STELLINGEN

1. A high participation rate in an international environmental agreement does not necessarily imply its success, as frequently publicized by politicians and the media. (*this thesis*)

2. Contrary to intuition, lobby contributions by industry are compatible with participation in an international climate agreement. (*this thesis*)

3. Strategic voting undermines the success of an international environmental agreement, but not because voters elect a 'less green' government but because strategic voting makes the agreement unstable. (*this thesis*)

4. The main (but often forgotten) purpose of science is to enhance the well-being of humans, which entails also to be in equilibrium with the environment.

5. A change in the attitude towards the environment needs to begin in childhood; this should be the base for the scientists of tomorrow.

6. *Quod me alit me extinguit* – 'What lights me extinguishes me' (*Shakespeare, Pericles*); this summarizes perfectly the experience of doing a Ph.D.

7. The current European immigration policy based on the oxymoron of 'integration without assimilation' is bound to fail.

Stellingen behorende bij het proefschrift:

On the political economy of international climate agreements

Juan Carlos Altamirano Cabrera

Wageningen, 23 February 2007

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Para mi Madre y Erika,
mi estrella del Norte y mi estrella del Sur

Preface

This thesis is the culmination of a process that began seven years ago when I first left Mexico. Now it is time to acknowledge and thank all the people that have helped me through the endeavor of doing a Ph.D. First of all, I would like to thank my supervisors Ekko van Ierland, Michael Finus, Hans-Peter Weikard and Rob Dellink. Ekko thank you for your guidance throughout all these year, in particular for showing me the way to be a researcher. Michael, thanks for all your support, the long discussions over the phone and for becoming more than my supervisor. Hans-Peter, with whom I spend many, many hours of valuable discussions, thanks for your patience and for being there whenever I have a question. Rob thanks for sharing your ideas and your expertise in modeling, it really helped me a lot.

The process of doing a Ph.D. is definitely a solitary task. Thus, a comfortable working environment becomes crucial for achieving good results. I would like to thank all my colleagues at the Environmental Economics and Natural Resources Group at Wageningen. Thank you Ada, I really enjoyed being your roommate. Erik, you are very good colleague and a very kind person, thanks for all the help! Cheers Kelly for being the South African spark of the group. Thanks Morteeza, life is always better with an Iranian joke a day. Thanks to Wil and Sjoukje for being so helpful. Also thanks to Xueqin, Mikel, Marcus and all the other past members of the group with whom I share good moments. Gracias Elena for all your help with MATLAB!

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Finally, words cannot express my gratitude to those that guide me not only through my Ph.D. but through my life. Thank you Mum for being the light that lights my steps and thank you Erika for choosing me to share your life and for being the sunshine throughout my cloudy days.

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Chapter 1. Introduction

1.1. Background

Policies on climate change have become key elements on the political agendas of governments worldwide. Climate change represents a major challenge for international cooperation. Sovereign countries need to discuss and design a common policy to tackle this challenge. As Wagner (2001) explains, cooperation among sovereign countries often takes the form of international environmental agreements (IEAs). These agreements recognize that, for many countries, free-riding would be more attractive than cooperation considering that countries often act following self-interest. Hence, the success of an international environmental agreement depends on its ability to strategically manipulate the incentives of countries to cooperate in order to protect the environment (Barrett 2003).

The array of actions to deal with climate change can be broadly categorized in two: adaptation measures and mitigation measures. Adaptation relates to those measures taken in order to adapt to the new conditions posed by a changing climate. These measures range from changing crop-planting times, to dyke building, to wearing lighter clothes, to hiring insurance (Fankhauser, 1998). Studies on adaptation measures recognize that for individual regions climate change may be beneficial (see, among others, the overview paper of Tol et al., 1999; Mendelsohn, 2000; and Tol, 2002a, 2002b). Mitigation measures focus on reducing emissions of greenhouse gases (GHGs) to the atmosphere. Studies on mitigation measures analyze the tradeoffs between damages due to climate change and mitigation costs (see the overview of Weyant, 1999 and 2004). These measures differ, thus, in that adaptation to climate change generates local benefits, whereas mitigation generates global benefits through global externalities. In a first-best world, governments would need to balance costs and benefits from mitigation with the benefits and costs from adaptation (Fankhauser et al., 1999; Mendelsohn, 2000). This thesis focuses on mitigation measures for climate change, namely abatement of GHGs. However, I recognize that adaptation plays an important role on the incentives for cooperation. For instance, countries with low adaptation costs might have strong incentives to free-ride in the negotiations on mitigations targets.

The mitigation approach recognizes that in order to effectively address climate change, global cooperation is needed. Cooperation would enable a significant reduction of the emission (i.e. abatement) of GHGs. The benefits from mitigation measures constitute a pure global public good. Firstly, these benefits are non-excludable. Benefits from any level of abatement of GHGs are global, irrespective of where abatement takes place. Secondly, benefits are non-

rival. This means that the individual appropriation of these benefits does not decrease the amount that is available for others. The public good nature of the benefits from abatement results in strong free-rider incentives. Some countries can enjoy the benefits of having a lower global level of GHGs even if they are not involved in any abatement action. This becomes an important obstacle for cooperation within an international climate agreement (ICA).

The remaining parts of the discussion are organized in seven sections. Section 1.2 gives an overview of two current approaches to mitigate climate change. Section 1.3 describes briefly the environmental implications of climate change. Section 1.4 presents an overview of the policy problems posed by climate change. Section 1.5 presents a short overview of the literature used for the analysis of this thesis. Section 1.6 presents the objective, research questions and new insights. Section 1.6 describes the methodology used throughout this thesis. Finally, Section 1.7 presents the overall organization of the remaining chapters of the thesis.

1.2. Current policies to tackle climate change

Currently, there are two types of policies on cooperation to tackle climate change: (i) diffusion and promotion of technology and (ii) definition of emission reduction targets. Although the ultimate goal of both approaches is to reduce GHGs emissions, the means to attain this are different. The technological diffusion and promotion approach focuses on efforts to tackle climate change that are not codified within a binding agreement. This approach highlights the relevance of promoting and diffusing novel technologies as a mean to reduce the costs of abating GHGs emissions. The main example of this approach is the Asia-Pacific Partnership on Clean Development and Climate (also known as AP6). The AP6 was established on 12 January 2006 by Australia, Japan, China, India, South Korea and the USA under a non-legally binding Charter. This Charter states that the purpose of the Partnership is to "create a voluntary, non legally-binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging and longer term cost-effective, cleaner, more efficient technologies and practices among the Partners" (Australian Government, Department of Foreign Affairs and Trade, 2006). To attain its objective, the AP6 has set up public-private sector task forces in eight common areas: cleaner fossil energy, renewable energy and distributed generation, power generation and transmission, steel, aluminum, cement, coal mining, and building and appliances.

The emission reduction targets approach set limits to emissions of GHGs through legally binding commitments codified in an ICA. The Kyoto Protocol is the most prominent example of this approach. In order to tackle climate change, the Kyoto Protocol was signed under the

UN Framework Convention on Climate Change (UNFCCC) at the third session of the Conference of the Parties in Kyoto, Japan, on 11 December 1997. The Protocol aims at a reduction of at least 5 percent below 1990 levels of emissions of greenhouse gases from Annex I Parties[1] in the commitment period 2008-2012 (UNFCCC 1997). The Protocol was subject to ratification, acceptance, approval and accession by its signatories. It entered into force on February 16th, 2005, after the ratification of at least 55 Parties to the Convention, incorporating Annex I Parties which accounted for at least 55 % of the total CO_2 emissions for 1990. Under the Protocol most of the abatement burden falls on the developed countries and economies in transition, whereas developing countries do not accept any binding abatement targets. As of 18 January 2006, 158 states and regional economic integration organizations have deposited instruments of ratifications, accessions, approvals or acceptances to the Protocol. Currently, the total percentage of CO_2 emissions from those Annex I countries that have ratified the Protocol is 61.6% (UNFCCC 2006).[2]

The Kyoto Protocol has two distinctive characteristics: (i) it sets high short-term abatement targets and (ii) it stresses that developed countries have the full responsibility of tackling climate change (Barrett and Stavins, 2003). These characteristics have an important effect on the decisions of countries to join and ratify the agreement. The Protocol took a long time to enter into force because several major players, like the USA, the European Union, and Russia could not agree on important details of the design of the treaty. In particular, these players could not reach a consensus on the abatement obligations for its members. Developing countries, for instance, do not have any abatement obligation. The USA has many objections in this respect and eventually these led them to leave the agreement and to pursue an alternative climate change policy that finally resulted in the AP6 Partnership.

Even if strategies such as the AP6 Partnership or the Kyoto Protocol are successful on attaining their objective, they can only be regarded as a first step to tackle climate change. There are several key issues to consider for the future success and design of policies to deal with climate change (Nordhaus and Boyer, 2000). These issues include: How desirable and successful in terms of implementation is the mechanism of reducing (stabilizing) emissions? Are the emission reductions sufficient or excessive? Are there other mechanisms that may help to have a more comprehensive global policy for climate change? What is the role of technological innovation? What is the level of political acceptance of such policies given the

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[1] Annex I Parties include the 15 state members of the European Union as of 1995, plus Australia, Bulgaria, Canada, Croatia, Czech Republic, Estonia, Hungary, Iceland, Japan, Latvia, Liechtenstein, Lithuania, Monaco, New Zealand, Norway, Poland, Rumania, Russia, Slovakia, Slovenia, Switzerland, the Ukraine, and the USA.

[2] For a good overview of the process, the evolution and the main caveats of the Kyoto Protocol see Barrett (2003), Chapter 15.

huge spectrum of national political regimes? The reduction in GHGs that would be achieved by the Kyoto Protocol and the AP6 Partnership may not be sufficient to tackle climate change, considering that CO_2 emissions will continue to grow in the developing countries. Even if the level of emissions is stabilized, it is very likely that the concentration of these gases in the atmosphere would remain at high levels (or even) increase and this will affect Earth's climate for a long time (IPCC, 2001). This may cause that the surface temperature would continue to rise causing long-lasting, irreversible effects (e.g. melting of polar ice sheets). Consequently, it is important to design climate policies which become effective not only in the short-run but also in the mid- and long-run.

1.3. Environmental problem

According to the International Panel on Climate Change (IPCC), global climate has changed as a result of industrialization and the corresponding increase in the economic activities (IPCC 2001). These processes have resulted in a substantial increase in the emission and concentration of GHGs above their pre-industrial levels. GHGs include, mainly, carbon dioxide, methane and nitrous oxide. GHGs are emitted by activities such as combustion of fossil fuels, agriculture and changes in land use. Though natural emission of GHGs (e.g. from volcano eruptions and marshes) exceed man-made emissions, the latter clearly pose an extra factor of pressure upon the ecological systems. Furthermore, high concentrations of these gases are likely to cause an increase in the mean world temperature – a phenomenon commonly known as global warming – and important changes in the ecological systems of the world (IPCC 2001). These changes include, among others, a rise in the global mean level of the sea, a reduction of snow and ice covers, an important retreat of glaciers, and a change in the pattern of the precipitations. I present in Table 1.1 some of the changes in the climatic system of the Earth during the last century. Furthermore, these changes would have important impacts not only on the global ecosystem but also on the social and economic systems. I present a selection of these impacts in Table 1.2.

Table 1.1 Selected impacts on Earth's atmosphere, climate and biophysical systems during the 20th century

Indicator	Observed changes
Global mean surface temperature	Increased by 0.6 ± 0.2 ºC
Heavy precipitations events	Increased at mid- and high-northern latitudes
Frequency and severity of drought	Increased summer drying and drought incidence in parts of Asia and Africa
Global mean sea level	Increased at an average annual rate of 1-2 mm
Arctic sea-ice extent and thickness	Thinned by 40% in recent decades in late summer to early autumn and decrease in extent by 10-15% since the 1950s in spring and summer
Permafrost	Thawed, warmed, and degraded in parts of polar, sub-polar, and mountainous regions
El Niño events	Became more frequent, persistent, and intense during the last 20 years
Coral reef bleaching	Increased frequency

Source: adapted from Table SPM-1 from IPCC (2001), page 5.

Climate change also affects negatively the social and economic systems worldwide. In terms of human health, climate change has a direct effect through increased heat stress, as well as loss of lives due to flood and storms. Indirectly, it can affect human health through changes in the disease vectors (e.g. proliferation of mosquitoes), an increase of water borne pathogens, changes in the quality of air and water, and availability of food. Moreover, there will be an increase in the risks of coastal floods and erosion that would cause the displacement of a large part of the population that inhabits small islands and low-lying coastal zones. However, not everything is negative. There are also positive effects from climate change – see Table 1.2. There will be increased crop yield in some regions caused by the increase in temperature and higher precipitation, there will be fewer deaths related to cold temperatures, less demand of energy for heating purposes and in particular a higher level of human amenity and human recreation due to higher temperatures and milder winters (Nordhaus and Boyer, 2000; Tol, 2002a and 2002b).

Table 1.2 Selected expected impacts from climate variability

Indicator	Observed changes
Higher maximum temperatures, more hot days and heat waves	Increased incidence of death and illnesses in older age groups
	Increased heat stress in livestock and wildlife
	Shift in tourist destinations
	Increase risk of damage to crops
	Increase in energy demand for cooling
Increase in minimum temperatures, fewer cold, frost days and cold waves	Decreased cold-related human morbidity and mortality
	Decreased risk of damage to crops
	Reduced heating demand
More intense precipitation	Increased flood, landslide, avalanche and mudslide damages
	Increased soil erosion
	Increase on the recharge of some floodplains aquifers
Increased summer drying and associated risk of drought	Decrease crop yields
	Decrease in water quantity and quality
	Increased risk of forest fires
Increase in tropical cyclone peaks wind and precipitation intensities	Increased risk to human life and of epidemics infectious diseases
	Increased coastal erosion, damage to coast ecosystems
Intensified droughts and floods associated with El Niño events	Decreased agricultural and rangeland productivity
	Decreased hydro-power potential

Source: adapted from Table SPM-2 from IPCC (2001), page 6.

Table 1.2 offers a mixed picture on the effects of climate change. However, on a global scale, it is likely that the positive effects would have a lower impact than the negative effects. Furthermore, there is a considerable consensus in the international policy arena that negative effects are going to be evident in the near future (IPCC, 2001). Then, the international community clearly pushes to take actions to address climate change.

1.4. Policy problem

It is globally recognized that an important action to tackle climate change is the reduction of emissions of GHGs. A significant reduction of these gases is only possible through international cooperation. However, international cooperation is not that easy. Countries are

sovereign and often act following self-interest. Furthermore, there are large barriers of technical, economic, political, cultural, social, behavioral and institutional nature that makes cooperation difficult (IPCC, 2001; Bargiacchi, 2005). IEAs are one of the instruments to codify the efforts of cooperation to face climate change. An IEA has to recognize that sovereignty and self-interest play a decisive role for signing, ratifying and complying with the agreement (Barrett, 2003, Chapter 1; Wagner, 2001). An IEA, then, becomes a strategic instrument for shaping environmental policy and it need to be designed to foster cooperation. The design of such an agreement is a delicate task facing two problems at two levels. Firstly, at the international level, an IEA should ensure self-enforceability. Secondly, at the national level, an agreement should be politically feasible.

The first design problem, self-enforceability, is related to the fact that countries are sovereign and often are driven by self-interest. An IEA, to be effective, must be *self-enforcing* (Barrett 2003, Chapters 1 and 5). There is no world government or supranational authority that is in charge of the enforcement of an IEA. Furthermore, countries cannot be forced to sign an agreement or to remain in it. Thus, an IEA should make it attractive for countries to sign and comply with its terms (Barrett, 1994; Wagner, 2001). Climate change, thus, poses a different policy problem than national environmental problems. At the national level, there are institutions built explicitly to ensure the compliance of environmental policies. The government is in charge of enforcing the laws. This cannot be done at the international level. It will be a clear interference with the principle of sovereignty among nations. However, policy-makers have more tools to foster self-enforceability, for instance: (i) the inclusion of minimum participation clauses (such as the Kyoto Protocol), (ii) contemplating if the treaty should be open to all or should be of exclusive nature, (iii) considering less ambitious targets or a different distribution of abatement burdens, and (iv) the use of incentives, such as side payments through permit trading.

The second design problem is related to the fact that the interests of a country are represented at international negotiations by its government. Governments, nevertheless, do not have a fixed set of preferences or reflect entirely the concerns of their citizens (Persson and Tabellini, 2000; Chapter 1; Mueller, 2003, Chapter 20). The position of governments is influenced quite often by domestic political negotiations. In these negotiations, governments interact with other political actors such as ministries, political pressure groups (or lobbies) and in ultimate terms with the electorate. The design of an IEA should consider this fact and thus try to be politically feasible at the national level. Political economy scholars have recognized the challenge that international policy-makers face in order to implement treaties that are acceptable for the national political actors. They recognize that governments do not design and implement policies (including environmental) with the only purpose of enhancing the welfare of their citizens as a whole (Persson and Tabellini, 2000; Chapter 1; Mueller,

2003, Chapter 20). Politicians recognize the effect of their decisions on national political actors. These actors influence the policy decisions (including political positions in international negotiations) of their representatives. They can influence policy decisions indirectly as in the case of the lobbies or directly through the electoral process.

