to explore robust energy/technology options for tackling the long term emissions reduction problem. The second one uses a *5-region world model* and focusses on the learning by doing phenomenon which characterizes the market penetration of new technologies. The following chapter addresses the interesting linkage that exists between global environmental change and local pollution with its *Health effects*. The analysis is conducted from a computable general equilibrium model. The same type of modelling is used in the next chapter devoted to a *Swiss perspective on carbon tax and international emissions trading*. The last three chapters deal with various aspects of impacts of climate change for Switzerland. An *Overview of extreme climatic events*, the analysis of the *Swiss agriculture in a changing climate* and *Modelling Climate Change impacts & vulnerability in Switzerland* conclude this book.

Therefore, the volume begins with very general modelling issues and converges toward implementation issues, using mostly examples from Switzerland.

We take this opportunity to thank all those who helped us in the preparation of this volume, in particular Prof. M. Beniston who invited us to contribute to the series and the NCCR-"Climate" head-office for the financial support that permitted this endeavor.

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Chapter 1

CLIMATE POLICY COOPERATION GAMES BETWEEN DEVELOPED AND DEVELOPING NATIONS: A QUANTITATIVE, APPLIED ANALYSIS

Claudia Kemfert

Abstract This paper investigates climate control coalition games of developed and developing nations. It studies whether incentives exist for non-cooperating nations to join a coalition based upon issue linkage. Issue linkage is considered through increased R&D expenditures triggering improved technological innovations that advance energy efficiencies. Model calculations demonstrate that incentives exist for non-cooperating countries to join a climate control coalition if nations cooperate on technological innovations. Restrictions on trade such as sanction mechanisms against non-cooperating countries are not necessarily an incentive to join a coalition. Technological spillover effects lead to improved economic situations and increased energy efficiencies in non-cooperating countries. We compare climate control coalitions of developed and developing nations. Developing nations can benefit by climate control if it is linked with technology cooperation.

1. Introduction

Nearly all scientific reports, including the youngest IPCC report, confirm once more that humankind's impact on the natural environment has never been greater and is causing substantial long-term and irreversible climatic changes. One important source of climate change are anthropogenic greenhouse gas emissions. Increasing atmospheric concentrations of greenhouse gases have a substantial impact on the global temperature and sea level which generate extensive economic, ecological and climatic impacts. Irreversible climate changes induce significant costs, and no future efforts can reverse the resulting damage. International climate control agreements intend to shrink this process. A substantial reduction of GHG emissions requires cooperation between countries. However, greenhouse gas emissions reduction is still an international public goal necessitating long term and global economic efforts. The formulation of the Kyoto protocol and the following negotiation attempts represent one initial outcome of cooperative international climate control policy actions.

Latest negotiation outcomes confirm that individual countries are mainly concerned with potential economic disadvantages regarding emissions reduction. Maximization of national welfare leads to either unilateral operations, a formation of small coalitions or free ride actions. Whether a stable coalition can be reached depends on the opportunities to reduce interest conflicts regarding a minimum agreement. A bargaining situation contains opportunities to collaborate for mutual benefits. As real negotiation processes demonstrate, a full agreement of all players is unlikely. More realistically, some players may act independently or unilaterally to maximize their own welfare and self interests, while other players create small and stable coalitions (Carraro and Siniscalo (1992), Carraro and Siniscalco (1993) and Hoel (1994)). The decision to join a coalition or to initiate a partial coalition depends on the difference in net benefits of a cooperative and a non-cooperative strategy (Barrett (1994)). As long as the environment and climate are treated as a public good and there are no penalties or sanction mechanisms for polluting entities, there will be no economic incentives to act environmentally friendly neither unilaterally nor cooperatively. Moreover, as long as cooperative behavior is imposed by voluntarily actions, finding a common or global agreement is driven by the varying interests of negotiating countries. These interests must be harmonized between nations or groups of countries.

A variety of incentives exist to free ride. A free riding position is seen in the recent decision of the US to leave the previously established climate control coalition. This paper explores the scope of cooperation for greenhouse gas emissions reduction by using game theoretic approaches. The purpose of this paper investigates whether incentives for free riding countries exist to join an existing coalition for international climate control cooperation. The payoffs for all players are contrasted and assessed by a world integrated assessment model. Different incentives to cooperate are analyzed by diverse assumptions regarding future impact assessment. Issue linkages are studied by combining climate control targets with increased expenditures of R&D triggering environmentally friendly technologies. Furthermore, Barrett's idea of issue linkage of joint climate control cooperation and trade patterns is compared. Section one of this paper gives a brief overview of international climate control agreements. Section two describes the game theoretic approach of issue linkage. Section three briefly illustrates the modelling framework used to study these impacts, while section four shows the main modelling results. The last section concludes.

2. International Climate Control Coalitions

The greatest success of international climate control policy was the establishment of the Kyoto Protocol. It is one of the leading and most important international environmental agreements in the history of global negotiation and bargaining policies. However, recent climate change negotiation processes confirm that the initial climate change control coalition was not stable: the United States, the world's largest economy and emitter of greenhouse gases (GHGs) left the coalition and now acts as a singleton and free rider. The reason for this behavior can be explained by game theoretic validation: economic payoffs of free riding are higher than joining the coalition.[1] This paper confirms this by using global modelling results. Because the remaining climate coalition partners still intend to reach an international climate control agreement, the environmental effectiveness is potentially diminished. International greenhouse gas reductions imposed by the Kyoto protocol can most likely not be met.

A variety of incentives exist for free riders or instable coalition partners to join or remain in the game. Carraro and Siniscalo (2002) and Carraro and Galeotti (1995) investigate policy strategies for increasing environmental cooperation. One proposal includes the option to pay off countries whose net benefits cannot overcompensate net costs. The stability of the agreement is reached by a redistribution mechanism among signatories. Carraro and Siniscalco (1993) and Hoel (1994) study self-financed transfers used to offset free riding. The symmetry of the coalition group can be reached by a system of transfers. They found that strategic behavior may undermine the implementation of side payments. Free riders tend to overestimate economic disadvantages, whereas coalition members could underestimate the initial gains of cooperation.

The USA's free riding position is (among others) a major problem for international climate policy. Game theory suggests that issue linkage may help increase incentives to join a coalition and overcome free riding. The concept of issue linkage has been introduced to abolish potential asymmetries among counties (see Folmer, Mouche et al. (1993), Cesar and de Zeeuw (1996)). The idea behind this proposal is that countries benefiting from different issues should combine all issues to obtain a stable, symmetric and favorable coalition. Pioneering studies of issue linkages are made by Tollison and Willet (1979), Haas, Keohane et al. (1993) and Sebenius (1983). They propose issue linkages with a public good such as the environment, and other issues, e.g. international security and finance. Barrett (Barrett (1995), Barrett (1997)) propose linking environmental protection negotiations with trade liberalization. Free riders would have to pay a penalty implemented as a trade sanctions. He finds that the threat of penalties can enlarge the coalition; a grant coalition is therefore hard to obtain. Carraro and Siniscalco (1997), Carraro and Siniscalo (1995) and Katsoulacos (1997) propose linking environmental negotiations with increased expenditures in R&D. Technological cooperation is only possible if countries collaborate on environmental issues. Issue linkage could be an incentive for free riders to join a coalition. Issue linkage is based on the idea that the benefits of free riding regarding a public good must be offset by the gains of a jointly provided club good. Tol, Lise et al. (2000) explore the incentives of joining a coalition by issue linkage through side payments as capital and

[1] The recent announcement (February 14, 2002) of the US administration proposes a voluntary environmental program avoiding huge economic losses due to economic growth reductions.

technology transfer. They find that technology transfer increases the incentives to cooperate. Model results of this study confirm that finding.