1.5. Short overview of literature

I make use of three strands of the literature to analyze the impact of design characteristics and political factors on an ICA: (i) cost-benefit modeling, (ii) game theory, and (iii) political economy. The first strand includes studies on IEAs from a cost-benefit perspective (e.g. Nordhaus, 1994; Nordhaus and Yang, 1996; Manne and Richels, 1997; and Tol, 1999; and the overview articles of Weyant, 1999, 2004, among others). These studies are mainly devoted to assess the abatement costs and benefits (reduced environmental damages) of various abatement measures. This analysis is useful in answering questions such as, which abatement level would be optimal from a global point of view? How should abatement burdens be allocated to achieve a certain abatement target at the least cost? What are the economic impacts of different abatement measures? Who are the winners and losers under a particular abatement scheme? This literature studies the tradeoffs between damages due climate change and abatement costs from reducing emissions of GHGs. In this strand, it is assumed that a country chooses the efficient abatement level – i.e. the one that maximizes the net benefits or minimizes total abatement costs – as the policy to implement.

The second strand includes game theoretical studies (e.g. Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994, 1997a, 1997b, 2002 and 2003; Hoel and Schneider, 1997; Rubio and Ulph, 2003; Rubio and Casino, 2005; Eyckmans and Finus, 2006; among others) that analyze the incentive structure of countries signing an IEA. Most of these studies focus on whether or not an IEA is stable. An agreement is stable if it internally and externally stable (d'Aspremont et al., 1983). Internal stability means that there is no country that is better off by leaving the agreement. External stability means that there is no country that is better off by joining the agreement. Furthermore, these studies are devoted to answer questions such as, which conditions allow that an IEA is signed and ratified by a large number of countries? On which abatement targets would countries agree? How many and which countries will accede to an IEA? Would an IEA be stable? The general results from this literature – see Wagner, 2001; Finus 2003 – are that (i) full cooperation (i.e. that all countries participate and remain in an agreement) is difficult to attain, thus, in many cases only IEAs that comprise few countries are stable; (ii) that the larger are the gains of cooperation, the stronger are the free-rider incentives, and that stable IEAs can reap only part of these gains; and (iii) that the size of stable agreements depends on how the net benefits from abatement are distributed. These studies, thus, highlight the role of the design of a treaty. The success of an IEA depends to a

large extent on how the terms of an agreement make that a large number of countries sign and have incentives to comply with its terms.

The third strand of literature focuses on the influence of national political actors and national electoral processes on international policy-making. These studies recognize that governments often have interests not aligned with those of their domestic constituents (see Persson and Tabellini 2000, Chapter 1; Mueller, 2003, Chapter 20). Moreover, most political economy scholars explicitly consider that the incentives embodied in elections and other political control systems may ultimately determine what a government can and will do at the international negotiation table. Studies on the political economy of environmental policy (e.g. Fredriksson, 1997; Aidt, 1998; Conconi, 2003; among others) answer questions such as, do governments care about the political pressure groups in their environmental decision-making process? Does the general electorate influence the decisions at the international policy arena? These questions (on the effect of lobby groups and strategic delegation) have not been examined in detail within the context of formation of IEAs – with exception of Haffoudhi (2005a and 2005b) and Buchholz et al. (2005).

These three strands of the literature are not completely unrelated. There are studies that combine cost-benefit modeling with a political economy focus (e.g. Böhringer and Vogt, 2004) or cost-benefit modeling with game theory (e.g. Bosello et al. 2003; Eyckmans and Finus, 2006). However, this thesis is the first analysis that combines the cost-benefit, game theoretical and political economy strands of the literature for the analysis of ICAs. I use the STAbility of COalitions (STACO) model (Dellink et al., 2004; Finus et al., 2006) to attain this objective and answer the research questions that will be stated in the next section. STACO is model that combines a game theoretical module with an empirical module – see the details about the model in Section 1.7. For the game theoretical part, the model assumes membership in ICAs as a process of coalition formation. The empirical module considers a benefit function and an abatement cost function for twelve heterogeneous world-regions. STACO then calculates the payoffs and abatement levels for all the resulting coalitions (agreements) that can be formed in the game. Then, the payoffs are used to test for stability of these agreements. I extend the specification of STACO to test the impact of the design characteristics and the implication of political economy aspects on the stability and effectiveness (in terms of net benefits and abatement levels) of an agreement. Henceforth, in this thesis, I use indistinctively the terms effectiveness and success as the abilities that an IEA-ICA has to actually reduce GHGs and consequently increase the payoffs of the countries.

1.6. Objective and research questions

This thesis analyzes the impact of design characteristics and national political actors on the potential stability and success of ICAs. Design characteristics refer to how an agreement is tailored in terms of membership, side payments and abatement obligations (among other issues). National political actors are lobbies, general electorate and other national institutions that could have an impact on the decisions of the government at the international negotiations. My analysis focuses on the conditions under which an ICA can be expected of being self-enforcing, politically feasible and effective in terms of abatement. Thus, this thesis contributes to the literature on the stability and effectiveness ICAs by linking the impact of design characteristics with the relevance of the national political actors. The objective of this thesis leads to the following *five research questions*:

i. How do membership rules affect the stability and success of an international climate agreement? What is the role of decision rules such as unanimity and simple majority voting in the context of an exclusive membership climate agreement?

   Intuition and the literature on public goods suggest that global welfare increases with participation in an agreement. Hence, any restriction on membership would hamper the effectiveness of ICAs. However, these statements do not consider that ICAs have to be self-enforcing and that restricting membership may help to increase stability and the effectiveness in these agreements. The contribution of this thesis in this respect is to consider the effect, in terms of participation and abatements levels, of restricting membership on a treaty. I analyze the case where signatories vote for the accession of new members. I focus on two decision rules, unanimity and simple majority voting.

ii. How do different initial allocations of emission permits affect the stability and effectiveness of an ICA? What type of criteria should be used on the initial allocation of permits in order to increase the effectiveness of an ICA?

   Most studies on ICAs have focused on the impact of different allocation of emissions permits on net abatement costs. However, they do not consider that these agreements have to be self-enforcing. In this thesis, I extend the analysis of ICAs to consider the effect of different permit allocation schemes in the stability and effectiveness of an agreement. Furthermore, I analyze the impact of two different criteria of allocating emission permits: equitable and based on the status quo.

iii. Does a uniform distribution (in relative terms) of abatement targets lead to more successful ICAs? Is it possible to improve the effectiveness of ICAs through considering less ambitious (though non-efficient) abatement targets?

Many international agreements on transboundary pollutants (such as the Montreal Protocol and the Kyoto Protocol) specify their abatement obligations as uniform emission reduction (or quotas). Abatement levels, thus, do not entirely recognize that countries face different marginal abatement costs. Quotas are, thus, inherently inefficient. A possible rationale for this policy is that quotas may offer a more even distribution of abatement burdens. Hence, countries are more likely to sign and remain in the agreement under a quota regime. Even though quotas are inefficient this may be overcompensated by an increase in the participation in the agreement. In this thesis, I extend the analysis of ICAs to include the effect of three uniform quotas. These quotas differ in the assumptions on how coalition members agree on the level of the uniform emissions reductions.

iv. Do national pressure groups (lobbies) foster or hinder cooperation in an ICA?

There is evidence that political pressure groups affect governments' decision about participation and the level of policy implemented in an international agreement. This fact is missing in most part of the literature on stability of ICAs. Thus, I analyze in this thesis the potential impact of lobby groups on government's decisions about participation and level of policy agreed when they sign an ICA. Furthermore, I analyze some effects of lobbying on the size and stability of the resulting agreement within a specific setting on their interaction with governments.

v. Does strategic behavior of voters result in less effective ICAs?

A political economy analysis of an ICA needs to recognize that voters delegate their decision power to their representatives at international negotiation tables. The representatives (governments) then negotiate the terms, conditions and obligations that their countries would follow when joining an international agreement. The strategic delegation framework has been applied to analyze the effectiveness of IEAs on transboundary pollutants but under some restrictive assumptions (e.g. assuming symmetric countries). Furthermore these studies do not test for stability of the agreement. I extend this literature by studying the effect

of strategic delegation on the effectiveness and stability of an ICA for asymmetric countries.

1.7. Methodology

In the game theoretical literature of IEAs (see Chapter 2), it is often assumed, for analytical convenience, that counties are symmetric – i.e. that all countries have the same structure of costs and benefits. This analysis has provided many valuable insights and general theoretical results on the analysis of formation and stability of IEAs. However, in reality, countries differ in their form of assessing the benefits and costs from abatement of GHGs. General theoretical results considering asymmetric countries are difficult to obtain. Hence, simulations are needed. However, the complexity of the analysis through simulations increases with the number of countries considered and with the level of the refinement of their distinctive characteristics. Hence, in order to model heterogeneity, authors often consider only two asymmetric countries (e.g. Endres and Finus 2002) or a stylized type of asymmetry among the countries (e.g. Finus and Rundshagen 1998a).

In this thesis, I use the STACO model to attain the objective and answer the research questions posed in section 1.4. STACO is a numerical simulation model for twelve heterogeneous world regions based on an empirical calibration (for details on the calibration of the model see Chapter 3 and Dellink et al. 2004).[3] The model, firstly, recognizes that the framework must be simple enough to be tractable from a game theoretical perspective. Secondly, it reflects important results and features from more detailed climate models – such as the DICE model (Nordhaus, 1994) – in terms of development of global emissions and concentrations of GHGs. Thirdly, it considers a time horizon that is relevant for climate change analysis. Fourthly, it recognizes that there should be a sufficient number of participants in order to make the analysis attractive in a reasonable time of calculation.

STACO combines a game theoretical module with an empirical module. It analyzes ICAs as a coalition formation process among heterogeneous world-regions. Regions gather to sign an ICA in order to reduce their emissions of GHGs. An agreement is thus a coalition of participating countries. I further assume what I call a 'cartel-formation' framework, where only one coalition (agreement) can be formed at a time. The game theoretical module considers coalition formation as a two-stage game. At the first stage, regions decide on their

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[3] STACO was developed by the Environmental Economics and Natural Resources Group (Juan Carlos Altamirano Cabrera, Rob Dellink, Ekko van Ierland, Arjan Ruijs and Hans-Peter Weikard) in collaboration with the Operations Research Group (Eligius Hendrix, Niels Olieman and Elena Sáiz) of Wageningen University, The Netherlands, and Michael Finus from Hagen University, Germany.

membership in a coalition; at the second stage, regions choose their abatement strategies. At the first stage, it is assumed that regions can choose between two membership strategies: to sign an ICA or not. Those who sign the ICA become signatories of a coalition and those who do not sign become singletons. At the second stage, abatement levels are chosen considering a payoff function calibrated according to the empirical module. The empirical module considers, in the tradition of cost-benefit analyses, that regions base their membership decisions on a net benefit function. This function comprises *benefits* of abatement (in the form of avoided damages of climate change) and *costs* of abatement. The empirical module provides estimates for benefit and costs of twelve world-regions and captures long-run effects of GHGs accumulation (focusing on CO_2) over a period of 100 years. It assumes stationary abatement strategies for game theoretical tractability. I present in chapter 3 a detailed explanation of the calibration of the benefit and abatement cost functions. Furthermore, STACO helps me to determine the number and size of stable agreements. To test for stability I use the concept of internal and external stability introduced by d'Aspremont et al. (1983). [4]

I modify STACO to include political economy aspects into the analysis. The modifications are focused on four categories: changes in membership, changes in the elements of the payoff function, changes in the way of choosing the abatement level for coalition members, and the inclusion of a median voter perspective. Firstly, I modify the model to consider an exclusive membership agreement, where members decide about the accession of new signatories. Secondly, I modify the model to include the outlay or gains of permit trading in the payoff function and to include the contributions from lobby groups. Thirdly, I modify the model such as abatement decisions consider that a uniform abatement quota is implemented among coalition members. Fourthly, I include in the payoff function of STACO (and other functional specifications) a term reflecting the different valuations of the benefits from abatement depending of the type of the government that is elected. The elected government, in turn, is the one that maximizes the payoff of the median voter.

The version of the STACO model that I use throughout this thesis has been developed in the context of a larger project within Wageningen University, The Netherlands – see footnote 3. Recently, the research team has refined the model to consider more 'sophisticated' modeling issues than those presented in this thesis. The simplicity of the version of STACO that I use, allows me to concentrate on the underlying nature of the incentives to participate in an ICA and the effect that national political actors may have on it. The research questions, the results, the conclusions and the eventual policy recommendations of this thesis have to be put in the context of this version of the model and its caveats. In particular, there are three caveats to

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[4] I use the software package MATLAB to compute the abatement levels, payoffs, number and size of stable coalitions. However, other applications of the STACO model, e.g. within a stochastic framework, are tested using FORTRAN (see Dellink et al. 2005).

consider for the version of the STACO model that is used in this thesis. Firstly, the cost-benefit approach followed to assess benefits and costs assumes that the environmental effects of emissions and concentrations of GHGs follow a smooth trend. Hence, STACO does not consider any threshold effects – i.e. that at a certain level environmental damages may become irreversible because they are extremely costly or physically impossible to repair. Secondly, the model considers a constant abatement path. However, STACO has been refined to consider dynamic aspects in terms of calculating dynamic optimal paths of abatement (STACO version 2.1) – see Nagashima et al. 2006. Thirdly, this version of STACO considers what it is called a 'one-shot game'. This type of game considers that players make a decision about their strategies (i.e. on membership and abatement levels) once and for all. Hence, it does not consider the fact that decisions may be revised after certain period. Weikard, Dellink and van Ierland (2006) uses STACO version 2.1. to analyze the effects of renegotiations on the stability and effectiveness of an ICA. Fourthly, I assume a 'cartel-formation' setting, thus, only one agreement can be signed at the time. STACO has been also extended by Finus, Sáiz and Hendrix (2004) to include the possibility of having many simultaneous agreements – i.e. to allow for multiple coalitions. I recognize that a different setting, e.g. a dynamic version of STACO, the possibility of revising abatement strategies, or multiple coalitions – would render quantitatively different results than those presented here. However, qualitatively, many of the insights of this thesis may still hold to the refined versions of the model – see Nagashima et al. 2006 and Finus, Sáiz and Hendrix (2004).

1.8. Outline of the thesis

Chapter 2 presents the overview of the non-cooperative game theoretical literature about coalition formation and IEAs-ICAs. In addition, I present the main concepts and definitions from game theory and political economy that will be used along the thesis.

Chapter 3 presents the empirical calibration of the STACO model. I explain how the functional forms and parameters for the payoff function (i.e. the benefit and abatement cost functions) and GHGs concentrations are derived.

Chapter 4 presents an analysis of the role of membership rules and voting schemes for ICAs. I depart from the common assumption that countries can freely join an ICA. I analyze an exclusive membership agreement where countries decide about the accession of new members. I model this decision process through two decision rules: unanimity and simple majority voting. In this chapter, I show that an exclusive membership agreement fosters participation in an ICA. Furthermore, I show that stable agreements under unanimity voting result in higher levels of global abatement and payoff than stable agreements under majority voting.

Chapter 5 focuses on the implication of different allocation schemes of emission permits for stability and the success of international climate agreements. I analyze the following question: Would an allocation based on equitable principles be more successful in encouraging cooperation than an allocation based on the status quo? To analyze this question I consider the effects of two different types of initial allocation of permits on the success and stability of an ICA. The first type refers to 'pragmatic schemes' that allocate permits according to the status quo. I consider two schemes that allocate permits according to different reference levels of emissions. The second type refers to 'equitable schemes' that allocate permits based on some equity criteria frequently discussed in the literature. I analyze six schemes of this type that include, among others, a per-capita allocation and an allocation based on energy efficiency. I find that permit trading can raise participation and improve the success of ICAs. Furthermore, I find that distributing permits according to the 'pragmatic schemes' result in stable agreements that improve, in terms of net benefits and abatement levels, upon the situation when permits are distributed according to the 'equitable schemes' – because in the latter there are no stable agreements at all.

Chapter 6 presents a study on the effect of uniform abatement quotas on the stability and success of ICAs. Four scenarios are tested. These scenarios differ in the allocation of abatement duties among coalition members. Apart from the standard assumption of an efficient abatement scheme, I consider three designs of a uniform emission reduction quota, 'Joint Quota', 'Median Quota Proposal' and 'Lowest Quota Proposal'. Additionally, it is considered that quotas can be traded among signatories. The results show that uniform quotas help to increase participation in stable ICAs. Furthermore, the stable agreements under the median and lowest quota designs – with and without trade – clearly improve upon the situation when there is no cooperation in terms of global abatement level and payoff.

Chapter 7 examines the effects of lobby groups on the size and stability of climate agreements. I depart from the assumption that governments only consider the aggregated welfare level of their regions in their policy decisions. I assume that governments seek to maximize their own political revenue considering the pressure from lobby groups. This pressure is modeled as prospective contributions that reflect the willingness to pay of a lobby to influence government's policy in their favor. I consider two types of lobbies: industry and environmentalists. I show that although lobby contributions help to stabilize an ICA, the stable agreement does not improve much, in terms of global abatement and payoff, upon the situation without cooperation. Furthermore, I find that, contrary to intuition, a member of a stable agreement may collect industry contributions.

Chapter 8 analyzes the effect of strategic delegation on ICAs. The literature on coalition formation of ICAs shows that, due to strong free-rider incentives, these agreements do little to tackle climate change. However, there might be another reason for a non-effective ICA, namely, that voters support governments whose environmental preferences differ from their own. Thus, when governments' representatives meet at the international negotiation tables, they will bargain for an agreement that does not tackle effectively the environmental problem. Voters choose a 'less green' government because it gives them a better bargaining position at the negotiations – in terms of abatement burdens or side payments. I find that when countries sign an agreement, voters have an incentive to elect their government strategically. However, the resulting agreement improves in terms of abatement upon the case without cooperation. Finally, I find that strategic voting does not undermine the success of IEAs because voters elect 'less green' governments, but because strategic voting makes IEAs unstable.

Chapter 9 summarizes, presents the general conclusions, the general discussion and the lines of future research of this thesis.

Chapter 2. Endogenous coalition formation, political economy and international environmental agreements

2.1. Introduction

Coalitions are everywhere, from politics to economics, from individuals to countries, from local councils to Parliaments. A coalition is formed whenever two or more agents (individuals, firms, political parties, governments, countries) coordinate their actions in order to reach a common objective. In economics, coalitions are present in numerous fields (Bloch 1997, 2003; Bandyopadhyay and Chaterjee, 2006). These fields include international trade (e.g. custom unions), industrial organization (e.g. formation of cartels), local public finance (e.g. taxation policies in adjacent communities), political economy (e.g. political parties in the Parliament) and environmental economics (e.g. international environmental agreements).

The aim of this chapter is to give an overview of the coalition formation analysis and how it has been applied to the analysis of international environmental agreements (IEAs). Furthermore, I highlight its relation with the political economy approach and with the topics treated in this thesis. I restrict the overview to non-cooperative game theory because it is the focus of this thesis; however, the interested reader can refer to Missfeldt (1999) and Finus (2001) for an overview on the cooperative approach.

The study of coalition formation is a key area in game theory. As Bloch (1997, 2003) points out, the concern about coalition formation might be traced back to the seminal work of von Neumann and Morgenstern (1944) where they highlighted topics such as: "How the coalition worth is going to be distributed among the members? Which coalitions will be formed? How other coalitions affect the incentives to cooperate?" (Bloch 2003, p.35). *Cooperative game theory* focuses on answering the first of these questions, neglecting the analysis of competition among coalitions. In the cooperative approach, the analysis concentrates on the case of full cooperation (i.e. when all agents join the same coalition, forming what is known as the grand coalition). In contrast, *non-cooperative game theory* analyzes coalition formation as an endogenous process which includes the possibility of partial cooperation. Thus, the focus is not only on full cooperation but also on other intermediate coalition structures. A

coalition structure is a partition of the set of N players representing all the coalitions formed in the game (Bloch 1997).[1] Trivially a coalition can only contain one player, in which case it is called a singleton. A non-trivial coalition, then, is formed when two or more players act together. A coalition structure can include both non-trivial coalitions and singletons. For convenience, throughout this thesis, if a coalition structure only contains singletons I refer to it as the singleton coalition structure.

The structure of this chapter is as follows, Section 2.2 describes the tools used to analyze coalition formation as an endogenous process in a general framework. Section 2.3 presents how coalition formation has been applied to the analysis of IEAs, in particular those related to climate change. Section 2.4 presents an overview of political economy issues, its relation to IEAs and links these topics with the contents of the thesis. Section 2.5 concludes.

2.2. Endogenous coalition formation with externalities

Coalitions in economics are, most of the time, smaller than the grand coalition. In international trade for example, there are many regional treaties such as NAFTA or EFTA. The endogenous coalition formation (ECF) approach is useful to analyze partial cooperation. This approach assumes that players can freely form coalitions and that the number of coalitions in the game is endogenously determined.[2] Moreover, the ECF approach is useful for a further reason. It helps to analyze situations where coalitions create externalities between them. The ECF approach is used to analyze many economic phenomena such as cartel formation, competition among regional tax policies and agreements to tackle transboundary pollution problems. These phenomena are characterized by the fact that coalition (agreement) formation creates an externality for those players that are outside the new agreement – these outsiders can be either other coalitions or singletons. The externalities arise because the payoff (i.e. the material gain obtained by a player whenever a coalition is formed) of outsiders is affected when a coalition is formed or expanded (Yi 2003). The externalities can be classified depending on their effect on the payoffs of outsiders. They can be either positive or negative. A positive externality exists when, after a coalition is formed or two or more coalitions are merged, there is a positive effect on the payoff of the outsiders.

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[1] Throughout this chapter we use the term partition and coalition structure interchangeably.

[2] The overview given throughout this section assumes that many coalitions can be formed and coexist at a time – i.e. there are multiple coalitions. In the remaining sections of this chapter, I change this assumption to consider what I called a 'cartel formation' framework where only one coalition can be formed at a time. I refer to this type of games as a 'cartel formation' given its parallel to oligopoly theory, where it is usually assumed that a cartel (coalition) is formed and that it competes in the market with a fringe – i.e. a set of the singletons.

Conversely, negative externalities exist when the payoff of outsiders is negatively affected due to coalition formation.

During the 1990's the economic analysis of coalition formation (e.g. Bloch 1997, Ray and Vohra 1997, Yi 1997) focused on a framework introduced originally by Thrall and Lucas (1963): the partition function approach. This framework acknowledges that the payoff of a coalition should depend on the entire coalition structure and that a change in the coalition structure has an effect on all the coalitions. Hence, it highlights the role of externalities. A partition function is a mapping which associates to each coalition structure a vector representing the payoff of all coalitions (Bloch 1997 and 2003). Consider a set of N players. Then, define a coalition structure $K = \{k_1, k_2, \ldots, k_M\}$ as the collection of coalitions k_h, $h \in \{1, 2, \ldots M\}$, where M is the total number of coalitions belonging to coalition structure K. Denote by Φ a partition – i.e. the set of all possible coalition structures that can be formed. Assume further that there is an outcome (or payoff) function $F_K : K \to \mathbb{R}^M$. This function maps each coalition structure K into M vectors of payoffs corresponding to each coalition within K. Then, the partition function $F : \Phi \to \{F_K\}$ is a function that assigns to each partition its payoff function (Thrall and Lucas 1963). Hence, in the partition function approach, the payoff of a coalition is a function of all the coalitions formed in the game.

However, for economic applications, the partition function approach has a major shortcoming: it does not specify the underlying force driving the interaction between coalitions. This shortcoming has been overcome by making ad-hoc assumptions about the behavior of coalitions. Ray and Vohra (1997, 1999) use an assumption, introduced by Ichiishi (1981) stating that inside each coalition players behave cooperatively in order to maximize the coalitional payoff, whereas coalitions and singletons interact in a non-cooperative fashion. Hence, the partition function is obtained as the Nash equilibrium payoff of the game played among the coalitions.[3] The partition function is a powerful tool to analyze the role of externalities between coalitions. Nevertheless, in economic analysis, it is important to know how each player individually evaluates its payoff and how this is related to changes in the entire coalition structure. A related approach, the valuation function, is then used to analyze such questions. A valuation assigns to each coalition structure a vector of *individual* payoffs. This approach can be thought, then, as a per-member partition function. The valuation function assumes that there is an exogenously fixed rule on how to distribute the coalitional payoff (Bloch 2003). The analysis throughout this thesis is based on the valuation function approach.

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[3] If coalitions decide simultaneously about their strategies the resulting equilibrium is also called Partial agreement Nash equilibrium (PANE), see Chander and Tulkens (1997).

The valuation function approach has been applied to study economic phenomena that can be described as two-stage games. In these games, at the first stage, players decide to form coalitions (i.e. they form a coalition structure) and, at the second stage, they engage in a non-cooperative game (for instance, they can compete in a market in a Cournot fashion) generating a valuation function. Assuming that at the second stage there is a unique equilibrium, then, the entire game can be simplified to consider only the resulting valuation function for each possible coalition structure. Furthermore, the valuation function is also helpful to describe the effects of positive and negative externalities on the game. For a valuation function, a positive externality exists when, after a coalition is formed or two or more coalitions are merged, there is a positive effect on the payoff of the outsiders. Conversely, negative externalities exist when the payoff of outsiders negatively affected due to coalition formation.

In the remaining sections of this chapter the overview is confined to cases that use a valuation function approach within what I called 'one-shot games'. These games consider that players make a decision about their strategies once and for all. They do not consider that these decisions may be revised after certain period. The analysis of other type of games, called 'repeated games', recognize the fact that players may change their decisions after some time. The interested reader can refer to Barrett (1997b and 1999), Finus and Rundshagen (1998b), Asheim et al. (2006), and Weikard, Dellink and van Ierland (2006) that analyze IEAs in a repeated game framework.

The two-stage games analyzed with the valuation function approach may be classified according to the defining characteristics of each stage. I present in Table 2.1 a summary of this classification for the characteristics that are relevant for this thesis.[4] At the first stage there are three defining characteristics: sequence of coalition formation, number of coalitions and membership. Firstly, a model may assume that either all players announce simultaneously its decisions about membership on a coalition (see among many others Carraro and Siniscalco, 1993; Barrett, 1994; and Yi, 2003) or that the announcement is sequential. The latter means that an initiator proposes a coalition, if all prospective members agree then the coalition is formed and the remaining players may or not form coalitions. If the proposal is not accepted then a new one is formulated until a coalition is formed (see Bloch, 2003). Secondly, the number of coalitions that can be formed from the announcement of the players may be restricted to one, playing what I called 'cartel formation' games (see among others Botteon and Carraro, 1997; Jeppessen and Andersen, 1998; Yi, 2003) or unrestricted, thus, several coalitions may form, playing what I called 'multiple coalitions' games (see Finus, Sáiz and Hendrix, 2004; Finus and Eyckmans, 2006; Bosello et al., 2003). Thirdly, a

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[4] For a more detailed classification of this type of models, applied to IEAs, see Finus (2003).

model may assume that all players are free to join or leave the coalition (an open membership game, see Barrett, 1994, 1997a; Yi, 2003; Finus et al., 2006), or outsiders are not free to join existing coalitions (an exclusive membership game). In an exclusive membership game, players announce the coalitions that they would like to form (or equivalently which members they would like to have as coalition partners) and only those coalitions that have been announced can be formed (see Hart and Kurz, 1983; Bloch 1997, 2003; Finus and Rundshagen, 2003a; Finus, Sáiz and Hendrix, 2004).[5]

Table 2.1 Classification of models on coalition formation

Stage	Characteristic	Type
1st stage	Sequence of coalition formation	Simultaneous
		Sequential
	Number of coalitions	Single ('cartel formation')
		Multiple
	Membership	Open
		Exclusive
2nd stage	Strategies choice	Coalitional payoff maximization
		Other (e.g. restricted maximization)

At the second stage, players engage in a non-cooperative game. The models can be characterized by how players choose their strategies, given the announcement at the first stage. Players may choose their strategies following the assumption of coalitional payoff maximization (CPM) or an alternative assumption. The CPM assumption follows Ray and Vohra (1997, 1999) and Ichiishi (1981), and states that coalition members maximize their coalitional payoff whereas singletons maximize their individual payoffs. An alternative to this assumption might be to assume that coalition members maximize their own payoff considering that they have to propose a uniform abatement quota for the rest of coalition members. There are few examples of papers on these alternative assumptions (see for instance Barrett 2002; Finus, 2004). There is no restriction about what type of alternative may replace the CPM assumption, the analysis in this respect is still at its infancy.

Considering the classification of Table 2.1, throughout this thesis I use a model of simultaneous membership and 'cartel formation'. Then players announce simultaneously their membership strategies considering that only one coalition can be formed at a time and that the remaining players remain as singletons. Economic applications of this approach are varied and include when firms form a cartel (first stage) and then compete in the market

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[5] In Chapter 4, I analyze the effect of exclusive membership in the STACO model, however my approach differs from Hart and Kurz (1983) and Bloch (1993) in that the decision of accession reflects political economy aspects through voting.

(second stage), or when countries form a custom union (first stage) abolishing tariffs among members and then fix a joint tariff (second stage); or when countries sign an international environmental agreement (first stage) and then decide on environmental policies (second stage).

2.3. Endogenous coalition formation and international environmental agreements

2.3.1. Context

Nowadays, IEAs are an important instrument to tackle environmental problems, specifically those of global nature like climate change. IEAs are examples of endogenous coalition formation. In these agreements, a group of countries (players) gather in order to decide upon a common policy to tackle a transboundary environmental problem – e.g. whale hunting, transport of hazardous waste, acid rain, or climate change.[6] Signatories of such type of agreements recognize the externalities that they impose on each other. Furthermore, as mentioned above, the process of signing an IEA can be described as a two-stage game. At the first stage, countries decide whether or not they sign an IEA. At the second stage, they choose the policy to be performed according to the specifications of the agreement.

As Finus (2003) points out, two factors affect the effectiveness of an international climate agreement (ICA). Firstly, the global public good nature of the problem (see Chapter 1) that gives rise to strong free rider incentives, and secondly, the lack of a supranational authority that can enforce the agreement. An ICA, thus, has to be self-enforcing. Self-enforceability is important because the free-rider incentives of the members may impinge the success of the agreement. ICAs and IEAs in general, are subject to two types of free-riding: (i) a member may be better off by remaining outside the agreement and (ii) a member may not comply with the terms of the agreement. In the latter, the agreement will be not effective.

The models that study ICAs may be classified according to which type of free riding they are addressing (Finus 2003). The models that analyze the first type of free riding described above are called *membership* models. They are concerned mainly with the process of coalition formation and the stability of membership. They are not concerned with whether and how abatements targets are enforced. The models that are focused on the second type of free

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[6] The analysis on IEAs described in this Section is restricted to the cartel formation approach applied to the analysis of agreements to tackle climate change. The case of multiple coalitions (i.e. when two or more coalition can be formed simultaneously) is not reported here, but an overview on this topic can be found in Finus (2003) and Finus and Rundshagen (2003).

riding are called *compliance* models. They emphasize the role of sanctions on enforcing compliance with the terms of an agreement. Compliance models often assume a given structure of membership (coalition) and are less interested in coalition formation. The summary that I present in the rest of this chapter is focused on membership models. The interested reader can find an overview of compliance models for climate change in Finus (2003).

The remainder of this section is organized as follows, in Section 2.3.2, I describe how ICAs have been modeled as two-stage games. In Section 2.3.3, I discuss how stability has been considered in the analysis ICAs.

2.3.2.International climate agreements as two-stage games

The core of a membership model is a two-stage game. At the first stage, countries decide whether or not they want to become coalition members; at the second stage, countries choose their abatement strategies. These strategies are chosen considering a payoff function. The payoff function for a country $i \in \{1, 2, \ldots, N\}$ is represented as net benefits from abatement – i.e. benefits from abatement minus abatement costs – or equivalently as net costs from emissions – i.e. benefits from emissions minus damages from emissions, see Diamantoudi and Sartzetakis (2006). Benefits from emission reduction are a function of the overall level of abatement of the N countries because of the public good nature of the problem. These models capture, thus, the positive externalities as a result of coalition formation. Whenever two or more countries form a coalition (i.e. sign an agreement) then a part of the benefits of forming a coalition are also enjoyed by the outsiders. There are two further assumptions in the simplest version of a membership model. Firstly, the model focuses only on single deviations from the coalition. Secondly, when a country leaves the coalition, the remaining coalition members stay together in a smaller coalition.

In the setting of a membership game, the payoff function for country i, π_i, is given by

$$\pi_i = B_i \left(\sum_{j=1}^{N} \sigma_{ij} q_j \right) - C_i (q_i) \qquad (2.1)$$

where $B_i(\cdot)$ are benefits from global abatement $\sum_{j=1}^{N} \sigma_{ij} q_j$ and $C_i(q_i)$ are abatement costs. Thus, countries receive benefits from both domestic and foreign abatement, and σ_{ij} are called transport coefficients, i.e. the part of the abatement of country j that benefits i. For the case of

a regional transboundary pollutant (e.g. acid rain) $0 \leq \sigma_{ij} \leq 1$ and for a global pollutant (e.g. greenhouse gases) $\sigma_{ij} = \sigma_{ji} = 1$. Benefits are assumed to be increasing $\partial B_i / \partial q_i > 0$ at a decreasing or constant rate $\partial^2 B_i / \partial q_i^2 \leq 0$. Abatement costs are assumed to be increasing $\partial C_i / \partial q_i > 0$ at a strictly increasing rate $\partial^2 C_i / \partial q_i^2 > 0$. This conditions have to be met for any abatement level in $q_i \in [0, e_i^{max})$ with e_i^{max} equal to the maximum level of emissions for country i. Furthermore, in the literature, it is assumed that there is an interior equilibrium abatement vector at the second stage. Considering all these assumptions and a payoff function such as (2.1), then a Nash equilibrium at the second stage exists and it is unique (see Finus and Rundshagen, 2003a).