The Kyoto protocol allows flexible ways to reach GHG reduction targets. Emissions diminution can be attained through domestic abatement efforts or by international flexible mechanisms like emissions trading between developed nations, investment transfers of energy efficient projects between developed nations (Joint Implementation JI) or developing nations (Clean Development Mechanisms CDM). If emissions trading is not allowed globally but between industrialized countries, the potential main seller of permits will be Russia due to its recent economic slump.[2] Because the USA is the largest greenhouse gas emitter, they will potentially demand a considerable share of emissions permits. The United States' defection induces a reduction of emissions permits demand and therefore the price of permits. This lowers the revenues for permit sellers like Russia and compliance costs for other coalition members like the European Union and Japan. Because of smaller compliance costs, incentives are lowered to invest in climate-friendly technologies. Furthermore, the remaining coalitions run the risk of becoming unstable because of reduced payoffs for Russia, an important player. In order to not lose the economic gains from emissions trading, Russia will try to act strategically by influencing the market price. They could bank emissions and sell only part of their emissions permits in the beginning of the first commitment period. The recent negotiation agreement draws from formerly discussed limits of emissions permit trading.[3]

3. Game Theoretic Approach of Issue Linkage

Emissions reduction is costly for the countries most responsible for climate change. Because of the global character of the climate change problem, each nation could benefit from emissions reductions by other nations. The incentive to reduce emissions in one specific country is very small. This phenomenon is referred to by many authors as a "prisoner's dilemma" (for example Barrett (1994), Barrett (1998), Carraro and Siniscalco (1997), Carraro and Hourcade (1998), Carraro (1999), Cesar (1994)). However, some countries might have an incentive to create a small or grant coalition[4] to improve net benefits; the *game theory of cartel stability* mentions this (see Carraro (1997), Carraro and Siniscalco (1998) and Carraro (1999)). A stable coalition or cartel is characterized by external and internal stability. *Internal stability* means that no country in

[2] This is confirmed by many modeling studies such as those done by Manne and Richels (2001), Elzen and de Moor (2001), Böhringer (2001), Buchner, Carraro et al. (2001) and Kemfert (2002a)

[3] Previous negotiations were influenced by the so-called "supplementarity condition" that any emissions trading should only be supplemental to domestic action. Recent negotiations confirm that there should be no trading limits, although they stress a so-called commitment period reserve, whereby countries must demonstrate via recent inventories that they indeed have made emissions reductions and are not selling credits they are unlikely to have. This would not distort trading, as Babiker, Jacoby et al. (2002) demonstrate.

[4] The grant coalition describes that coalition where all negotiating parties agree.

the coalition has an incentive to leave the cartel. *External stability* implies that no country outside the coalition has an incentive to join the cartel. A cartel is *profitable* if all members of the stable coalition are better off inside the cartel than outside.

We assume that the coalition of emissions reduction nations occurs between n countries, n ≥ 3, indexed by $i = 1 \ldots n$, $n \geq 3$. Nations can commit (C) or defect (D). The collective action is an n-tuple $(x_1, x_2, \ldots, x_n) \in X^N$ with $x_i \in \{C, D\} = X_i$ that represents the choice of country i and $X^N = X_1 \times X_2 \times \cdots \times X_n$. This can also be written as the pair $(x_i,\ x_{-i})$ with x_{-i} as strategies of all other players except i. The climate change "prisoner's dilemma" signifies: $u_i(D, \bar{x}_{-i}) > u_i(C, \bar{x}_{-i})$ for all $i \in N$. It demonstrates that a rejection always brings a better situation than a commitment. This payoff order has the characteristic that the n times D outcome $(\underbrace{D, D, ..., D}_{n})$ is a single pure Nash equilibrium strategy. Other weak "prisoner's dilemmas" with more than two players could induce further Nash equilibria (see Lise et al. (2001) for an overview).

The stability analysis of a cartel game is based on the approaches by Carraro (1997, 1998, 1999). $P_i(s)$ denotes the value for player I to a member of coalition s, $Q_i(s)$ is the value for player i not to be a member of coalition s (see also Kemfert, Lise et al. (2002) and Lise, Tol et al. (2001)). Cooperation of one player is reflected as unilateral action. Payoffs of unilateral action are shown as a "no cooperation" scenario in Table 1.6 (see Appendix). The payoffs are measured as cumulated consumption values in that specific region. If we consider the cartel game as a normal form game with four players, we can summarize the following payoff[5] matrix:

Table 1.1. Cartel Game as a Formal Game with Four Players

4	3	1	2	Cooperate	Defect
Cooperate	Cooperate	Cooperate		P_1(1,2,3,4), P_2(1,2,3,4,) P_3(1,2,3,4) P_4(1,2,3,4)	P_1(1,3,4), Q_2(1,3,4), P_3(1,3,4), P_4(1,3,4)
		Defect		Q_1(2,3,4), P_2(2,3,4), P_3(2,3,4),P_4(2,3,4)	Q_1(3,4), Q_2 (3,4), P_3(3,4), P_4(3,4)
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		P_1(1,2,3), P_2(1,2,3) P_3(1,2,3) P_4(1,2,3)	P_1(1,3), Q_2(1,3), P_3(1,3), P_4(1,3)
		Defect		Q_1(2,3), P_2(2,3), P_3(2,3),P_4(2,3)	Q_1(3),Q_2(3), P_3(3), Q_4(3)
		1	2	Cooperate	Defect
	Defect	Cooperate		P_1(1,2), P_2(1,2) P_3(1,2), P_4(1,2)	P_1(1), Q_2(1) Q_3(1), Q_4(1)
		Defect		Q_1(2), P_2(2), Q_3(2), Q_4(2)	Q_1(∅), Q_2(∅), Q_3(∅), Q_4(∅)

[5] Payoffs usually mean payments to the individual player, measured in utility values.

If no players want to leave the coalition, it is internally stable if $Pi(s) > Qi(s \backslash i)$ for all $i \notin s$. If no players want to join the coalition, it is externally stable, that is if $P_i(s \cup i) < Q_i(s)$ for all $i \in s$. A coalition is stable if it is both internally and externally stable.

Our analysis considers four different world regions. In the first part of the analysis, player one is the United States of America (USA,1), player two the European Union (EU,2), player three Japan (JPN,3) and player four Russia and Eastern Europe (REC,4). As can be seen later in the simulation analysis, the payoff matrix illustrates the different combinations of cooperation and defection games by individual players. Table 1.1 shows the individual payoffs as a formal game. In this analysis, only four regions reduce emissions. The other seven regions play a default strategy of zero emissions reductions. We follow the approach of Carraro and Siniscalco (1997) and Buchner, Carraro et al. (2002) where countries play a two-stage game. Negotiation countries ($i = 1, 2, 3, 4$) first decide non-cooperatively whether to join a coalition, i.e., the coalition game. Carraro and Siniscalco (1993) call this a "metagame" or a "one-shot" game. In the second stage, they play a non-cooperative, open-loop Nash game to determine their policy variables. That means (depending on the game's outcomes in stage one) players decide whether or not to act cooperatively. Because climate change control is a public good, incentives for free riding could only be offset by benefits resulting from technological or terms of trade improvements. Trade sanctions are imposed on those countries not cooperating on climate control. Incentives to free ride exist only because of potentially positive technology and terms of trade spillover effects. In a formal game, a position G contains the number N of players in the game, the possible outcomes X^G of the game and the related utility functions $u \equiv \{u_i\}_{i \in N}$. The following coalition combinations of the game are compared:

$$G = \left[\begin{array}{l} \{1,2,3,4\}, \left\{ \begin{array}{l} CCCC, CCDD, DCCD, CCDC, CDDC, CDCC, DDCC, CDDD, \\ DCDD, DDDC, DCDC, DCCC, CCCD, DDDD \end{array} \right\}, \\ \left\{ \begin{array}{l} u(CCCC), u(CCDD), u(DCCD), u(CCDC), u(CDDC), u(CDCC), u(DDCC), u(CDDD), \\ u(DCDD, u(DDDC), u(DCDC), u(DCCC), u(CCCD), u(CDDDD) \end{array} \right\} \end{array} \right]$$