When a country acts as a singleton, it maximizes (2.1) with respect to its own abatement taking the abatement of the other countries as given. The simultaneous solution of the n-first order conditions, $\partial B_i / \partial q_i = \partial C_i / \partial q_i$, results in the Nash equilibrium level of abatement that corresponds to the abatement vector if no coalition is formed. When countries act under full cooperation, they maximize the aggregate payoff over all countries, $\sum_{i=1}^{N} \pi_i$. The resulting first order condition $\partial \sum_{j \in N} B_j / \partial q_j = \partial C_i / \partial q_i$ indicates the socially optimal abatement level that corresponds to the abatement vector of the grand coalition. Since abatement in the Nash equilibrium is different from those in the social optimum, as long as there is a transboundary pollution problem (i.e. as long as $\sigma_{ij} \neq 0$), the global payoff increases through cooperation. When coalitions are smaller than the grand coalition (i.e. for partial cooperation) the behavior of coalition members follows what I called the coalitional payoff maximization (CPM) assumption at the second stage. This assumption states, following Ichiishi (1981) and Ray and Vohra (1997, 1999), that coalition members maximize the aggregate payoff of the coalition K, i.e. they maximize

$$\sum_{i \in K} \left[B_i \left(\sum_{j=1}^{N} \sigma_{ij} q_j \right) - C_i(q_i) \right] \tag{2.2}$$

whereas singletons maximize their own payoff – i.e. they maximize expression (2.1). Thus, signatories (acting as a single player) and non-signatories play non-cooperatively against each other. The result is the Nash equilibrium of the game.

The first order conditions for any coalition smaller than the grand coalition can be interpreted as best-reply or reaction functions (Finus 2003). These functions describe the optimal choice

of abatement for a coalition considering the level of abatement from the outsiders as given. The best-reply functions show how much of the abatement that a coalition undertakes is offset by a decrease on the abatement of the singletons. Only in special cases (if $\sigma_{ij} = 0$ or with linear damage functions) the optimal choice of emissions for coalition and non-coalition members is independent of the choices of each other (Folmer and van Mouche 2000, Finus 2003). In this case, the slope of the reaction functions is zero; these functions are called orthogonal reaction functions.

2.3.3. Stability of international climate agreements

In most of membership models, from a non-cooperative view, stability is tested with the concept of internal and external stability.[7] An agreement is called stable if it is internally and externally stable. These concepts were used by d'Aspremont et al. (1983) to study cartel formation in a static oligopoly framework. It is assumed that all countries choose their strategies simultaneously and that only single deviations from the coalition are possible. This approach is also called the Nash-Cournot framework given its parallel to the analysis of oligopoly theory.[8] A coalition is internally stable if none of the coalition members is better off by leaving the coalition. A coalition is externally stable if there are no singletons that would be better off by joining the coalition.

Consider a coalition structure K, a coalition member $i \in K$, and a non-coalition member $j \notin K$, then K is internally stable if

$$\pi_i(K) \geq \pi_i(K \setminus \{i\}) \quad \forall i \in K. \tag{2.3}$$

And it is externally stable if

$$\pi_j(K) \geq \pi_j(K \cup j) \quad \forall j \in N \setminus K. \tag{2.4}$$

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[7] The cooperative approach uses instead the concept of the core to analyze stability and has been applied to IEAs by Chander and Tulkens (1995, 1997) and more recently by Eyckmans and Tulkens (2003). These studies analyze the stability of the grand coalition considering an imputation, i.e. a vector that includes the payoff from emission reductions and monetary compensations. An imputation is stable if it lies in the core, i.e. if each country receives a sufficiently high share of the gains of cooperation, so that no singletons or group of countries finds it profitable to form a coalition different from the grand coalition (Finus 2003).

[8] We restrict our attention to the Nash-Cournot approach. For studies of IEAs that consider a Stackelberg type of competition see Barrett (1994) and for an overview on the Stackelberg approach and its results see Finus (2003).

Membership models have rendered many important insights to understand stability of IEAs. Since the seminal work of Hoel (1992), Carraro and Siniscalco (1993) and Barrett (1994) many new developments have been added to the analysis. In the following, I offer an overview of some of the issues that have been dealt within this framework. However, it is beyond the objective of this chapter to give a full summary of this literature. Excellent overviews on this are Wagner (2001), Barrett (2003) and Finus (2003). For convenience of exposition, the following discussion on membership models is divided in two parts according the identity of the players. Thus, I consider that a membership model can either consider symmetric players (if all players share the same characteristics) or consider asymmetric players (if players differ in their characteristics).

- Stability analysis of membership models with symmetric players

For symmetric players, the slope of the reaction function curves is a key element to derive some general results (see among others Carraro and Siniscalco 1993; Barrett 1994, 1997a; Carraro 2000). In particular, the results depend on how much the emissions reduction achieved by the coalition is offset by an increase in the emissions of the singletons – i.e. it depends on the slope of the best-reply functions. Barrett (1994) finds that, for orthogonal reaction functions, stable coalitions cannot contain more than three signatories, regardless of the total number of players. Finus (2003) explains that if the slope of the reaction function is -1 then no non-trivial coalition is stable, because all abatement from the coalition would be completely offset by the singletons. Finally, if the slope of the reaction functions is between zero and -1, the size of the stable coalition will depend on the parameters of the benefits and the abatement costs functions. In this case the grand coalition may be stable, but only if the gains of cooperation are very small (Barrett, 1994).

- Stability analysis of membership models with asymmetric players

The analysis of asymmetric countries gives a further insight into the problem of stability on ICAs. Theoretical results are difficult to obtain for coalitions larger than two members, hence the analysis often resort to numerical simulations. Barrett (1997a) finds that for orthogonal reaction functions the equilibrium size of a stable coalition is no larger than three for a sensible range of parameters. However, when the reaction functions are non-orthogonal, some parameter specifications make the grand coalition stable. Thus, a general result for the case of asymmetric countries is that the size of stable coalitions depends to a large extent on the size of the gains of cooperation and how these are distributed – see Finus and Rundshagen (2003a).

Models of asymmetric countries have been extended to study issues such as considering other benefits on top of those of abatement (also called non-material payoffs), the prospect of linking the ICA with another treaty of cooperation between members usually on trade or R&D (also called issue linkage), and whether or not transfers are available to coalition members (and the nature of these). In the following, I summarize the major findings on these issues.

Non-material payoffs

In international negotiations, countries consider elements beyond the cost-benefit dimension of a policy. For instance, there are reputation effects that influence the participation and the level of the policy agreed on an IEA. Countries may not want to show that they are not concerned about the environment because that would have negative consequences on other areas – e.g. tourism may decrease in countries that are not 'environmental friendly'. Some studies model this effects by adding an extra term in the payoff function additionally to the benefits and costs from abatement (e.g. Jepessen and Andersen, 1998; Hoel and Schneider, 1997). Jeppessen and Andersen (1998) analyze these reputation effects by including a non-material term into the payoff function, whereas Hoel and Schneider (1997) modeled this as non-environmental effects of breaching an IEA. The main result from both studies is straightforward and it shows that the larger the disutility of non-members from being an outsider the larger the stable coalitions would be. Trivially, if this type of disutility is large enough, the grand coalition would be stable.

Issue linking

IEAs are affected by free riding given that the gains of cooperation are non-exclusive to coalition members. In contrast, in a club good agreement the gains of cooperation are exclusively shared among signatories. Thus, cooperation may be increased if an agreement on a public good (such as an IEA) is linked to a treaty that involves a club good. There are some studies about linking two agreements, one on environmental issues and the other on issues such as cooperation in R&D or trade. In most of the studies on 'issue linkage' it is assumed that countries have to participate in both treaties and that the gains of cooperation in the linked agreement are exclusive to coalition members. Carraro and Siniscalco (1993) show that, for the case of linkage on R&D, linking negotiations is more profitable than having two separate agreements. Furthermore, the linked agreement allows for higher participation than the IEA by itself. They find that using the gains of the R&D agreement, which are exclusive to members, to offset the free rider incentives of the IEA leads to reach full cooperation in both agreements. Buchner et al. (2002) study, using the estimates of the RICE model (Nordhaus and Yang, 1996), the incentives of USA to comply with the abatement targets

established by the Kyoto Protocol considering that signatories can also participate in an agreement on R&D cooperation. They find that their model does not produce evidence that USA will comply with the Kyoto targets, because the threat of being excluded from the R&D agreement is non-credible. Moreover, they find that an agreement that only focuses on cooperation on innovation and diffusion of technology (without binding abatement targets) is more likely to attain cooperation among countries. However, such type of agreement would not do much to tackle climate change.

Barrett (1997b) studies the effect of linking an IEA to a trade agreement. He assumes that the trade agreement captures only those goods that are exported and relevant for the environmental treaty. The Montreal Protocol, for instance, banned the trade of CFCs between members and non-members of the Protocol. Countries are allowed to trade if and only if they are also signatories of the IEA. When a signatory defects from the IEA, the remaining coalition members impose a trade restriction on it. In this case, coalition members impose a total ban to trade with the defecting country. Using numerical simulations, Barrett shows that this retaliation strategy is a credible threat of coalition members and that, under certain set of parameters, free-riding can be deterred completely. As no country wants to defect the IEA, in equilibrium, no trade sanction is implemented.

Transfers

The analysis of asymmetric countries shows that cooperation is difficult to attain because of two factors: the CPM assumption and the intrinsic heterogeneity in the benefit-cost structure of countries. These factors result in an uneven distribution of the abatement burden among coalition members. Hence, some countries may find it attractive to free-ride. Nevertheless, countries that still find it attractive to stay in the coalition may think of compensating those that want to free-ride. These compensations may take the form of transfers. Transfers are relocations of monetary or in-kind resources (e.g. technology transfer) in order to increase cooperation in an IEA.

For the analysis of monetary transfers on IEAs it is assumed that transfers have to be self-financed, i.e. that they should be paid out of the gains of cooperation. Most of the studies, however, find that this is not enough to ensure full cooperation. The gains of cooperation are not always sufficient to compensate all countries that sign the agreement. Thus even with transfers, the grand coalition is stable only in few cases. Botteon and Carraro (1997), study the effect of transfers on IEA stability using the empirical estimates of Musgrave (1994) to calibrate a payoff function (in terms of net costs from emissions reduction) for five world regions. They consider two burden sharing rules borrowed from cooperative game theory: the Shapley value and the Nash bargaining solution. The Shapley value, in short, distributes the

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cost burden proportionally to the marginal contribution of each player to the coalitional payoff. The Nash bargaining solution makes coalition members to minimize the product (over all coalition members) of the difference between the net costs of the cooperative and the singleton situation. Botteon and Carraro find that the grand coalition is not stable and that only three coalitions are stable under the Nash bargaining solution and only one using the Shapley value. From the stable coalitions the best, in terms of emission reduction, is the one obtained considering the Shapley value. Furthermore, Botteon and Carraro explore the possibility of enlarging a stable coalition through compensation, such that the enlarged coalition is internally stable. They find that under the Nash bargaining there are no coalitions that could be successfully enlarged but that under the Shapley value the stable coalition can be enlarged to form the grand coalition.

There are three general results from the literature presented in this section (see Finus, 2003; Finus and Rundshagen, 2003a): (i) full cooperation (i.e. that all countries participate and remain in an agreement) is difficult to attain, thus, in many cases only IEAs that comprise few countries are stable; (ii) that the larger the gains of cooperation the stronger are the free-rider incentives, and that stable IEAs can reap only part of these gains; and (iii) that the size of stable agreements depends on how the net benefits from abatement are distributed (for instance via transfers).

2.4. Political economy of international climate agreements

2.4.1. Context

Political economy studies the political processes through which economic decisions are made. A key feature of this approach is that it provides a rationale for collective action, in particular in issues that involve the provision of a public good (such as the provision of greenhouse gas abatement to tackle climate change). Political economy complements environmental economics in this respect. Environmental economics offers recommendations on the design of efficient and effective environmental policies, but usually using a set of very restrictive assumptions. Most environmental economics models conceive governments as monolithic entities whose optimal goal is to increase the welfare of their citizens (Persson and Tabellini 2000, Chapter 1; Oates and Portney, 2001; Mueller, 2003, Chapter 20). Political economy, however, considers government's actions not as purely driven by welfare maximizing objectives. Governments are political actors susceptible of being influenced by other political actors. For instance, political decision-making processes may be influenced by a desire of the government to increase its prestige, to enhance the possibilities of being reelected or to increase its budget (Buchanan and Tullock, 1962; Persson and Tabellini,

2000). Studies on political economy recognize this, and might help to explain why efficient policy recommendations (from an environmental economics point of view, for instance) tend to diverge from its actual implementation. Furthermore, it may help to anticipate the political acceptability of a policy. There are many studies of political economy on environmental policy-making. Most of these are, however, devoted to national environmental policies (see Sandler, 1992; Hillman and Ursprung, 1994; Schneider and Volkert, 1999; Yandle, 1999; and the survey of Oates and Portney, 2001). Few studies analyze IEAs from a political economy perspective (see Michaelowa and Greiner, 1996; Carraro and Siniscalco, 1998; Michaelowa, 1998; Congleton, 2001; Vogt, 2002; Böhringer and Vogt, 2004) and even fewer combine this approach with the analysis of IEAs as coalition formation (Haffoudhi, 2005a, 2005b; Buchholz et al., 2005).

The studies referenced in Section 2.3 have given many valuable insights to understand the underlying incentive structure of ICAs. Only under very special circumstances the grand coalition is stable and stable coalitions do not do much to tackle climate change. These results reflect the underlying set of restrictive assumptions about the analysis of ICAs as coalition formation. In actual political negotiations, countries may decide about policies without explicitly considering maximization criteria. The CPM assumption of coalitional payoff maximization (CPM) – i.e. that countries choose their abatement levels in order to maximize the coalitional payoff – seems also very restrictive. The resulting abatement targets may be considered excessive and not evenly distributed among coalition members. As Barrett (2002; 2003, Chapter 15) and Finus (2004) point out it is necessary to go beyond this assumption in order to reflect more actual aspects of the negotiations in the international policy arena. Countries face many important political constraints and have to consider many other factors apart from efficiency in order to negotiate and sign an ICA. It is not clear, for instance, what type of political process is behind the CPM assumption.

The actual design of ICAs differs greatly from the assumptions of the literature reviewed in Section 2.3. The policy adopted in most ICAs may not be the efficient solution for the coalition. In many cases, inefficient targets are implemented, mostly due to political reasons. Furthermore, the national representatives at the negotiations are assumed to be benevolent agents that truly represent the interests of their citizens. It is considered, for example, that the maximization of net benefits from abatement is the only factor that drives the decision of signing an ICA and defining abatement levels of signatories. These restrictions may be overcome by considering elements of political economy in the analysis.

In the remainder of this section, I provide an overview of some of the political economy factors that have been considered in the analysis of ICAs. I concentrate on those that are relevant for this thesis; Congleton (2001) offers a good overview for a much broader context

of political economy aspects for IEAs in general. The focus is on four main topics: (i) membership rules and voting schemes, (ii) equity issues as a basis for permit trading, (iii) use of quotas, and (iv) the influence of national political actors.

2.4.2. *Membership rules and voting mechanisms*

Many of the studies on the stability of ICAs assume that these are open membership treaties. All countries are free to join or leave the agreement. This assumption is in line with almost all international agreements that deal with global issues − with few exceptions, such as the Antarctic Treaty, see Barrett (2003), Chapter 6. The public good nature of global environmental problems, like climate change, may suggest that a treaty would be more successful as more countries join. However, this does not take into consideration that ICAs have to be self-enforcing. Thus, an agreement might actually tackle the environmental problem better if not all countries are allowed to join. Finus and Rundshagen (2003a, 2003b), for instance, analyzing the games introduced by Hart and Kurz (1983), indicate that exclusive membership may help to increase stability of an IEA.

Most of the studies on exclusive membership are theoretical or have very restrictive assumptions on the characteristics of players (symmetric or two-country models). There are few studies that have an empirical module to characterize asymmetric players. An example is Eyckmans and Finus (2006). They study coalitional games that represent different designs of agreements on climate change. One of the designs concerns exclusive membership as in the games introduced by Hart and Kurz (1983): the game Δ and the game Γ. In the game Δ, players simultaneously announce a list of members with which they would like to form a coalition. The countries with the same list of members form a coalition. In the game Γ, players make a list with whom they would like to form a coalition but a coalition is formed if and only if all members on the list has made the same proposal. For example, consider that there are three players in the game $i \in \{1,2,3\}$. Then assume that players 1 and 2 announce that they would like to form the grand coalition, i.e. that $\{(1,2,3)\}$ is formed, and that player 3 would like that all remain as singletons, i.e. that they remain as $\{1,2,3\}$. Considering this, a coalition between players 1 and 2 will be formed in the game Δ but no coalition will be formed in the game Γ. The empirical part of the Eyckmans and Finus (2006) relies on estimates of the RICE model (Nordhaus and Yang, 1996) for six world-regions. They find that exclusive membership leads to higher levels of emission reduction and global welfare than open membership and that a more restrictive way of acceding to an IEA (as with the game Γ) may not be detrimental for its success.