4. Applied Modeling Tool

Empirical validation is based on the applied general equilibrium model WIAGEM. WIAGEM is an integrated assessment model merging an economy model based on a dynamic inter-temporal general equilibrium approach combined with an energy market model and climatic sub-model covering a time horizon of 50 years incremented into five-year time steps.[6] The basic idea behind this modelling approach is the evaluation of market and non-market

[6]The core economic model code was established by Tom Rutherford in 1998. The model has been enlarged by including a 50-year time period, all greenhouse gases, climate change impact assessment, endogenous technological change and issue linkage. The model is written in the computer language GAMS (MPSGE) and solved by the algorithm MILES, see Rutherford (1993).

impacts induced by climate change. The model includes an endogenous determination of technological changes. The economy is represented by 25 world regions aggregated into 11 trading regions with each region covering 14 sectors. The sectoral disaggregation contains five energy sectors: coal, natural gas, crude oil, petroleum and coal products, and electricity. The dynamic international competitive energy market for oil, coal and gas is modelled by global and regional supply and demand, the oil market is characterized by imperfect competition with the intention that OPEC regions can use their market power to influence market prices. Energy related greenhouse emissions occur as a result of economic and energy consumption and production activities. Currently, a number of gases have been identified as having a positive effect on radiative forcing (IPCC (1996)) and are included in the Kyoto protocol as “basket” greenhouse gases. The model includes three of these gases: carbon dioxide (CO2), methane (CH4) and nitrous dioxide (N2O) which are considered the most influential greenhouse gases within the short term modelling period of 50 years. Excluding the other gases is not believed to have substantial impacts on the analysis’ insights.

Because of the short term application of the climate sub-model, we consider only the first atmospheric lifetime of greenhouse gases, assuming that the remaining emissions have an infinite lifetime. The atmospheric concentrations induced by energy related and non-energy related emissions of CO2, CH4 and N2O have impacts on radiative forcing, influencing potential and actual surface temperature and sea level. Market and non-market damages determine regional and overall welfare development.

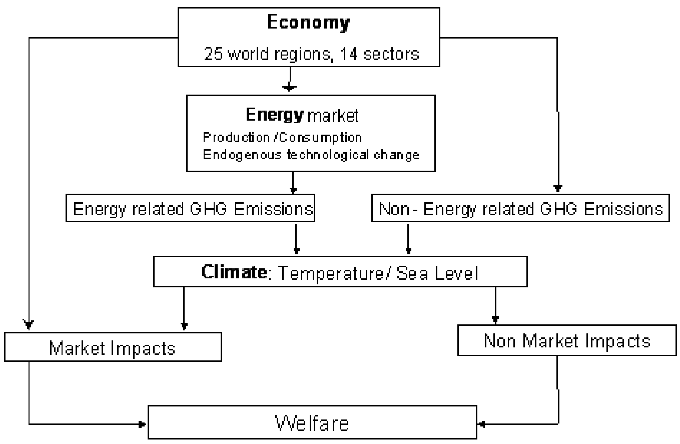

Figure 1.1. Welfare Determination in WIAGEM

In each region, production of the non-energy macro good is captured by an aggregate production function. The production function characterizes technology through transformation possibilities on the output side and substitution possibilities on the input side. In each region, a representative household chooses to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. In each period, households face the choice between current consumption and future consumption which can be purchased via savings. The trade-off between current consumption and savings is given by a constant inter-temporal elasticity of substitution. Producers invest as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by a uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and a unit of consumption is equalized within and across countries. Domestic and imported varieties for the non-energy good for all buyers in the domestic market are treated as imperfect substitutes by a CES Armington aggregation function, constrained to constant elasticities of substitution. Emission limits can be reached by domestic action or by trading emission permits within Annex B countries allocated (initially) according to regional commitment targets. Those countries meeting the Kyoto emissions reduction target stabilize their mitigated emissions at 2010 levels.

Goods are produced for the domestic and export market. Production of the energy aggregate is described by a CES function reflecting substitution possibilities for different fossil fuels (i.e., coal, gas, and oil), capital, and labor representing trade-off effects with a constant substitution elasticity. Fossil fuels are produced from fuel-specific resources and the non-energy macro good subject to a CES technology.

Induced technological change is considered as follows: Energy efficiency is improved endogenously by increased expenditures in R&D. This means that in the CES production function, energy productivity is endogenously influenced by changes in R&D expenditures. The CES production structure follows the concept of ETA-MACRO combining nested capital and labor at lower levels. Energy is treated as a substitute of a capital labor composite determining (together with material inputs) overall output. Energy productivity is increased endogenously by increased R&D expenditures. The incentives to invest in technology innovations are market driven. Because energy efficiency is improved by increased R&D expenditures, emissions reduction targets can be reached with less production drawbacks. Furthermore, investment in R&D and technological innovation gives a comparative advantage. The share of R&D expenditures of total expenditures is endogenously determined by production changes. However, this also means that investment in R&D expenditures competes with other expenditures (crowding out). Spill over effects of technological innovations are reflected through trade effects and capital flows. That means that non R&D cooperating countries developing technological innovations can benefit from spill over effects through trade of technological innovations and capital flows that can be used for R&D investments. Model calculations show that capital flows increase to non-cooperating countries because of improved competitiveness effects and terms of trade effects. This triggers spill over effects regarding technological innovations and energy efficiency improvements through increased R&D investments.[7]

5. Impacts of Trade Coalitions Cooperating on Climate Control

5.1 Kyoto Climate Blocs

We investigate different coalitions of climate control and issue linkage. "No cooperation" means unilateral action on climate control. Full cooperation incorporates Kyoto greenhouse gas emissions targets by Annex I regions. As mentioned in Section 3, we consider four different players from developed and less developed nations. WIAGEM considers eleven total regions. In this analysis, only four regions reduce emissions. The other seven regions play a default strategy of zero emissions reductions. We distinguish between Climate Control (CC) scenarios where Annex I permit trade (AT) is allowed or not (NT). Issue linkage is covered by cooperation between induced technological change through increased R&D investments (R&D). A potential punishment for non-cooperating countries is concealed by trade barriers (TB). In these scenarios, we assume that coalition partners exclude non-cooperating countries both from climate control, and also from secondary issues such as R&D cooperation and technological improvement. Although in reality it might be difficult to exclude non-cooperating countries or to implement trade sanctions (which might be against WTO laws), an artificial simulation of potential economic consequences might give insights and answers into why some countries act strategically. Model simulations try to restrict technology and economic spillover effects to those countries not cooperating. However, later model results show that a full restriction is not feasible. The following table summarizes all scenarios:

Scenario	Description
CC –NT	Climate Control- without emission permit trading- no trade (NT)
CC- AT	Climate Control- with emission permit trading- Annex I permit trade (AT)
R&D	Cooperation of coalition partners on R&D development- permit trading is allowed
R&D- CC	Cooperation of coalition partners on R&D development- permit trading is allowed- with Climate Control activities (CC)
TB	Trade barriers against non-cooperating countries
TB-CC	Trade barriers against non-cooperating countries plus climate control activities of coalition partner