In Chapter 4, I study the effect of exclusive membership on the stability and effectiveness of an ICA. However I consider an approach different from the games introduced by Hart and Kurz (1983). Instead, I assume that the rules of accession of new members are similar to decision rules used in international organizations, such as NATO and the European Union. The decision rules that I consider for the accession of new members are unanimity and simple majority voting.

2.4.3. Permit trading and equity considerations

Emission permits are considered crucial instruments to address many environmental problems, in particular at the national level. Furthermore, their advantages are also advocated at the international level. Currently, its relevance under the context of the ratification of the Kyoto Protocol and the actual functioning of emissions trading within the States of the European Union, highlight the importance of this instrument. There are many questions open to debate on this issue, for instance: How will permits be allocated? Is this allocation fair? Would it be accepted by everyone? Some studies on permit trading and ICAs (e.g. Eyckmans et al., 1994; and Germain and van Steenberghe, 2003) note that many permit allocation schemes do not guarantee individual rationality for all members (i.e. that all members are better off than in the situation without an agreement) though they are considered to be fair – e.g. a per capita allocation.

Studies on stability of ICAs that deal with permit trading may be classified according to the allocation of permits. Rose et al. (1998) distinguish three types of rules for the distribution of permits: (i) allocation-based criteria, if the rule determines the initial allocation of permits, (ii) outcome-based criteria, if the rule determines the final allocation after trade has taken place, or (iii) process-based criteria, that considers the factors associated with trading. Many studies of ICAs have focused on outcome-base rules (e.g. Bosello et al., 2003; Weikard, Finus and Altamirano-Cabrera, 2006, among others). In Chapter 5, I analyze allocation-based rules and its impact on participation and success (in terms of global abatement and payoff) of ICAs.

2.4.4. Uniform abatement quotas

Most of the studies on ICAs, assume that abatement decisions of members and no-members are efficiently chosen. However, this assumption contrasts with the factual evidence on IEAs. Many international agreements, for transboundary environmental problems, specify a uniform quota for all participants. For instance, the Helsinki Protocol suggested a reduction of 30 percent of sulfur emissions from 1980 levels by 1993 – see Barrett (2003), Chapter 6. This is of course inefficient, given that countries have different marginal abatement costs. In

spite of this inefficiency, the use of uniform quotas is wide-spread on international environmental policy – for details see Wolf (1997). Most of the literature presented in Section 2.3 assumes a CPM behavior. However, as I pointed out, this assumption might be very restrictive. An inefficient solution like the quota could obtain better results. There are analyses of IEAs that assume a quota instead of CPM. These analyses date back to the study of Hoel (1992). Hoel (1992) analyzes an agreement where abatement targets are chosen following three criteria. These criteria are: (i) social optimal allocation, (ii) socially constrained allocation (such as no country is worse off than in the status quo) and (iii) uniform emissions reduction according to the proposal of the median country. Hoel finds that the grand coalition is not stable in any of these cases, and that under partial cooperation only small coalitions (no larger than two members) are stable.

Later contributions, e.g. Endres (1997) and Eyckmans (1999), among others, compare a uniform emission tax with a uniform emission quota in the context of an ICA. They find that a quota may render better environmental and economic results than a tax. Though the quota is inefficient in principle, this is compensated by the fact that allows for solutions that are closer to what is required following cost-benefit considerations – i.e. the level of abatement in the social optimum. This result is confirmed when it is applied to the analysis of stability of IEAs (see Endres and Finus, 2002).

A quota may help to increase participation and effectiveness in an ICA. Participation increases because a quota (different from the CPM assumption) represents a less uneven distribution of the abatement burdens. Countries may find that, in terms of net benefits, it is better to join an agreement that implements a quota than if they are required to perform the abatement levels dictated by the CPM assumption. Thus, the effectiveness of an agreement may increase because a quota may compensate its inefficiency by attracting more participants to a stable ICA. A stable agreement with modest abatement targets may actually help to tackle climate change, thus 'modesty pays' as Finus (2004) explains. In Chapter 6, I abandon the CPM assumption to consider that coalition members choose their abatement strategies following a uniform quota. Furthermore, I link the criteria to choose a quota with rules that reflect decision rules found in actual negotiations. I analyze the case when quotas are chosen according to the median quota proposal (equivalent to choose the quota via simple majority voting) and according to the lowest proposal (equivalently to choose the quota via unanimity voting). Finally, I analyze a system of tradable abatement quotas.

2.4.5. National political actors

A political economy analysis of an ICA should recognize that governments' concerns go beyond the maximization of the net benefits from climate policy. The analysis needs to

include also how national political actors affect the actions of governments at international negotiations. The political situation in each country determines the position of negotiators in an ICA. In the following, I present two elements that may be included in the analysis, political pressure groups (or lobbies) and voters, in order to reflect this political economy considerations.

I abandon the assumption of welfare maximizing governments at the national level. I consider governments that not only care about the outcome of the environmental policy but also about the particular political characteristics that they encounter domestically. Thus the decision that a government takes at the negotiations of an ICA may be influenced by their national political actors

• Lobby groups

In a representative democracy, political decision-making is not solely influenced by the concerns of the general electorate. In addition, governments recognize the pressure exerted by lobbies. Lobby groups participate in the political process in order to influence political outcomes. Political economy studies on the effect of lobby groups in policy-making may be divided in two approaches, depending on the motives that lobby groups have when they contribute to politicians (Grossman and Helpman 1994, 1996). The first approach considers that lobbies have an *electoral motive* and thus intend to promote the candidate that reflects their preferences on a policy issue. The second approach considers that lobbies have an *influence motive* such that contributions aim to influence the policy of an incumbent politician. The electoral motive approach stresses the political competition among two opposing political candidates and how these interact with lobby groups (see Hillman and Ursprung 1988). In this approach, competing political parties announce the policies (e.g. on trade or environmental issues) that they would implement if they are elected. Lobby groups evaluate their welfare prospects under the alternatives offered by each party and support the candidate that ensures them the highest level of welfare. Lobbies, thus, weight the expected benefit from the election of their favorite candidate against the costs of supporting her.

In the influence motive approach, which is the approach that I follow, policies are assumed to be implemented by an incumbent government that maximizes its political support function. This function includes the contributions made by lobbies and social welfare. The analysis abstracts from the electoral process and focuses on analyzing the effects that lobby groups have on the policy outcomes. This approach was introduced by Stigler (1971) and Hillman (1982) and was used to analyze international policy-making by Grossman and Helpman (1994, 1996 and 2001). They apply the political support function approach to the analysis of trade policies. Grossman and Helpman study the equilibrium structure of trade protection,

where an incumbent politician makes a policy decision (a vector of import and export taxes and subsidies) in order to maximize the weighted sum of social welfare and total lobby contributions – implicitly recognizing that both have an influence on the possibility of the incumbent politician to be reelected. Contributions are assumed to be small, thus having no effect on the electoral outcome, but influencing only the policy. Lobby groups represent industry interests that make contributions in order to influence the government in their favor. The government's objective function has the following specification

$$G = aW(p) + \sum_i C_i(p) \qquad (2.5)$$

with $a \geq 0$ as the weight that the government attaches to the aggregate gross-of-contributions welfare $W(p)$, $C_i(p)$ is the contribution schedule from lobby i and p is the vector of the policy chosen by the government. The political equilibrium emerges from a two-stage non-cooperative game in which lobbies simultaneously choose their political contribution schedules at the first stage and the government sets the policy level at the second. The equilibrium involves a set of contribution functions, $C_i^*(p)$, one for each organized lobby group and a domestic policy vector, p^*, that maximizes the government's objective taking the contributions schedule as given. Grossman and Helpman (1994) find that the structure of industry protection is a function of the state of political organization of the industry groups, the ratio of domestic/foreign industrial output and the elasticity of import demand/export supply. Furthermore, they found that the protection provided by the organized industry groups increases with the relative weight that the government puts to contributions – i.e. the parameter a in (2.5) – and falls with the fraction of the voters that belong to an organized lobby group.

The political contributions approach has been further applied to study the influence of lobbies on environmental tax policy (Fredriksson 1997), on the link of trade and international environmental policies (Conconi 2003) and the relation of democracy levels and their impact for international policy-making (Fredriksson et al. 2005). However, the impact of lobbies on the stability of ICAs has not been fully addressed in the literature. Only Haffoudhi (2004a, 2004b) has addressed this question. The analysis in these papers is confined to symmetric countries negotiating an ICA following the general framework described in Section 2.3. Governments receive contributions from two lobbies (industry and environmentalist) and, following Grossman and Helpman (1994), contributions enter into the political support function of the government. I follow a similar approach in Chapter 7, however the analysis that I present is for asymmetric countries and it consider two types of environmentalist lobbies: greens and supergreens. Green lobbies are concerned only about the environmental

impacts that affect their region, whereas supergreens are concerned about global environmental damages.

- Strategic delegation

Voters delegate their decision power to their representatives at international negotiation tables. The representatives (most of the times the government) then negotiate the terms, conditions and obligations that their countries will follow when joining an international agreement – on trade or environmental policy for instance. The strategic delegation framework focuses on this type of issues. However, the impact of strategic delegation on ICAs negotiations has not been fully explored yet. Strategic delegation assumes that voters delegate the power to sign an agreement to a representative government. It further assumes that voters cannot influence the policies directly but indirectly by electing a politician – that reflects the preferences of the voter. The simplest version of this framework (for international policy-making) considers that an international agreement on issues such as foreign capital taxes or environmental policies, is a two-stage game. At the first stage, voters (following the majority rule) elect their preferred politician that at the second stage will negotiate the international policy. Voters take the result of a foreign election as given and then choose the candidate that would yield the most favorable position at the subsequent policy game. A key result from this approach is that voters often elect a politician that has different preferences than their own, because it gives them an advantage at the international policy negotiations (for an overview see Persson and Tabellini, 2000, Chapter 12).

The strategic delegation approach has mainly been applied to economic phenomena such as international tax policies and the provision of transboundary public goods. Persson and Tabellini (1992) analyze a two-country, two period model to study the effect of strategic delegation on capital taxation, considering that capital may become more mobile (e.g. as with the European Union integration). In their model, the population in each country elects a government (through majority voting) that sets a tax policy, taking the tax policy of the other country as given. The game that they study has the following stages, firstly, simultaneously, in each country a government is elected following the majority rule. Secondly, elected governments simultaneously commit to a tax policy for own and foreign capital. Finally, having observed these policies, private investors make a decision concerning their investments in each country. It would be expected that elected policy-makers implement the policy preferred by the median voter. However, Persson and Tabellini show that voters may find it optimal to elect a government that is less sensitive to the prospects of the tax policy because this offsets the economic consequences of higher capital mobility on the tax rate.

Segendorff (1998) studies the effect of strategic delegation on the bargaining process between two countries for the provision of a transboundary public good. Countries are assumed to produce two goods, one private and the other public shared between the two nations. The ideal allocation of both goods is a function of the preferences of the citizens. In each country, the principal may delegate the task of the negotiations to a selected citizen that is appointed as agent. Although the analysis of Segendorff does not consider an electoral process, the principal may be thought as the decisive (median) voter and the agent as the government. The delegation is a two-stage game where in the first stage principals simultaneously choose agents and in the second stage the agents bargain over the global allocation of the public good. The bargaining is solved following the Nash bargaining solution where the threat point is given by the reservation utilities of the agents. Segendorff finds that its is better for the principals to choose an agent that has stronger preferences for the private good than their own because this lowers the reservation utility of the other agent and thus weakens its bargaining position.

Finally, Buchholz et al. (2005) is the only study on the effect of strategic delegation on IEAs. They study an IEA as a three-stage game, at the first stage citizens elect politicians (where the median voter elects his preferred candidate); at the second stage elected politicians negotiate over the level of economic activity and transfers (according to the Nash bargaining solution), if an agreement is reached then the agreement becomes binding, otherwise, countries adopt a non-cooperative policy (Nash equilibrium); if no agreement is reached, governments implement the non-cooperative policy that constitutes the threat point for the bargaining stage. The model comprises two symmetric countries that produce a domestic good and environmental damage both locally and abroad. Buchholz et al. show that in the equilibrium, each median voter chooses a government which cares less about the environmental problem than she does, because this improves the position of the government at the bargaining stage. These results hold irrespective of whether or not countries participate in an IEA. Furthermore, the elected governments of countries that sign an agreement are even less environmental concerned than those elected when countries do not cooperate. Hence, IEAs are not successful in tackling the environmental problem. In Chapter 8, I follow a similar approach to Buchholz et al. (2005). However, different from them, I study a model of two asymmetric countries, without transfers, for a pure public good. Furthermore, I study the stability of the resulting ICAs.

2.5. Conclusions

I explain in this chapter that endogenous coalition formation is often used to study IEAs and that it has provided many valuable insights. In particular, this approach helps to analyze the problems posed by the presence of positive externalities in these agreements. For the

particular interest of this thesis, I focus on ICAs. The analysis of IEAs and ICAs covers a wide spectrum of issues, such as the role of non-material payoffs, issue linkage and transfers. The main results from the literature show that full cooperation is difficult to attain, that when the gains of cooperation are large, free-rider incentives are string and stable coalitions reap only a small part of them, and that the size of stable coalitions depends to a large extent on how the benefits from cooperation are distributed. These results reflect the underlying set of assumptions about the analysis of ICAs. These assumptions may seem very restrictive. For instance, in actual political negotiations, governments often take decisions without explicitly considering welfare maximization criteria. Thus, the CPM assumption, which is used in many studies on ICAs, seems very restrictive. Furthermore, it is not clear what type of political process is behind the CPM behavior of countries. It is necessary to go beyond this assumption to include more elements of political economy into the analysis.

I have discussed in Section 2.4 three ways to improve the analysis on stability of ICAs. Firstly, the analysis could reflect features from the actual negotiations of international agreements. For instance, the analysis of voting mechanisms to restrict the accession of new members (see Chapter 4) and the effect of equity criteria on a permit trading scheme (see Chapter 5). Secondly, the CPM assumption might be replaced in order to recognize that a less uneven distribution of abatement burdens could have a positive impact on the participation and effectiveness of an ICA. This might be achieved through considering a uniform abatement quota (see Chapter 6). Thirdly, the assumption of welfare maximizing governments at the national level could be abandoned. Often government concerns are not exclusively focus on environmental policy and the influence of national political actors may be a determinant for the position of a government at the negotiation of an ICA. Thus, the analysis might be extended to include the effect of lobby groups (see Chapter 7) and strategic voting on the formation of ICAs (see Chapters 8).

Chapter 3. Empirical calibration of the Stability of Coalitions (STACO) model[*]

3.1. Introduction

We present in this chapter the specification and calibration of the functions used in the STAbility of COalitions (STACO) model. The aim of STACO is to analyze international environmental agreements to tackle climate change as a process of coalition formation. The model is used to determine which coalitions among regions are stable and what will be the corresponding effect on the regional abatement levels and global stock of CO_2. The STACO model calculates the payoff from CO_2 abatement for each possible coalition structure and compares the changes in payoffs for individual regions from leaving or entering a coalition – i.e. it tests for internal and external stability of an agreement (d'Aspremont et al. 1983). We follow the standard assumption in coalition formation theory in which members maximize the aggregated coalitional payoff, whereas singletons maximize their own payoff (Ichiishi, 1981; Ray and Vohra, 1997 and 1999). Note that we only look at CO_2 emissions and concentrations; other greenhouse gasses are, for simplicity, not included in the analysis.

Damages due to climate change would be likely to occur in the longer run, given that they depend on the accumulated levels of CO_2. Hence, it is essential for the model to choose a time horizon that is sufficiently long. The STACO model covers the time period from the year 2011 to 2110. Throughout this thesis, we denote with t all years in the model horizon, i.e. t=2011, 2012,…, 2110. STACO captures the net present value of the stream of payoffs generated between 2011 and 2110. Data for individual years between 2011 and 2110 are used to calculate the stock of CO_2 in 2110 and to calculate the net present value of benefits and

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[*] This chapter is a modified version of Dellink, R.B., Altamirano-Cabrera, J-.C., Finus, M., van Ierland, E.C., Ruijs, A. and H-.P. Weikard (2004). Empirical Background Paper of the STACO Model. Mimeo, Wageningen, Wageningen University.

abatement costs. Throughout this chapter, and the rest of this thesis, all prices ($) are in 1985 US dollars[1] unless indicated.

STACO considers twelve world regions. The regions are USA, Japan, European Union (EU-15) other OECD countries (O-OECD), Eastern European countries (EE), former Soviet Union (FSU), energy exporting countries (EEX), China, India, dynamic Asian economies (DAE), Brazil and 'rest of the world' (ROW).[2] The regions are denoted with a subscript i and the set of regions is denoted by N.