Table 1.6 illustrates the regional payoffs of all scenarios. It shows the cumulated payoffs up to the first commitment period 2012. The unilateral action on

[7] In this paper, we assume standard parameterisation, as illustrated in Kemfert (2002b) and Kemfert (2004)

R&D investments and energy efficiency improvement can be seen as the current climate control policy of the United States of America. As other model calculations have also demonstrated, meeting emission reduction targets is costly for those regions facing real emissions reductions, i.e. Europe, USA and Japan. Within the first commitment period, Russia and Eastern European countries benefit from a surplus of emissions permits that can be traded. Because of this, and due to the above-described public good character of climate change, countries with binding emissions targets benefit from climate control free riding. Obviously, countries always benefit from a "do-nothing" climate control strategy. This is also because we consider only a 50-year time period; significant climate damages that exceed economic benefits occur after this period. However, we intend to assess whether opportunities exist that would allow incentives for cooperation both on climate control and technological improvements. Additionally, it is evaluated whether trade sanctions against non-cooperating countries can lead to cooperative behavior. As Table 1.2 shows, all countries with binding emissions targets can profit from emissions trading with Russia. Unilateral emissions reduction is only profitable if no trading is authorized. Cooperative behavior makes all players better off if emission permit trading is allowed. Small coalitions benefit cooperating nations with binding emissions reductions targets. Russia, as a main seller of permits, wants to cooperate with as many potential buying countries as possible. The USA and EU always prefer joining a coalition with Russia if permit trading is allowed. For the USA, it is profitable to join a small coalition with Japan and Russia because of reduced compliance costs resulting from lower permit demand and a decreased permit price.

Nations cooperating on technological improvements are better off only if they unilaterally apply innovations. Bilateral trade improves competitiveness effects and increases welfare. The most important outcome of this analysis is the USA's incentive to cooperate on technological improvements. However, the USA as a free rider on technological innovations could also benefit from spillover effects resulting from technological improvements in cooperating countries. The USA would prefer to join a coalition with Japan and Russia instead of a coalition with both Europe and Japan who face binding emissions reduction targets. Trade barriers are not a significant incentive to join a coalition. Because of the international principal terms of trade effects from strong nations like the USA, Europe and Japan, it seems that trade restrictions against non-cooperating countries is a punishment against themselves. The only exemption is a partial coalition between Japan, Europe and Russia on climate control and trade barriers against the USA. We find an internally and externally stable coalition where Europe, Japan and Russia cooperate on climate control and apply trade barriers against the USA. However, this small coalition is not profitable. Another externally and internally stable coalition is the small coalition between Europe and Russia on climate control and potential emissions trading. This coalition is also not profitable.

Table 1.2. Internally and Externally Stable Coalitions

	CC-NT	CC-AT	R&D	CC-R&D	TB	CC-TB
Internally	Ø	{USA,EU,JPN,REC} {EU,JPN,REC} {USA,JPN,REC} {USA,EU,REC} {USA,REC} {EU,REC} {JPN,REC}	{EU,JPN,REC} {USA,JPN,REC} {USA,EU,REC} {USA,REC} {EU,REC} {JPN,REC}	{USA,EU,JPN,REC} {EU,JPN,REC} {USA,JPN,REC} {USA,EU,REC} {USA,REC} {EU,REC} {JPN,REC} {EU,JPN}	{EU,JPN,REC} {USA,JPN,REC} {USA,EU,REC} {JPN,REC}	{EU,JPN,REC}
Externally	{USA,EU,REC}	{EU,REC}	Ø	Ø	{EU,JPN,REC}	{EU,JPN,REC}
Stable	**Ø**	**{EU,REC}**	**Ø**	**Ø**	**{EU,JPN,REC}**	**{EU,JPN,REC}**

The ranking of all payoffs is evidence that the USA always benefits from free riding on climate control. However, there is a visible incentive to join a coalition on technological innovations instead of unilateral action. The USA prefers to join a small coalition on climate control as well as issue linkage with Europe and Russia instead of Japan and Russia. The reasons for this are stronger terms of trade and competitiveness effects in a coalition with Europe and Russia. However, additional to the "business as usual defect" Nash equilibrium, there are three further Nash equilibria where the USA, Japan and Russia cooperate on climate control: emissions trading, climate control and issue linkage of R&D cooperation, and pure R&D cooperation without climate control. By ranking all payoffs according to their different coalition options, we summarize the following payoff matrices to show the Nash equilibrium in the shadowed boxes:

1. CC-NT

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		5,7,3,11	7,3,9,9
	Defect			4,9,7,2	8,8,8,4
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		2,6,2,10	6,2,11,7
		Defect		3,12,4,1	8,8,8,4
		1	2	Cooperate	Defect
	Defect	Cooperate		10,4,1,3	8,8,8,4
		Defect		8,8,8,4	8,8,8,4

2. CC-AT

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,6,5,7	5,7,7,10
	Defect			7,9,6,9	4,4,4,5
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		1,2,1,1	2,1,12,2
		Defect		3,11,3,4	4,4,4,5
		1	2	Cooperate	Defect
	Defect	Cooperate		11,3,2,3	4,4,4,5
		Defect		4,4,4,5	4,4,4,5

3. R&D

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,3,7,8	5,8,9,9
	Defect			6,9,5,6	4,5,4,4
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		1,2,1,1	2,1,12,2
		Defect		3,10,2,3	4,5,4,4
		1	2	Cooperate	Defect
	Defect	Cooperate		12,4,3,5	4,5,4,4
		Defect		4,5,4,4	4,5,4,4

4. CC- R&D

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,6,6,7	2,7,7,9
	Defect			5,10,5,6	1,4,2,3
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		7,1,8,1	6,3,12,5
		Defect		3,12,3,2	1,4,2,3
		1	2	Cooperate	Defect
	Defect	Cooperate		12,2,1,4	1,4,2,3
		Defect		1,4,2,3	1,4,2,3

4. TB

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		12,4,12,7	9,8,1,10
	Defect			7,12,8,8	8,7,9,5
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		5,3,7,3	11,6,3,4
		Defect		6,1,4,1	8,7,9,5
		1	2	Cooperate	Defect
	Defect	Cooperate		1,2,2,3	8,7,9,5
		Defect		8,7,9,5	8,7,9,5

5. CC-TB

REC	JPN	USA	EU	Cooperate	Defect
Cooperate	Cooperate	Cooperate		6,7,8,7	10,6,2,9
	Defect			9,12,11,4	7,5,10,6
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		5,9,6,1	11,8,1,3
		Defect		8,1,4,5	7,5,10,6
		1	2	Cooperate	Defect
	Defect	Cooperate		1,4,9,2	7,5,10,6
		Defect		7,5,10,6	7,5,10,6

Europe prefers to join a small coalition on climate control and issue linkage on technological innovation with the USA and Japan instead of Japan and Russia. However, it is more beneficial for Europe to join a coalition with the USA and Russia. As coalitions with Russia demonstrate, all countries with binding emissions reduction targets favor a small or full coalition with Russia. Russia offers the supply of permits; the lower the demand for permits, (i.e. the fewer Annex I regions joining the coalition), the lower the compliance costs and the more profitable the coalition is for nations with binding emissions reduction targets. However, if we include stronger assumptions about climatic impacts of climate change resulting from less stringent emissions reduction targets, benefits of less binding reduction targets always exceed the damages of climate change. Japan favors joining a coalition on climate control and innovations with Europe and Russia or the USA and Europe instead of Russia and the USA. Japan benefits from technological innovations, and their main trading partners are the USA and Europe.

5.2 Developing Country Climate Blocs

As in the previous chapter, we investigate different climate coalitions of climate control and issue linkage. We assess the impacts of climate blocs and issue linkage of developing countries, and base our analysis on the same assumptions as before. As developing countries do not have binding emission reduction targets, incentives to join a climate coalition are primarily based on economic benefits or secondary benefits of climate control policies, e.g. the reduction of conventional air pollution. We assume that developing countries try to maximize their economic benefits by R&D cooperation or trade coalitions.

No cooperation means unilateral action on climate control. Full cooperation incorporates the greenhouse gas emissions targets of developing countries (China CHN, Sub Saharan Africa SSA, Latin South America LSA and Asia ASIA). The emissions target is represented by these regions following their "business as usual" baseline emissions path. The other seven regions play a default strategy of zero emissions reductions. We distinguish between climate control (CC) scenarios where emissions permit trade (ET) is allowed or not (NT). We investigate different climate control collations between Annex I regions. A potential punishment for non-cooperating countries is concealed by trade barriers (TB). The different combined abbreviations illustrate the climate control blocs. For example, "CHNLSAASIA" shows the cooperative climate policy of the regions China, Latin South America and Asia. Table 1.7 shows the payoffs in millions of dollars.

All developing regions prefer to cooperate on climate policy in climate blocs if emissions trading is allowed. A climate control policy means developing regions must reduce their emissions according to their baseline emissions, which results in economic welfare losses, Table 1.7 shows the payoffs. This is primarily caused by the assumption that developing countries have to reduce a substantial amount of emissions which leads to binding emissions reduction targets. If flexible mechanisms such as emissions trading cannot be applied, economic costs are even higher. Negative welfare implications induce terms of trade losses. This explains why the regions would prefer to act individually instead of in full cooperation on climate control if no emissions trading is allowed. This can be explained by the fact that countries can economically benefit from emissions trading. If emissions trading is not allowed, countries suffer substantially. A full cooperation means that all countries are reducing emissions, which causes both economic declines within the country but also terms of trade losses by spillover effects. Acting individually results in fewer negative economic spill over effects.

China favors a cooperation with Asia in comparison to Latin South America. Latin South America also prefers to cooperate with Asia. Both effects can be explained by the strong trade relations with Asia. Because of the economic growth assumptions of the regions Latin South America and China, Asia appears to be the main seller of emissions permits. If emissions trading is allowed, a cooperation with Asia is always attractive for China and Latin South America due to reduced emissions reduction costs. As Table 7 shows, these climate coalition blocs are stable. Sub Saharan Africa is too small of a trade region to induce major impacts on the world trade market. This also means that the other regions have no incentives to prefer a cooperation with SSA. Latin South America benefits from cooperation on climate control with China and Asia only if emissions trading is allowed. However, because of negative terms of trade effects, positive welfare implications will not reach that extent if only LSA and China or Asia cooperate on climate control. Emissions trading means fewer negative welfare implications. Issue linkage by R&D cooperation seems to be a very beneficial situation for developing countries, i.e. it leads to internally stable coalitions. However, no coalition is also externally stable at the same time.

Trade sanctions in climate blocs do not seem to be a valid instrument for increasing incentives to cooperate on climate control. Although we find internally stable coalitions if China and Asia induce trade sanctions against Latin South America, this climate control bloc does not appear to be a sound strategy, as it induces negative welfare implications. This explains why we cannot find any externally stable coalition. However, climate control coalitions that lead to favorable economic situations due to permissible emissions trading are neither externally nor entirely stable.

Table 1.3. Internally and Externally Stable Coalitions

	CC-NT	CC-ET	R&D	CC-R&D	TB	CC-TB
Internally	{CHN,SSA,ASIA} {SSA,LSA}	{CHN,LSA,ASIA} {SSA,LSA,ASIA} {LSA,ASIA} {CHN,ASIA}	{CHN,LSA,ASIA} {CHN,SSA,ASIA} {SSA,LSA,ASIA} {SSA,ASIA} {LSA,ASIA} {CHN,ASIA}	{CHN,LSA,ASIA} {CHN,SSA,ASIA} {SSA,LSA,ASIA} {SSA,ASIA} {LSA,ASIA} {CHN,ASIA}	{CHN,ASIA}	{CHN,SSA,ASIA}
Externally	Ø	Ø	Ø	Ø	Ø	Ø
Stable	**Ø**	**Ø**	**Ø**	**Ø**	**Ø**	**Ø**

The ranking of all payoffs is evidence that the climate control regions prefer to cooperate with Asia. This explains why Asia benefits the most from a full cooperation (i.e. the grant coalition) on climate control if trading is allowed (see CC-ET scenario). The following table summarizes the rankings of the different scenarios.

Table 1.4. Ranking of Payoffs

1. CC-NT

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		4,5,3,1	6,4,11,7
	Defect			5,9,5,8	1,11,1,11
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		8,7,12,10	3,1,9,6
		Defect		2,12,8,2	7,6,7,4
		1	2	Cooperate	Defect
	Defect	Cooperate		11,8,2,5	7,6,7,4
		Defect		7,6,7,4	7,6,7,4

2. CC-AT

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,6,4,12	1,2,1,6
	Defect			7,9,6,3	6,11,11,8
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		5,7,9,11	2,1,12,1
		Defect		3,12,2,2	4,5,5,4
		1	2	Cooperate	4,5,5,4
	Defect	Cooperate		11,4,3,5	4,5,5,4
		Defect		4,5,5,4	4,5,5,4

3. R&D

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		7,2,8,8	4,7,6,5
	Defect			6,3,2,4	5,1,3,8
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		9,4,1,1	2,8,11,12
		Defect		3,10,4,3	1,5,10,7
		1	2	Cooperate	Defect
	Defect	Cooperate		12,11,7,11	1,5,10,7
		Defect		10,5,8,11	1,5,10,7

4. CC- R&D

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,6,6,7	2,7,7,9
	Defect			5,10,5,6	1,4,2,3
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		7,1,8,1	6,3,12,5
		Defect		3,12,3,2	1,4,2,3
		1	2	Cooperate	Defect
	Defect	Cooperate		12,2,1,4	1,4,2,3
		Defect		1,4,2,3	1,4,2,3

4. TB

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		12,5,10,11	5,3,5,12
		Defect		7,12,6,5	10,11,7,8
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		9,9,2,10	11,6,3,2
		Defect		6,1,8,1	8,8,9,3
		1	2	Cooperate	Defect
	Defect	Cooperate		1,2,1,4	8,8,9,3
		Defect		8,8,9,3	8,8,9,3

5. CC-TB

ASIA	CHN	SSA	LSA	Cooperate	Defect
Cooperate	Cooperate	Cooperate		8,9,5,7	5,7,4,1
		Defect		7,12,6,5	12,3,3,8
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		10,8,12,9	11,6,1,3
		Defect		6,1,7,6	9,5,9,4
		1	2	Cooperate	Defect
	Defect	Cooperate		1,4,9,2	9,5,9,4
		Defect		1,4,8,2	9,5,9,4

Sub Saharan Africa is an economically small country which does not induce negative terms of trade effects on the world market. Furthermore, because of a low emissions baseline development, SSA does not require emissions permits. Both interrelations induce regions like Latin South America and China that demand emissions permits to cooperate with SSA. On the one hand, the permit prices decrease due to lower demand. On the other hand, SSA does not induce negative terms of trade effects. These effects explain the higher ranking of climate control coalitions cooperating with SSA.