The structure of this chapter is as follows, in Section 3.2, we derive an expression for the total stock of CO_2 as a function of emissions and global abatement levels. In Section 3.3, we present the payoff function used in STACO. In Section 3.4, we derive an expression for environmental damages and benefits for the model. In Section 3.5, we derive the abatement cost function of STACO. In Section 3.6, we describe how we aggregate the components of the payoff function over time. Finally, in Section 3.7, we present the final function that is used in the analysis using STACO. [3]

3.2. Stock of CO2

We use the market scenario from the DICE model (Nordhaus, 1994) for the calculations of emissions and stock of CO_2. [4] In the market scenario there is no emission reduction, but the damages due to climate change are considered to have a negative impact on the global economy. Damages are expressed in monetary terms, as a result of a lower level of gross world product (GWP or global GDP). This implies that, in this scenario, there is a feedback loop from the environment to the economy. We use this scenario to calculate the reference

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[1] In line with Ellerman and Decaux (1998).

[2] EU-15 comprises the 15 countries of the European Union as of 1995. O-OECD includes among other countries Canada, Australia and New Zealand. EE includes, among others, Hungary, Poland, and Czech Republic. EEX includes, among others, the Middle East Countries, Mexico, Venezuela and Indonesia. DAE comprises South Korea, Philippines, Thailand and Singapore. ROW includes South Africa, Morocco and many countries in Latin America and Asia. For details, see Babiker et al. (2001).

[3] A full list of the parameters used in STACO is presented in Appendix 3A, Tables 3A1 and 3A2.

[4] In this thesis the original version of the DICE model is used (Nordhaus, 1994). Though there are more recent versions of the DICE model (e.g. Nordhaus, 2000), the original version has the advantage that its model specification, with its strengths and weaknesses, is widely known.

levels of emissions and stock of CO_2. We labeled these reference points as the uncontrolled level of emissions and uncontrolled stock of CO_2 respectively.

As we will explain in Subsection 3.4.1, we use a different damage function than DICE. Furthermore, the estimate of the damage impacts on the economy in a situation without abatement should reflect the damages envisaged in STACO[5]. This involves rescaling the damage function in the DICE model to be consistent with the damage function used in the STACO. To be precise, the parameter that governs the level of damages at a doubling of CO_2 concentrations is adjusted (as we discuss in Subsection 3.4.1), given that we consider that the stock of CO_2 is the main force driving adverse environmental impacts. The rescaling results in an 'adjusted' market scenario that provides the best expectation of the development of uncontrolled emissions and stock of CO_2 for the situation in which the regions do not react on climate change. This constitutes the reference scenario for STACO.

We derive the stock of CO_2 as a function of the uncontrolled emissions of CO_2 and the level of abatement. The analysis builds on Nordhaus (1994). Since greenhouse gases are uniformly mixing in the atmosphere, the stock of CO_2 is only relevant from a global perspective. Let $M_t(q_t)$ give the stock of CO_2 in period t as a result from a series of global abatement levels $q_{2011}, ..., q_t$, with $q_t = \sum_{i \in N} q_{i,t}$. The CO_2 stock in the year t depends on three components: (i) the pre-industrial stock of CO_2, (ii) the part of the stock of CO_2 in 2010 which remains in the atmosphere in year t, and (iii) the uncontrolled emissions minus the abatement of all regions between the years 2011 and t as long as they remain in the atmosphere in year t.

The CO_2 stock depends, firstly, on the pre-industrial stock of CO_2, $M_{pre-ind}$, that it is assumed to be an equilibrium level, i.e. this stock remains constant over time. Secondly, on the part of the stock of CO_2 in 2010 that remains in the atmosphere in year t. Each year a part of the excess stock of CO_2 above the pre-industrial level decays. The decay factor, or the annual removal rate of carbon, equals 0.00866, value taken from DICE. Thirdly, on the global uncontrolled net level of emissions between the years 2011 and t as long as this emissions remain in the atmosphere in year t. Emissions in the year 2010 are used as starting point for

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5 Given the feedback loops between environment and economy, damages have an indirect effect on the level of emissions.

calculating the uncontrolled emission levels between the years 2011 and 2110. We assume that global uncontrolled emissions E_t grow linearly over time. We estimate, using OLS regression, that $E_{t+1} = E_t + 0.153$. Furthermore, the starting value for emissions in 2010 is taken from our adjusted market scenario of the DICE model (see above) and equals $E_{2010} = 11.96$ Gton. Note that regional emissions $E_{i,t}$ are not given in DICE. The shares of the regions that we consider in the model are taken from Ellerman and Decaux (1998), the same source for STACO's abatement cost function.[6] Then, we assume that some fraction of the annual emissions remains in the atmosphere – set at 64%, based on the DICE model – and the remaining emissions decay over time (with a factor 0.00866). The carbon sinks take up the remainder of the annual emissions. CO_2 stock levels refer to the stocks at the end of the year. For that reason, emissions and abatement in 2010 are already included in the stock of 2010, and emissions in the year t itself are included in the stock of year t.

The stock of CO_2 in year t, M_t, then, can be expressed as:

$$
\begin{aligned}
M_t\left(q_{2011},...,q_t\right) = M_{pre-ind} + \left(1-0.00866\right)^{(t-2010)} \cdot \left(M_{2010} - M_{pre-ind}\right) \\
+ \sum_{s=2011}^{t} \left((1-0.00866)^{t-s} \cdot 0.64 \cdot \sum_{i\in N}\left(E_{i,s} - q_{i,s}\right)\right)_.
\end{aligned}
\tag{3.1}
$$

As a reference point, the uncontrolled stock of CO_2, i.e. in the absence of abatement, can be determined:

$$
\begin{aligned}
M_t\left(\mathbf{0}\right) = M_{pre-ind} + \left(1-0.00866\right)^{(t-2010)} \cdot \left(M_{2010} - M_{pre-ind}\right) \\
+ \sum_{s=2011}^{t} \left((1-0.00866)^{t-s} \cdot 0.64 \cdot \sum_{i\in N} E_{i,s}\right)_.
\end{aligned}
\tag{3.2}
$$

The uncontrolled stock can be directly calculated using expression (3.2) From the DICE model we estimate that the starting stock of CO_2 is $M_{2010} = 835$ Gton. This leads to an uncontrolled stock of CO_2 in 2110 of $M_{2110}\left(\mathbf{0}\right) = 1585$ Gton – see Figure 3.1. The actual

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[6] Note that these regional emissions only serve as reference point to the model and do not influence the results. The calculated regional emission shares are given in Appendix 3A, Table 3A2.

DICE calculations, using our adjusted market scenario, give a corresponding value of 1576 Gton. The difference between the STACO and the DICE stock of CO_2 is a result of the estimation on the development of emissions over time. STACO slightly overestimate the emissions in the last 25 years of the time horizon.
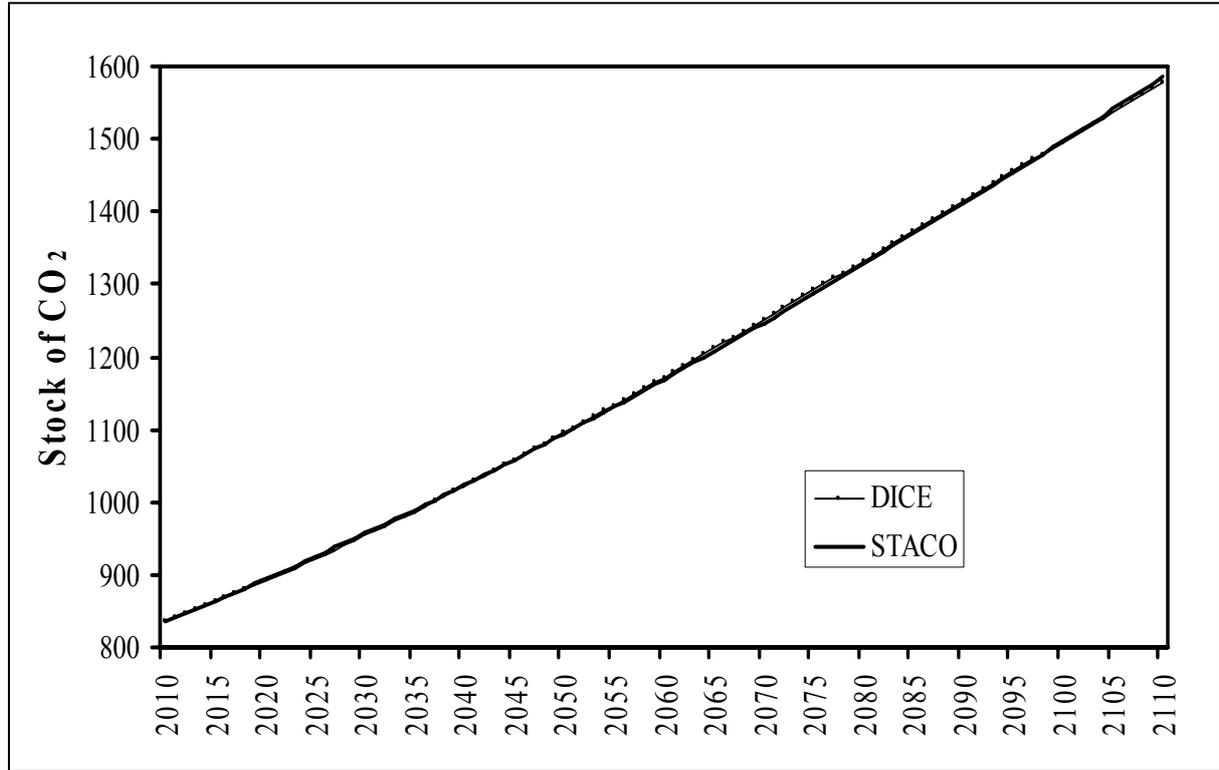
Figure 3.1   Uncontrolled stock of CO_2 in Gigaton according to the DICE market scenario and the STACO calibration.

Finally, considering (3.1) and (3.2), the controlled stock for abatement levels from 2011 onwards can be expressed as a function of the uncontrolled stock as follows:

$$M_t\left(q_{2011},...,q_t\right) = M_t\left(0\right) - \sum_{s=2011}^{t}\left(1-0.00866\right)^{t-s}\cdot 0.64\cdot q_s \; . \tag{3.3}$$

3.3. The payoff function

The payoff for region i at time t, $\pi_{i,t}\left(q_{i,t}\right)$, is defined as the regional benefits of global abatements minus the regional abatement costs

$$\pi_{i,t}\left(q_{i,t}\right) = B_{i,t}\left(q\right) - C_{i,t}\left(q_{i,t}\right). \tag{3.4}$$

This payoff function is the basic element for the game-theoretical analysis in this thesis. In the followings sections of this chapter, we explain how we calibrate the benefit and the abatement cost functions.

3.4. Environmental damages and benefits from abatement

STACO considers benefits from abatement that are equivalent to avoided environmental damages from emissions. In order to calculate the benefit function, we begin with an expression for damages as a function of the stock of CO_2; this is the basis to calculate a regional benefit function in order to match the specification that we have in expression (3.4). The calculation of regional benefits (regional avoided environmental damages) is done in three steps. Firstly, the functional form of the damage function is determined, giving global damages in year t as a function of the stock of greenhouse gases (and these as a function of abatement). From this the global benefit function is derived. Secondly, the parameter values for this global benefit function are determined. Thirdly, the global benefits are disaggregated over the regions. We explain these three points in the following subsections.

3.4.1. Global environmental damages

As a starting point for the global damage function we look at the specification of damages in DICE. In the DICE model, damages in time t are a function of the change in temperature:

$$D_t = \gamma_D \cdot \left[\frac{\Delta T_t}{3}\right]^2 \cdot Y_t \tag{3.5}$$

where D_t are total damages in billion US\$, γ_D is the impact on GDP due to an increase in temperature of $3^\circ C$, ΔT_t is the increase in world temperature and Y_t is global GDP.

However, for the STACO model we need damages as a function of the stock of CO_2. Following Germain and Van Steenberghe (2003), we use an approximation of the full climate module and specify a change in temperature directly as a function of the stock of CO_2:

$$\Delta T_t = \eta \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \tag{3.6}$$

where η is a parameter. Substituting equation (3.6) into equation (3.5) give us the global damages as a function of the stock of CO_2:

$$D_t = \left(\frac{\gamma_D}{9} \right) \cdot \left[\eta \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot Y_t \tag{3.7}$$

The value of η can be calculated by looking at the damages for a doubling of the stock. The DICE model assumes that a doubling of the CO_2 concentrations (i.e. $2 \cdot \left(M_{pre-ind} \right) = 1180 \, \text{Gtons}$) leads to an increase in temperature of 3 degrees at some year t – i.e. $\Delta T_t = 3$. Then, from (3.6), we obtain that $3 = \eta \cdot \ln \left(1180 \, \text{Gton} / 590 \, \text{Gton} \right)$ and thus $\eta = \frac{3}{\ln (2)}$. Substituting this back into (3.7) we get

$$D_t = \left[\frac{1}{\ln (2)} \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot \left(\gamma_D \cdot Y_t \right) \tag{3.8}$$

Note that in the damage function (3.8), damages implicitly are a function of the level of abatement, q_t, through the stock of CO_2, hence, we can express damages as $D_t \left(M_t \left(q_{2011}, ..., q_t \right) \right)$.

3.4.2. Empirical calibration of global damages and benefits

The STACO model maximizes the net benefits from abatement, see expression (3.4). The model uses a benefit function instead of a damage function, but note that benefits are equivalent to avoided damages. If alternatively damages were used, the optimization procedure would minimize total costs – i.e. damages plus abatement costs – and both procedures will yield the same output (see Diamantoudi and Sartzetakis, 2006). Thus, the benefits for STACO are calculated as avoided damages in the following fashion:

$$B_t(q_t) = D_t(M_t(\mathbf{0})) - D_t(M_t(q_t)). \qquad (3.9)$$

The next step in calibrating the benefit function is the choice of the scale parameter γ_D - the only unknown parameter in expression (3.8). Nordhaus uses a value of 0.0133 (*i.e.* 1.33% of GDP) for this parameter. However, it is often argued that the DICE estimate of environmental damages is rather low (Tol, 1996).[7] Therefore, we scale the global damage function using the more detailed study of Tol (1997), where the estimated year of doubling of concentrations is roughly in line with ours. Tol presents an estimate of total damage costs of 2.7% of GDP for a doubling of CO_2 concentrations, then $\gamma_D = 0.027$. The associated level of (undiscounted) GDP, Y_{2061}, is calibrated from the DICE model and equals 70,284 billion US\$[8].

3.4.3. Regional disaggregation of the benefits

The benefit function in (3.9) only corresponds to global benefits. In the STACO model, we use a regional benefit function. We introduce μ_i to denote the share of annual benefits for region i. The distribution of the benefits over the regions is based on Fankhauser (1995) and Tol (1997). However, comparing the numbers of Fankhauser (1995) and Tol (1997) is not straightforward. For instance, Fankhauser's numbers are based on purchasing-power-parity exchange rates, whereas Tol uses market exchange rates. Moreover, the categorization in regions varies significantly between them. For instance, Tol provides numbers for USA and

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[7] This is the case for both the original and later versions of the DICE model.

[8] This figure was obtained from the DICE model using a weighted average of the estimated GDP level in 2055 and 2065 and then adjusting the 1988 prices to 1985 prices, using US-OMB (2003), in order to make the numbers comparable with the abatement costs.

Canada together, while Fankhauser puts Canada in the category 'Other OECD'. Given that more detailed estimates are not available, it was unavoidable to make some *ad-hoc* decisions in order to have the estimates for the regional shares of STACO.

Two alternative sets of regional shares were constructed. The first alternative ('STACO calibration I') is primarily based on the estimates of Fankhauser (1995), which have relatively high shares for the OECD regions and relatively low shares for the non-OECD regions. As Fankhauser does not provide information for all regions in the STACO model, some additional assumptions have to be made. The second ('STACO calibration II'), is based as far as possible on Tol's estimates; again additional assumptions are required. The resulting calibrated absolute regional damage costs and the associated shares for both calibration alternatives are given in Table 1.

Table 3.1 Distribution of annual damage costs over different regions in absolute amounts and shares according to the two calibration alternatives.