5.3 Combined Climate Blocs

In this section we consider different climate coalition blocs and issue linkage options of both developed and developing regions. More precisely, we compare different climate coalitions of the nations USA, Russia and Eastern Europe (REC), China (CHN) and Latin South America (LSA). As before, we detect that Russia (as the main seller of emissions permits) wants to cooperate with the USA and vice-versa. However, Latin South America and China also prefer to cooperate with the USA instead of Russia. The reason for this is that both China and Latin South America can compete with Russia in sales of emissions permits to the USA. Developing countries can sell emissions permits as they are below their emissions baseline because of emissions reduction caused by carbon-friendly technologies. This is confirmed by Russia's revenues that are reduced if China and Latin South America join the coalition on climate control. This is also shown by fewer welfare increases measured in payoffs.

Table 1.5. Ranking of Payoffs

1. CC-NT

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		12,10,9,8	11,12,7,10
	Defect			1,6,8,6	2,8,3,5
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		8,5,5,3	5,1,10,10
		Defect		9,4,4,12	10,11,11,7
		1	2	Cooperate	Defect
	Defect	Cooperate		5,1,12,2	10,11,11,7
		Defect		4,8,1,4	10,11,11,7

2. CC-AT

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		9,10,2,5	12,12,10,9
	Defect			7,4,3,1	6,3,6,11
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		11,6,5,12	8,5,4,3
		Defect		3,12,2,2	10,10,12,8
		1	2	Cooperate	Defect
	Defect	Cooperate		4,8,1,4	10,10,12,8
		Defect		5,1,12,2	10,10,12,8

3. R&D

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		7,11,2,5	8,4,6,1
	Defect			6,1,8,10	1,6,9,11
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		2,6,4,7	3,2,11,6
		Defect		4,10,1,4	9,9,5,3
		1	2	Cooperate	Defect
	Defect	Cooperate		10,3,3,12	9,9,5,3
		Defect		5,1,10,2	9,9,5,3

4. CC- R&D

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		9,9,2,7	6,5,3,1
	Defect			8,4,7,8	12,11,11,9
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		2,12,4,6	3,3,9,5
		Defect		4,8,1,4	7,7,6,3
		1	2	Cooperate	Defect
	Defect	Cooperate		10,3,3,12	7,7,6,3
		Defect		5,1,10,2	7,7,6,3

4. TB

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		7,11,3,3	1,7,6,5
		Defect		6,2,5,10	12,12,9,9
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		2,8,4,11	2,3,11,7
		Defect		8,5,7,8	5,1,8,1
		1	2	Cooperate	Defect
	Defect	Cooperate		12,4,4,12	5,1,8,1
		Defect		6,5,8,2	5,1,8,1

5. CC-TB

LSA	CHN	USA	REC	Cooperate	Defect
Cooperate	Cooperate	Cooperate		7,10,3,7	1,8,4,8
		Defect		10,6,2,11	11,12,12,7
	3	1	2	Cooperate	Defect
Defect	Cooperate	Cooperate		6,5,1,3	2,9,5,5
		Defect		3,3,8,9	5,7,2,4
		1	2	Cooperate	Defect
	Defect	Cooperate		7,6,9,1	5,7,2,4
		Defect		8,4,7,12	5,7,2,4

Because of cheaper emissions reduction options, the USA always prefers to cooperate with Russia. Although both China and Latin South America could sell their so-called “hot air” as emissions permits, a cooperation with Russia is always more attractive to the USA. Russia wants to cooperate with the USA alone, especially if climate coalition games are connected with technological innovations. We find some internally stable coalitions where the USA and Russia are involved. R&D cooperation leads to beneficial situations for both developed and developing nations. The USA is always better off if they cooperate with developing nations like China, Latin South America, or Russia. Developing nations can benefit from technology transfer options and increased economic growth options. China especially benefits from a coalition with both Russia and the USA if emissions trading is allowed and coalitions cooperate on technological improvements. However, these coalitions are not externally stable, as potential climate control coalition members will always want to join this coalition.

6. Conclusion

This paper studied international climate control coalition games und investigated incentives for cooperation by issue linkage. Two main findings can be summarized. First, there are incentives for a climate control coalition coupled with issue linkage of technological innovations. A full cooperation on climate control and technological improvements benefit all nations in comparison to a unilateral strategy. There is an incentive for the USA to join either a full coalition or a smaller coalition on climate control and technological improvements with Europe, Japan, Russia and even developing nations like China. Technological innovations improve energy efficiencies, which again offer cheaper opportunities regarding emissions reductions. This leads to enhanced competitiveness effects and trade options. If Russia as the main seller of permits joins the coalition, issue linkage becomes most profitable. Developing countries benefit from cooperation of climate control and issue linkage of R&D cooperation because of positive economic growth effects. In total, for the majority of nations, cooperation on climate control and technological innovation gives stronger incentives to join a coalition than non-cooperating strategies.

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Appendix

Table 1.6. Payoffs in Millions of Dollars by 2010 (Cumulated discounted consumption.)

NO COOPERATION

	JPN	USA	EU	REC
CC-NT	1,849,719.15	3,438,623.75	3,938,267.81	332,098.39
CC-AT	1,853,643.79	3,451,473.35	3,946,925.08	331,932.03
R&D	1,851,774.91	3,455,640.79	3,942,645.43	331,599.30
CC-R&D	1,856,260.21	3,459,460.95	3,952,594.57	332,497.67
TB	1,840,374.77	3,448,695.06	3,934,686.11	332,065.12
CC-TB	1,850,933.92	3,447,167.00	3,941,053.56	331,366.38

FULL COOPERATION

	JPN	USA	EU	REC
CC-NT	1,847,850.27	3,438,137.55	3,929,910.53	330,734.20
CC-AT	1,863,548.83	3,460,597.35	3,947,818.98	332,234.81
R&D	1,871,316.14	3,450,538.79	3,945,221.64	332,209.92
CC-R&D	1,875,681.42	3,464,873.18	3,955,072.78	333,110.02
TB	1,860,529.00	3,446,373.82	3,947,023.05	332,268.08
CC-TB	1,850,279.81	3,455,588.23	3,940,655.60	331,490.61

EUJPNREC

	JPN	USA	EU	REC
CC-NT	1,847,663.39	3,563,948.87	3,937,680.58	331,690.80
CC-AT	1,854,668.35	3,571,898.58	3,948,107.33	332,355.59
R&D	1,852,029.03	3,564,876.05	3,943,396.66	331,813.64
CC-R&D	1,858,405.42	3,559,919.18	3,955,051.78	332,910.25
TB	1,840,499.33	3,493,910.29	3,934,944.23	332,270.80
CC-TB	1,850,959.15	3,470,751.21	3,941,176.68	331,492.06

USAJPNREC

	JPN	USA	EU	REC
CC-NT	1,848,317.49	3,434,664.68	3,943,839.32	332,522.62
CC-AT	1,853,859.03	3,460,996.47	3,952,196.60	333,221.36
R&D	1,851,899.49	3,463,153.15	3,948,216.95	332,888.63
CC-R&D	1,856,362.57	3,466,613.31	3,958,166.09	333,787.00
TB	1,840,474.33	3,449,053.30	3,932,540.97	333,487.54
CC-TB	1,851,521.37	3,449,715.45	3,935,084.08	332,613.63

JPNUSAEU

	JPN	USA	EU	REC
CC-NT	1,845,981.40	3,437,378.52	3,929,512.56	332,730.58
CC-AT	1,846,231.54	3,449,058.12	3,930,399.71	332,031.85
R&D	1,844,529.55	3,449,695.67	3,924,803.07	330,176.05
CC-R&D	1,860,385.46	3,456,336.39	3,962,852.93	330,745.31
TB	1,839,827.54	3,446,238.83	3,934,264.86	332,372.89
CC-TB	1,850,179.68	3,450,292.58	3,940,475.31	329,888.13

EUUSREC

	JPN	USA	EU	REC
CC-NT	1,871,211.21	3,437,138.52	3,935,880.01	331,884.16
CC-AT	1,875,135.85	3,461,347.47	3,955,046.31	334,094.78
R&D	1,873,266.98	3,459,856.02	3,946,770.81	333,071.53
CC-R&D	1,877,752.28	3,466,008.18	3,962,839.82	334,660.42
TB	1,830,120.54	3,453,930.91	3,943,138.23	334,227.87
CC-TB	1,838,347.69	3,458,012.23	3,958,564.05	335,159.51

USAREC

	JPN	USA	EU	REC
CC-NT	1,870,043.17	3,434,500.50	3,969,085.27	333,063.31
CC-AT	1,873,967.80	3,452,376.30	4,002,466.33	333,762.04
R&D	1,872,098.93	3,456,886.02	3,996,771.28	333,746.71
CC-R&D	1,876,584.23	3,464,882.18	4,003,841.92	334,512.52
TB	1,839,129.56	3,452,376.30	3,934,440.88	333,917.57
CC-TB	1,849,461.56	3,467,291.74	3,938,905.31	334,993.15

EUREC

	JPN	USA	EU	REC
CC-NT	1,868,875.12	3,568,877.98	3,937,020.56	332,106.71
CC-AT	1,890,191.91	3,584,047.56	3,953,166.33	332,805.44
R&D	1,881,899.16	3,565,888.20	3,944,237.29	332,011.55
CC-R&D	1,881,581.35	3,547,882.18	3,954,739.82	332,923.51
TB	1,838,922.67	3,447,449.85	3,936,670.36	332,805.44
CC-TB	1,848,785.67	3,443,041.79	3,946,177.79	333,304.54

EUUS

	JPN	USA	EU	REC
CC-NT	1,869,843.38	3,435,150.88	3,923,941.04	332,103.51
CC-AT	1,888,230.91	3,451,258.12	3,945,376.83	332,390.78
R&D	1,887,196.14	3,455,153.54	3,940,803.08	332,472.71
CC-R&D	1,887,505.46	3,459,009.74	3,952,353.36	333,371.09
TB	1,827,922.65	3,444,479.81	3,932,538.86	332,269.24
CC-TB	1,836,698.69	3,445,019.75	3,940,928.71	330,953.80

JAPUS

	JPN	USA	EU	REC
CC-NT	1,847,573.92	3,434,502.52	3,979,656.23	332,312.51
CC-AT	1,851,495.04	3,445,599.23	4,036,499.32	331,519.78
R&D	1,848,626.66	3,449,662.34	4,032,386.68	331,112.05
CC-R&D	1,858,745.33	3,459,045.70	4,042,069.80	332,711.92
TB	1,841,857.02	3,448,477.54	3,933,440.86	332,007.00
CC-TB	1,856,353.66	3,450,292.58	3,934,179.33	331,142.69

JPNREC

	JPN	USA	EU	REC
CC-NT	1,844,571.92	3,597,881.75	4,025,483.04	332,314.67
CC-AT	1,854,111.01	3,611,688.35	4,030,840.31	333,013.40
R&D	1,852,287.15	3,616,482.79	4,032,159.64	332,355.53
CC-R&D	1,857,284.47	3,619,707.95	4,042,051.92	333,186.79
TB	1,841,290.00	3,461,153.29	3,934,427.86	333,013.40
CC-TB	1,856,808.15	3,444,808.77	3,939,808.36	331,626.01

EUJAP

	JPN	USA	EU	REC
CC-NT	1,846,505.03	3,599,464.75	3,934,885.10	331,597.27
CC-AT	1,853,231.56	3,610,727.35	3,945,376.85	332,389.53
R&D	1,850,790.66	3,616,121.79	3,938,120.20	332,056.80
CC-R&D	1,856,712.46	3,620,034.95	3,953,436.80	332,955.17
TB	1,840,249.35	3,438,449.83	3,934,538.86	331,956.98
CC-TB	1,850,475.69	3,427,008.75	3,940,641.31	331,956.98

Table 1.7. Payoffs in Millions of Dollars for Developing Country Climate Blocs by 2010 (Cumulated discounted consumption.)

NO COOPERATION

	CHN	SSA	LSA	ASIA
CC-NT	249,040.70	171,709.81	571,443.50	680,793.98
CC-ET	249,579.31	172,351.55	572,669.28	680,444.86
R&D	249,322.83	172,559.68	572,085.58	679,746.61
CC-R&D	249,938.38	172,750.47	573,544.83	681,631.88
TB	247,758.31	172,212.80	570,918.17	680,724.16
CC-TB	249,207.41	172,136.48	571,852.10	679,257.83

FULL COOPERATION

	CHN	SSA	LSA	ASIA
CC-NT	248,527.74	170,669.14	569,692.40	676,604.48
CC-ET	250,682.16	181,475.55	572,319.06	690,918.61
R&D	268,864.06	167,457.68	574,661.79	680,357.23
CC-R&D	269,359.59	178,162.70	576,023.04	682,244.23
TB	267,912.54	169,891.56	572,202.32	690,988.44
CC-TB	248,861.17	180,557.71	571,268.39	679,382.06

CHNLSAASIA

	CHN	SSA	LSA	ASIA
CC-NT	248,784.22	297,034.93	570,856.27	682,888.73
CC-ET	250,603.87	292,776.78	574,151.53	680,868.42
R&D	249,576.95	281,794.94	572,836.81	679,960.95
CC-R&D	252,083.59	273,208.70	576,002.04	682,044.46
TB	247,634.07	217,428.03	570,682.72	680,929.84
CC-TB	248,786.16	195,720.69	571,304.87	679,132.51

CHNSSALSA

	CHN	SSA	LSA	ASIA
CC-NT	249,297.18	172,056.70	594,207.85	684,285.24
CC-ET	249,794.55	181,874.67	595,433.62	685,751.56
R&D	249,447.41	180,072.04	594,849.92	685,053.31
CC-R&D	250,040.74	179,902.83	596,309.18	686,938.59
TB	247,857.87	172,571.04	568,773.03	686,310.16
CC-TB	249,794.86	174,684.93	592,923.71	680,505.08

SSACHNASIA

	CHN	SSA	LSA	ASIA
CC-NT	249,040.70	170,464.58	593,040.45	682,888.73
CC-ET	242,167.06	169,936.32	556,443.91	681,422.41
R&D	242,077.47	166,614.56	554,243.22	678,323.36
CC-R&D	254,063.63	169,625.91	583,803.19	679,879.52
TB	247,211.08	169,756.57	570,496.92	709,282.59
CC-TB	248,453.17	172,923.92	571,273.85	677,779.58

SSALSAASIA

	CHN	SSA	LSA	ASIA
CC-NT	280,587.57	170,224.58	572,027.21	680,579.75
CC-ET	281,126.17	182,225.67	581,090.51	685,751.56
R&D	280,869.69	176,774.91	576,210.96	681,218.84
CC-R&D	281,485.24	179,297.70	583,790.08	686,938.59
TB	237,504.08	177,448.65	579,370.29	686,030.86
CC-TB	236,621.18	182,981.71	575,354.30	687,985.96