Region	STACO calibration I		STACO calibration II	
	Absolute (billion US$)	$\% = \mu_i$	Absolute (billion US$)	$\% = \mu_i$
USA	61.0	22.6	64.8	12.4
Japan	46.5	17.3	59.6	11.4
EU-15	63.6	23.6	33.5	6.4
O-OECD	9.3	3.5	8.7	1.7
EE	3.5	1.3	6.8	1.3
FSU	18.2	6.7	18.2	3.5
EEX	8.1	3.0	15.9	3.0
China	16.7	6.2	32.5	6.2
India	13.4	5.0	89.5	17.1
DAE	6.7	2.5	44.8	8.5
Brazil	4.1	1.5	27.5	5.2
ROW	18.3	6.8	122.0	23.3
WORLD	269.5	100	523.8	100
Subtotal OECD	180.4	66.9	166.6	31.8
Subtotal non-OECD	89.1	33.1	357.2	68.2

In *STACO calibration I*, the data for USA are directly taken from Fankhauser (1995). Damages for Japan are disaggregated from 'Other OECD' assuming that Japan has damages five times higher than in the rest of the countries considered there – this estimate is based on the share of Japan in total GDP of 'Other OECD' plus Japan (World Bank, 2002). For the EU-15, we use the estimate of Fankhauser for the European Union. The damages for Other OECD countries (O-OECD) are 1/6 of Fankhauser's estimate for Other OECD. The total damages in the OECD countries for 'STACO calibration I' match Fankhauser (1995): 180.4 bln. US$. For Eastern Europe (EE), no damage estimate is available. Based on the share of this region in global GDP (World Bank, 2002), we assume the damage share of this region to be 1.3% of global damages. Fankhauser provides an estimate for the former Soviet Union (FSU) that can be directly used. The estimate of the damage share for energy exporting countries (EEX) is based on Tol's estimate for Middle East, 3.0%, as Fankhauser does not provide an estimate for this. The value for China is directly taken from Fankhauser. For the last 4 regions, India, dynamic Asian economies (DAE), Brazil and rest of the World (ROW), Fankhauser does not provide sufficient regional information. To match global damages with Fankhauser's estimate, the sum of the damages for these 4 regions have to equal 42.5 bln. $. These damages are attributed to the 4 separate regions using their relative shares calculated in the STACO calibration II as discussed below.

In *STACO calibration II*, the estimates of Tol (1997) are the basis for our numbers. Tol provides estimates for Northern America (USA and Canada), a wider range of countries in Europe and Pacific OECD countries. The shares for USA, Japan and EU-15 are derived by rescaling Tol's estimates such that total OECD damages equal 166.6 bln. US$. The share of STACO region O-OECD is taken from the first calibration alternative and equals 5.2% of total OECD damages. The share for EE in calibration II is based on the same assumption as in calibration I: 1.3% of global damages. For FSU, the negative estimate of Tol is rejected and the absolute damage estimate of Fankhauser is used. The EEX estimate can be directly taken from Tol. For China, the share of the region in global damages is taken from calibration I. Tol's estimate for Asia is divided into two-thirds for India and one-third for DAE. Tol gives damages for the whole of Latin-America, and we assume that the contribution of Brazil is 25% of that estimate. Finally, the share of ROW is calibrated such that the total damage estimate for non-OECD countries matches with Tol. Note that the share of this region is much higher than in Tol's estimate. This happens because in the STACO classification, ROW

also includes all centrally planned Asian countries except China (i.e. Vietnam, Laos, Mongolia, and North Korea) and all Latin-American countries except Brazil.

Based on these shares, the regional total benefits equal the product of the share of the region and global benefits:

$$B_{it}(q_t) = \mu_i \cdot B_t(q_t) \tag{3.10}$$

3.5. Abatement costs

The source for the abatement cost function is the EPPA model as reported by Ellerman and Decaux (1998). We rescale their parameters in order to make them compatible with those used in STACO – Ellerman and Decaux calculates abatement costs in million US$, whereas STACO calculate them in billion US$. We introduce ξ_i and ζ_i as parameters for calculating the undiscounted annual abatement cost function in the STACO model as a function of the total abatement over the century (in billion US$):

$$C_{it}(q_i) = \tfrac{1}{3}\xi_i q_i^3 + \tfrac{1}{2}\zeta_i q_i^2 \tag{3.11}$$

In Ellerman and Decaux (1998), the region other OECD countries (equivalent O-OECD region in STACO), which includes mainly Canada and Australia, has a negative value. This may lead to technical problems in the STACO model and hence the parameters for the region O-OECD are recalibrated under the assumption that $\xi_{O-OECD} = 0$. The value for ζ_{O-OECD} is chosen such that a best fit is achieved for the discounted marginal abatement cost curve as used in the STACO model.

3.6. Aggregation over time

The STACO model captures the net present value of the stream of payoffs generated between 2011 and 2110. This stream is calculated considering the assumption that there is a constant abatement path over the time horizon of the model – given that we assume a 'one-shot game' this is not a major drawback, see Chapter 1. Denote the century regional abatement level as

$q_i = \sum\limits_{t=2010}^{2011} q_{it}$ and the global as $q = \sum\limits_{i \in N} q_i$, hence, the payoff function for the discounted costs and benefits is:

$$\pi_i(q_i) = B_i(q) - C_i(q_i). \tag{3.12}$$

The discounted payoff function can also be derived by discounting the stream of payoffs over time:

$$\pi_i(q_i) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \pi_{it}(q_{i,t}) \right\}. \tag{3.13}$$

Note that (3.12) and (3.13) give identical results. In the following, we show how we aggregate over time the components of the payoff function.

3.6.1.Assessing paths of abatement levels over time

Some path of abatement levels has to be specified exogenously in order to convert the dynamic equation (3.3) to be suitable for a static model. This has the advantage that abatement costs would also be constant over time – thus, we abstract from technological change. Considering that $q_i = \sum\limits_{t=2010}^{2011} q_{it}$ and $q = \sum\limits_{i \in N} q_i$, then we can express the 2110 stock of CO_2, following (3.3), as a linear function of the (century) abatement level[9]:

$$M_{2110}(q) = 1585 - 0.429 \cdot q \tag{3.14}$$

---

[9] Note that q_i is the *sum* over the periods for region i, not the level for an individual year. The abatement level for individual years equal the century abatement level divided by the number of years: $q_{i,t} = q_i/100$.

3.6.2. Discounted benefits

The discounted total benefits for a given level of abatement q equals the net present value of the stream of benefits over the model horizon:

$$B(q) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot B_t(q) \right\} \tag{3.15}$$

With corresponding regional benefits

$$B(q) = \mu_i \cdot \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot B_t(q) \right\} \tag{3.16}$$

The value of the discount rate cannot be taken from data, but to some extent reflects a subjective evaluation of the time preference of consumers. The discount rate is assumed to be positive but rather low, $r = 0.02$ (Weitzman, 2001). A low discount rate ensures some weight on future damage costs.

In the relevant range of M_t, between M_{2010} and $M_{2110}(\mathbf{0})$, using (3.8), (3.9) and (3.16), we obtain that the non-linear function is virtually linear and reduces to

$$B_i(q) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \mu_i \cdot \gamma_D \cdot \left(\frac{1}{\ln(2)} \right)^2 \cdot Y_t \cdot \sigma \cdot \left(\frac{M_t(\mathbf{0}) - M_t(q)}{M_{pre-ind}} \right) \right\} \tag{3.17}$$

where σ denotes the constant slope of the linear approximation with $\sigma = 0.72$.[10] The linear approximation of the non-linear function is shown in Figure 3.2.

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[10] Note that in (3.17), given the presence of Y_t, total discounted benefits are given in billion 1985 US$; none of the other parameters have units and the gigatons from the stock cancel out in the last term of the expression.
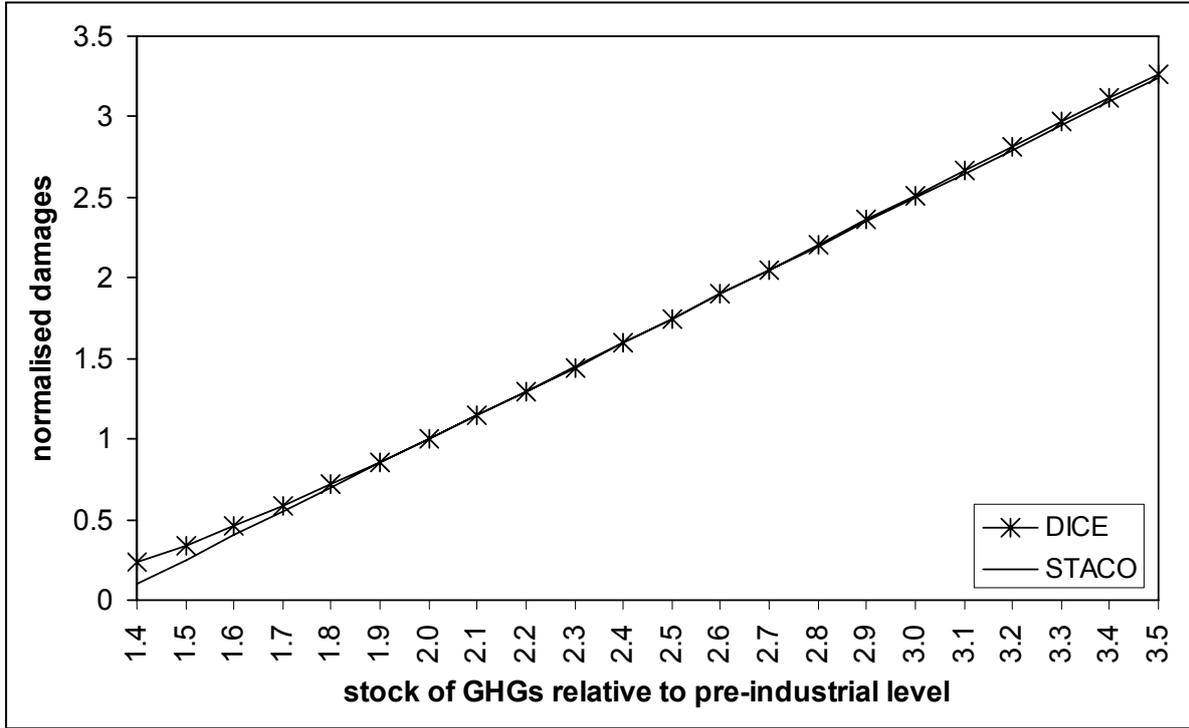
Figure 3.2 The normalized non-linear damage function based on the DICE model and the linear STACO approximation.

For sake of simplicity, the current version of the model is calibrated to a single observation for GDP, Y_{2061}, as this is the date of doubling of emissions. Alternatively, one could calibrate the model to a whole path of GDP levels for the entire century; however, from our estimates we find that the difference between both alternatives is less than 10 percent. Then, equation (3.17) can be rearranged to

$$B_i(q) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \mu_i \cdot \tau \cdot \left(M_t(0) - M_t(q) \right) \right\} \tag{3.18}$$

with $\tau = \gamma_D \left(\dfrac{1}{\ln(2)} \right)^2 \cdot Y_{2061} \cdot \left(\dfrac{1}{M_{pre-ind}} \right) \cdot \sigma = 4.815 \text{ billion US\$/Gton}$; then, using (3.2) and (3.3), we obtain

$$B_i(q) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \mu_i \cdot \tau \cdot \left(\sum_{s=2011}^{t} (1-\delta_M)^{t-s} \cdot 0.64 \cdot q/100 \right) \right\} \qquad (3.19)$$

Rearranging terms we get

$$B_i(q) = \mu_i \cdot \tau \cdot q \cdot \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \left(\sum_{s=2011}^{t} (1-\delta_M)^{t-s} \cdot 0.64/100 \right) \right\} \qquad (3.20)$$

To finally obtain

$$B_i(q) = \mu_i \delta_B \cdot q \qquad (3.21)$$

with $\delta_B = \tau \cdot \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot \left(\sum_{s=2011}^{t} (1-\delta_M)^{t-s} \cdot 0.64/100 \right) \right\} = 37.4\, \text{billion US\$/Gton}$.

As the stock of greenhouse gases is linear in the abatement level and damages are linear in the stock, it follows that the total benefit function is also linear in the global abatement level q. Hence, the global marginal benefits from reducing 1 ton of CO_2 spread over the 100 years do not depend on the abatement level and equal \$37.40.[11] This figure is in line with results from Plambeck and Hope (1996) who report that what they call their 'best' estimate for marginal benefits (in a regional scenario) falls within a range of US\$10-48 per ton of carbon considering a 90% confidence interval[12].

3.6.3. Discounted abatement costs

In order to derive the abatement cost function for STACO, we assume that the level of abatement is constant over time. Furthermore, the annual undiscounted abatement costs are also assumed to be constant over time, i.e. we do not account for any efficiency

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[11] We note that the slope of the benefit function as derived from the DICE model gives smaller marginal benefits: 18.42 \$/ton (this can be calculated by changing the scale parameter γ_D from 0.027 to 0.0133).

[12] Note that Plambeck and Hope's estimate is discounted to 1990, while our estimate is discounted to 2010. Discounting our estimate to 1990 leads to an estimate of marginal benefits of just over 25 \$/ton.

improvement. Hence, the total discounted abatement costs over the full model horizon can be calculated as the net present value of the stream of abatement costs over time

$$C_i(q_i) = \sum_{t=2011}^{2110} \left\{ (1+r)^{-(t-2010)} \cdot C_{it}(q_i) \right\} \tag{3.22}$$

We use r = 0.02 as in the discounting of benefits. Since $C_{i,2010} = C_{i,2011} = \cdots = C_{i,2110}$, equation (3.22) boils down to

$$C_i(q_i) = \delta_C \cdot \left\{ \tfrac{1}{3} \cdot \xi_i q_i^3 + \tfrac{1}{2} \cdot \zeta_i q_i^2 \right\} \tag{3.23}$$

with $\delta_C = \sum_{t=2011}^{2110} (1+r)^{-(t-2010)}$. For our calibration, we obtain that $\delta_C = 43.1$, and thus the discounted marginal abatement costs are $MC_i(q_i) = \delta_B \cdot \left\{ \xi_i \cdot q_i^2 + \zeta_i \cdot q_i \right\}$. The resulting MAC curves are represented in Figure 3.3. The curves are truncated at the point where abatement levels exceed 100 times the emissions in 2010, as this is the upper bound on abatement.
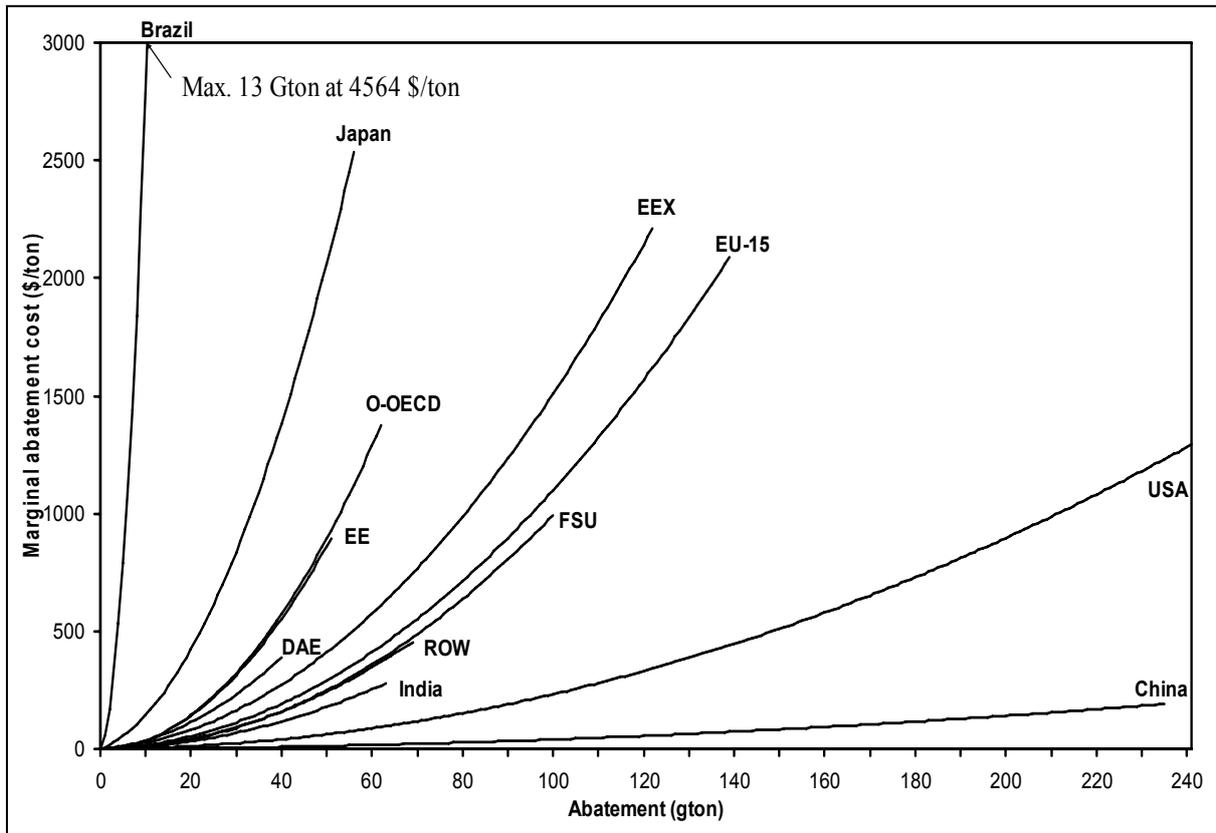
Figure 3.3 **Discounted marginal abatement cost functions for regions as calibrated in the STACO model (own calculations based on data from Ellerman and Decaux, 1998).**