SSAASIA

	CHN	SSA	LSA	ASIA
CC-NT	258,530.41	167,586.56	589,538.24	685,681.74
CC-ET	259,069.01	172,074.04	628,510.53	687,148.06
R&D	258,812.54	173,804.91	626,211.43	681,894.02
CC-R&D	259,428.08	178,171.70	624,792.18	683,646.73
TB	246,513.10	172,074.04	570,672.94	682,576.61
CC-TB	247,735.05	192,261.22	569,703.85	689,731.59

LSAASIA

	CHN	SSA	LSA	ASIA
CC-NT	258,530.41	301,964.04	570,196.25	683,586.98
CC-ET	286,127.43	304,925.76	579,210.53	685,053.31
R&D	279,447.08	282,807.09	573,252.98	680,158.86
CC-R&D	275,259.52	261,171.70	575,690.08	682,057.72
TB	246,306.21	170,967.59	572,902.42	685,053.31
CC-TB	247,059.16	168,011.27	576,976.33	686,100.69

SSALSA

	CHN	SSA	LSA	ASIA
CC-NT	269,164.93	172,403.58	569,108.70	680,799.10
CC-ET	284,166.43	172,136.32	571,421.03	680,903.61
R&D	284,744.06	172,072.43	570,243.23	709,492.07
CC-R&D	281,183.63	172,299.26	573,303.62	711,377.34
TB	235,306.19	167,997.55	568,770.92	680,928.28
CC-TB	234,972.18	169,989.23	571,727.25	678,845.25

CHNSSA

	CHN	SSA	LSA	ASIA
CC-NT	246,895.47	167,588.58	586,619.74	681,008.10
CC-ET	247,430.56	166,477.43	662,543.52	680,032.61
R&D	246,174.58	166,581.23	661,826.83	679,259.36
CC-R&D	252,423.50	172,335.22	663,020.06	681,846.13
TB	249,240.56	171,995.28	569,672.92	680,666.04
CC-TB	250,400.04	172,923.92	564,977.87	679,334.14

CHNASIA

	CHN	SSA	LSA	ASIA
CC-NT	243,893.47	330,967.81	658,658.73	684,285.24
CC-ET	250,092.26	332,566.55	656,884.51	685,751.56
R&D	249,835.07	333,401.68	661,599.79	680,502.84
CC-R&D	250,962.64	332,997.47	663,002.18	682,321.00
TB	248,673.54	184,671.03	570,559.92	685,751.56
CC-TB	255,081.64	169,778.25	570,606.90	679,517.46

CHNLSA

	CHN	SSA	LSA	ASIA
CC-NT	245,826.58	332,550.81	573,194.61	680,292.86
CC-ET	249,167.08	331,605.55	571,421.05	680,165.56
R&D	248,338.58	333,040.68	567,560.35	679,467.31
CC-R&D	250,390.63	333,324.47	574,387.06	681,352.58
TB	247,332.89	161,967.57	570,770.92	679,257.83
CC-TB	248,749.18	151,978.23	571,439.85	679,257.83

Table 1.8. Payoffs in Millions of Dollars of Different Country Climate Blocs by 2010 (Cumulated discounted consumption.)

NO COOPERATION

	CHN	USA	REC	LSA
CC-NT	252,887.88	3,375,625.96	330,401.47	575,529.41
CC-AT	253,426.48	3,382,918.98	331,100.20	575,237.56
TB	253,067.41	3,378,404.25	330,601.10	575,471.04
CC-TB	253,426.48	3,382,918.98	331,100.20	574,245.27

FULL COOPERATION

	CHN	USA	REC	LSA
CC-NT	251,605.49	3,379,098.82	331,399.66	574,945.71
CC-AT	253,759.91	3,388,822.85	346,372.53	583,993.08
TB	254,144.62	3,388,822.85	346,305.99	584,051.45
CC-TB	251,938.91	3,382,571.69	345,773.62	583,000.79

RECCHNLSA

	CHN	USA	REC	LSA
CC-NT	253,400.84	3,538,850.67	332,065.12	570,276.10
CC-AT	253,939.44	3,546,143.69	332,763.85	571,501.87
TB	253,811.20	3,536,766.95	332,697.31	571,618.61
CC-TB	254,631.93	3,537,114.23	333,595.68	572,844.39

USACHNLSA

	CHN	USA	REC	LSA
CC-NT	254,426.75	3,330,478.70	332,065.12	573,194.61
CC-AT	254,965.36	3,344,717.45	332,763.85	574,420.38
TB	254,914.06	3,345,064.73	331,100.20	574,887.34
CC-TB	255,606.55	3,353,746.90	331,333.11	575,996.37

CHNUSAREC

	CHN	USA	REC	LSA
CC-NT	253,400.84	3,406,881.75	337,721.54	592,456.75
CC-AT	253,939.44	3,417,647.64	338,420.27	591,230.98
TB	254,785.82	3,432,060.03	349,999.30	581,249.68
CC-TB	255,273.13	3,440,742.20	350,897.67	582,008.50

RECUSALSA

	CHN	USA	REC	LSA
CC-NT	272,123.77	3,410,354.62	332,065.12	576,113.11
CC-AT	272,662.38	3,417,647.64	332,763.85	577,338.89
TB	272,303.31	3,416,258.49	332,697.31	577,572.37
CC-TB	271,533.87	3,429,455.38	333,961.68	579,206.73

USALSA

	CHN	USA	REC	LSA
CC-NT	258,273.93	3,399,936.02	334,394.23	577,280.52
CC-AT	258,812.54	3,407,229.04	335,092.97	578,506.29
TB	258,453.47	3,407,229.04	334,593.87	578,623.03
CC-TB	258,479.11	3,415,563.92	334,194.59	580,665.98

RECLSA

	CHN	USA	REC	LSA
CC-NT	258,786.89	3,538,850.67	331,066.93	572,610.91
CC-AT	259,325.49	3,546,143.69	331,765.66	573,836.68
TB	258,966.42	3,541,628.96	331,732.39	573,836.68
CC-TB	258,735.59	3,533,641.37	332,597.49	574,712.23

USAREC

	CHN	USA	REC	LSA
CC-NT	256,222.10	3,389,517.42	349,367.11	580,782.72
CC-AT	256,760.71	3,396,810.44	350,065.84	582,008.50
TB	256,401.64	3,397,505.01	349,999.30	581,249.68
CC-TB	256,222.10	3,409,312.76	350,897.67	582,008.50

CHNUSA

	CHN	USA	REC	LSA
CC-NT	254,170.27	3,425,114.30	332,522.62	586,619.74
CC-AT	254,708.88	3,432,407.32	333,221.36	587,845.51
TB	254,785.82	3,432,060.03	332,722.26	587,086.70
CC-TB	255,273.13	3,440,742.20	332,389.53	587,845.51

CHNLSA

	CHN	USA	REC	LSA
CC-NT	252,374.92	3,535,377.80	334,394.23	455,286.96
CC-AT	252,913.53	3,542,670.82	335,092.97	456,512.73
TB	252,913.53	3,538,156.09	334,593.87	456,512.73
CC-TB	253,503.43	3,531,210.36	333,928.41	457,259.87

CHNREC

	CHN	USA	REC	LSA
CC-NT	253,913.79	3,545,796.40	331,690.80	588,370.84
CC-AT	254,452.40	3,553,089.42	332,389.53	589,596.61
TB	254,452.40	3,548,574.69	332,489.35	588,837.80
CC-TB	254,991.00	3,541,281.67	333,221.36	588,337.80