3.7. STACO payoff function

Finally, considering (3.12), (3.21) and (3.23), the total discounted payoff function for the STACO model is

$$\pi_i\left(q_i\right) = \mu_i \cdot \delta_B \cdot q - \delta_C \cdot \left\{ \tfrac{1}{3} \cdot \xi_i \cdot q_i^3 + \tfrac{1}{2} \cdot \zeta_i \cdot q_i^2 \right\}. \tag{3.24}$$

Appendix 3A

Table 3A1 Parameter values

Symbol	Description	Value	Units	Source
E_{2010}	Global CO_2 emissions in year 2010	11.96	Gton	DICE model
$E_{i,2010}$	Regional CO_2 emissions in year 2010	see table 3A2	Gton	own calculation based on the EPPA model
$M_{pre-ind}$	pre-industrial level of CO_2-stock	590	Gton	DICE model
M_{2010}	Stock of CO_2 in 2010, starting point for calculations	835	Gton	DICE model
r	Annual discount rate	0.02	n/a	assumption
μ_i	Share of region i in global benefits	see table below	n/a	own calculation
ξ_i	Parameter for abatement cost function	see table below	n/a	EPPA model
ζ_i	Parameter for abatement cost function	see table below	n/a	EPPA model
γ_D	Scale parameter for damages and benefits (share of GDP)	0.027	n/a	Tol (1997)

Table 3A2 Regional parameters

Region	$E_{i,2010}$	μ_i (calibration 1)	μ_i (calibration 1)	ξ_i	ζ_i
	%	%	%		
USA	0.202	0.226	0.124	0.0005	0.00398
Japan	0.047	0.173	0.114	0.0155	0.18160
EU-15	0.117	0.236	0.064	0.0024	0.01503
O-OECD	0.052	0.035	0.017	0.0083	0
EE	0.043	0.013	0.013	0.0079	0.00486
FSU	0.084	0.067	0.035	0.0023	0.00042
EEX	0.102	0.030	0.030	0.0032	0.03029
China	0.197	0.062	0.062	0.00007	0.00239
India	0.053	0.050	0.171	0.0015	0.00787
DAE	0.034	0.025	0.085	0.0047	0.03774
Brazil	0.011	0.015	0.052	0.5612	0.84974
ROW	0.058	0.068	0.233	0.0021	0.00805
WORLD	1	1	1	-	-

Chapter 4. The Effect of Membership Rules and Voting Schemes on the Success of International Climate Agreements[*]

Abstract

We empirically test the role of membership rules and voting schemes for climate change coalitions with the STAbility of COalitions model (STACO). The model comprises twelve world regions and captures long-run effects of greenhouse gas accumulation. We apply three stability concepts that capture the notion of open membership and exclusive membership with majority and unanimity voting. We show that exclusive membership leads to superior outcomes than open membership and that unanimity voting is preferable to majority voting in welfare and environmental terms. Our results suggest restricting membership in future international environmental agreements and they provide a rationale for unanimity voting as applied in many international organizations.

4.1. Introduction

International environmental agreements (IEAs) are examples of collective action to tackle global problems such as global warming. Game theoretic analyses of the formation of IEAs stress the difficulties in designing self-enforcing treaties because of free-riding. The presence of a strong free-rider incentive prevents most IEAs of being stable and effective. The Kyoto Protocol is a clear example of this problem. For studying these problems, non-cooperative game theory has proved to be a very fruitful approach (e.g., Bauer, 1992; Hoel, 1992; Carraro and Siniscalco, 1993; Barrett 1994, 1997a; Hoel and Schneider, 1997; Jeppesen and Andersen, 1998; and Rubio and Ulph, 2003).[1] Key results that emerge from this literature are: a) only small coalitions are stable and b) whenever full cooperation (global optimum) would generate large global welfare gains compared to a no cooperation (Nash equilibrium), stable partial cooperation achieves only little.

A stability concept that has been widely used in non-cooperative game theory is 'internal and external stability'. Internal stability means that no coalition member has an incentive to leave the agreement to become a non-signatory. External stability means that no non-signatory has an incentive to join the agreement. This stability definition implies that countries can freely choose to join or leave the agreement. In particular, the definition of external stability means that there is no restriction on membership. Thus, coalition formation may be seen as an open membership game.

Open membership seems in line with evidence on IEAs. Almost all protocols of major IEAs have no provision that restricts membership. Moreover, intuition and results of the public goods literature suggest that global welfare increases with participation in an agreement and therefore any restriction on membership would hamper the effectiveness of IEAs. However, those results have been derived without considering the restriction that IEAs have to be self-enforcing. Hence, in the presence of free-rider incentives, it seems worthwhile to study the effect on coalition formation when membership is restricted. For instance from the empirical study of Botteon and Carraro (1997) on global warming it appears that some coalitions are internally but not externally stable. This suggests that some of these coalitions could be stabilized if coalition members had the opportunity to deny accession of new potential entrants. Moreover, recent theoretical results by Finus and Rundshagen (2003a, 2003b)

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[1] There is also a large literature applying cooperative game theory to study stability of IEAs (see, e.g., Chander and Tulkens, 1995, 1997; Germain et al., 2000; and an overview in Finus, 2001, 2003). This literature is mainly normatively oriented and has focused on measures to stabilize the efficient grand coalition implementing a socially optimal emission or abatement vector.

obtained from a general framework suggest that exclusive membership may help to stabilize IEAs. The reason is that - though still internal instability poses a problem to IEAs - external instability is less of a problem because members of an IEA under exclusive membership can better control the accession of non-signatories that may upset coalitional equilibrium. However, Finus and Rundshagen (2003a, 2003b) point out that it is not possible to conclude at a general level what 'more stability' means in terms of the success of IEAs. Therefore, it is the purpose of this paper to study by means of an empirical model the implications of exclusive membership in terms of global welfare and environmental variables (global emissions and stock of greenhouse gases). We consider two exclusive membership rules – one with (simple) majority voting and a second with unanimity voting.

Hence, our analysis is in the tradition of the public choice theory that analyzes the effect of different voting procedures for instance in parliament and various national and international organizations on the provision of public goods.[2] By and large, this literature has focused on voting schemes where a given number of participants decide either on various policy options (platforms) or on the level of a policy instrument. In this context, voting means for instance deciding on new trade laws or whether and by how much tariff barriers within WTO should be reduced, passing a resolution within the United Nation Council and deciding on the implementation of antitrust laws within the European Union.

In contrast, our model makes a particular assumption on the policy level and implicitly on the policy instrument, but analyzes voting on membership. As will be outlined in more detail in Section 4.2, our assumptions imply that coalition members do not only choose their abatement strategies cost-efficiently but also optimal from cost-benefit considerations of the coalition. Though we do not pay special attention to policy instruments, our assumption de facto implies that an efficient policy instrument (e.g., a uniform tax) is implemented within a coalition without compensation payments or any kind of redistribution of the gains from cooperation. Thus, in our model, inefficiency stems from free-riding. As mentioned above, we consider stability under two membership rules (open versus exclusive membership) and for exclusive membership we consider two voting schemes: majority voting and unanimity voting. Our voting schemes under exclusive membership are frequently applied in international treaties (that are not necessarily public good agreements), like the NATO, the European Union, WTO or the United Nations. For instance, NATO and WTO vote by unanimity on new members. In addition, a new permanent member in the Security Council is

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[2] In the general context see for instance Buchanan and Tullock (1962), McNutt (1996) and Mueller (2003) and in the context of environmental policy Hahn (1989), Sandler (1992), Hillman and Ursprung (1994), Michaelowa and Greiner (1996), Michaelowa (1998), Dijkstra (1999), Schneider and Volkert (1999), and Yandle (1999) and Böhringer and Vogt (2004).

only accepted if there is no veto. The decision on accession of ten new member states in the European Union is an example of different voting rules. First, accession had to be accepted by the European Parliament by a simple majority and subsequently the European Council had to approve the accession by unanimity (Euractiv, 2003).

We believe that our paper extends previous work in several directions. First, we consider stability of IEAs not only under open membership but also under exclusive membership and different voting rules. Second, we confirm several conclusions of theory that have been derived under very restrictive assumptions (e.g., symmetric countries or heterogeneous countries with two types of countries). Third, our analysis captures important long-run effects of greenhouse gas accumulation that have been ignored by the non-cooperative game theoretic literature on coalition formation by and large.[3] Fourth, in contrast to other empirical studies (e.g., Botteon and Carraro, 1997), our analysis captures a sufficient number of different actors (12 regions) that makes the strategic interaction in the context of global warming interesting.

In the following, we lay out the game theoretical part of the model in Section 4.2 and the empirical part in Section 4.3. In Section 4.4, we discuss environmental and welfare aspects of coalition formation of our base case scenario and in Section 4.5 we report on results of various sensitivity analyses. Section 4.6 summarizes the main findings, draws policy conclusions and concludes with some remarks about future research issues.

4.2. Theoretical Background of the Model

4.2.1. The Structure of Coalition Formation

Coalition formation is modeled as a *two-stage game*. In the *first stage,* countries or regions $i \in I$ decide on their *membership* in a coalition; in the *second stage,* coalition members choose their *abatement strategies*. In the *first stage,* we assume that countries can choose between two membership strategies: 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'. This implies that countries that announce $\sigma_i = 0$ (signatories) form a singleton coalition and those that announce $\sigma_i = 1$ (non-signatories) become members of a non-trivial coalition (i.e., a coalition of at least two members). A particular set of announcements leads to a coalition structure

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[3] Exceptions are for instance Buchner et al. (2002), Bosello et al. (2003), Rubio and Ulph (2003) and Tol (2001).

(i.e., partition of players) $c = (c^S, 1, ..., 1)$. If country i and j are members of c^S in coalition structure $c = (c^S, 1, ..., 1)$, we will call this simply a coalition between country i and j; if $c^S = \{i\}$, we call this the *'singleton coalition structure'* and if $c^S = I$, we call this the *'grand coalition'*.

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

$$\pi_i(q) = \sum_{t=1}^{T} (1 + r_i)^{-t} (B_{it}(q_t) - AC_{it}(q_{it})) \tag{4.1}$$

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. 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 with no abatement.

In Section 4.3, we will lay out in detail how global abatement relates to global emissions and the stock of greenhouse gases and how this affects payoffs. At this stage, it suffices to note that we follow the standard assumption in coalition theory that countries belonging to the same coalition maximize the aggregate payoff to their coalition (Bloch, 1997). 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. That is, 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 coalition structure (grand coalition) implies an equilibrium abatement strategy vector corresponding to the 'classical' Nash equilibrium (global optimum). Thus, the highest global payoff will be obtained in the grand coalition. For the calibration of the payoff functions (also called net benefit functions below) - on which we report in Section 4.3 - it turns out that the equilibrium abatement vector q^* (for all coalition structures $c \in C$) is unique and lies well within the boundaries of the abatement space as defined above ($q_{it} \in [0, e_{it}^{BAU}]$).

Since the strategies in the second stage are fixed, the entire coalition formation game reduces to one single stage. This reduced stage game looks as follows: each country chooses its membership strategy, σ_i, the strategy vector $\sigma = (\sigma_1, ..., \sigma_N)$ is mapped into coalition structure c, leading to *valuations* $\upsilon = (\upsilon_1, ..., \upsilon_N)$, i.e., a payoff vector associated with a particular coalition structure. Hence, stability can be defined in terms of membership strategies σ.

4.2.2. Stability of Coalition Structures

Regardless of the membership rule, a coalition structure is only called stable if it satisfies the condition of *internal stability*. Internal stability means that no country i that is a member of coalition c^S because it announced $\sigma_i^* = 1$ (signatory) has an incentive to change its announcement to $\sigma_i = 0$ (and hence becoming a non-signatory), given the announcements of all other countries σ_{-i}^*. However, a stable coalition structure must also satisfy the condition of *external stability*. Under open membership, external stability means that no singleton j that announced $\sigma_j^* = 0$ (non-signatory) has an incentive to change is announcement to $\sigma_j = 1$ (an hence becoming a signatory), given the announcements of all other countries σ_{-j}^*. Clearly, if a coalition structure is externally stable under open membership, it will also be stable under exclusive membership. However, suppose that there is an incentive for a non-signatory to join coalition c^S (implying instability under open membership). Then, under exclusive membership, current members will vote on accession. Under majority voting, accession will only be accepted if a majority of current signatories benefits from accession, under unanimity, this is only the case if all members are better off after accession than before. Hence, it is evident that it is more difficult to upset an equilibrium coalition structure under exclusive membership than under open membership and under exclusive membership it is more difficult to upset an equilibrium under unanimity voting than under majority voting. Thus, abbreviating the set of equilibrium coalition structures under open membership, exclusive membership with majority voting and exclusive membership with unanimity voting by C(OM), C(EM-M) and C(EM-U), then $C(OM) \subset C(EM-M) \subset C(EM-U)$ must hold by simple theoretical reasoning. Therefore, the interesting question is: what does 'more or less stability' imply for coalition formation and, in particular, what are the environmental and welfare implications? At a theoretical level, this question can only be answered for very restrictive assumptions such as symmetric payoff functions (see, e.g., Finus and Rundshagen 2003a, 2003b). Therefore, it is important to analyze this question in an empirical context as we do in Sections 4.4 and 4.5.

Note finally that modeling coalition formation game as an announcement game implies that existence of an equilibrium is guaranteed: the singleton coalition structure is stable by definition. The reason is simple: suppose each country announces $\sigma_i = 0$, then no single country can induce another coalition structure by changing its announcement.

4.3. Empirical Background of the Model

4.3.1. Introduction

In this section, we describe the calibration of payoff function (4.1). 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 climate 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 number of different players. We consider twelve world regions. Since this requires disaggregated 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 and Decaux (1998). We set up an empirical model that we call *sta*bility of *co*alitions model, henceforth abbreviated STACO. STACO captures essential features of the long-run effects of greenhouse gas accumulation, but in a simple way.

In the following, we proceed in five steps. First, we describe the relation between emissions and stock of greenhouse gases. Second, we discuss damages implied by concentration. Third, we show how we derive benefit functions from damage cost functions. Fourth, we report on 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 Appendix 4A; a detailed description of the model is available from the authors upon request (Dellink et al., 2003).

4.3.2. 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 an excellent fit for the development of the stock of carbon dioxide:

$$e_{t+1} = e_t + d_E \tag{4.2}$$

where d_E denotes the uncontrolled annual *absolute* growth of global emissions, and $e_t = \sum_{i=1}^{N} e_{it}$. 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 (4.1), t=2011, ..., T=2110. For the starting value of emissions in 2010, we choose the value of DICE, which amounts to 11.96 gigatons CO_2. We estimate d_E in order to get the best fit for the development of stock of carbon dioxide in the atmosphere, M_t, in the market scenario of the DICE model.[4] This gives $d_E = 0.153$ gigatons per year.

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

$$M_t \left(q_{2011}, ..., q_t \right) = M_{pre-ind} + \left(1 - \delta \right)^{(t-2010)} \cdot \left(M_{2010} - M_{pre-ind} \right) + \sum_{s=2011}^{t} \left(\left(1 - \delta \right)^{t-s} \cdot \omega \cdot \left(e_s - q_s \right) \right) \tag{4.3}$$

That is, the stock at time t, M_t, depends on global emission and 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 (4.2), 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.

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[4] The error between the estimated stock and the stock according to DICE is smaller than 0.6 % in all periods.

For game theoretical tractability, we assume stationary abatement strategies, which implies that optimal annual emission reduction by region, $q_{it} = q_i / 100$, is constant over time. Again, a comparison with simulations with DICE shows that the bias introduced through this simplification is of minor importance when considering aggregate effects.

4.3.3. Benefit Functions

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.

$$D_t = \gamma_D \cdot \left[\frac{\Delta T_t}{3} \right]^2 \cdot Y_t \tag{4.4}$$

However, in order to establish a direct link between concentration and damages, we follow Germain and Van Steenberghe (2003), who use the following approximation of the full climate module:

$$\Delta T_t = \eta \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \tag{4.5}$$

where η is a parameter. Substituting (4.5) into (4.4), gives:

$$D_t = \left(\frac{\gamma_D}{9} \right) \cdot \left[\eta \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot Y_t \tag{4.6}$$

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.[5] Thus from (4.5), $\eta = 3 / \ln(2)$, which leads to:

$$D_t = \left[\frac{1}{\ln(2)} \cdot \ln \left(\frac{M_t}{M_{pre-ind}} \right) \right]^2 \cdot \left(\gamma_D \cdot Y_t \right) \tag{4.7}$$

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

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):

$$D_t = \left[\gamma_1 + \gamma_2 \cdot \left(\frac{M_t}{M_{pre-ind}} \right) \right] \cdot \left(\gamma_D \cdot Y_t \right) \qquad (4.8)$$

where γ_1 and γ_2 are calculated via OLS-regression.[6]. As the stock of carbon dioxide (see equation 4.3) is linear in abatement assuming stationary reduction strategies, damages as specified in equation 8 are also linear in abatement. 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 $\gamma_D = 0.027$.

Noticing that benefits from abatement can be interpreted as the difference between damages without and with abatement

$$B_t(q) = D_t(M_t(q=0)) - D_t(M_t(q>0)) \qquad (4.9)$$

and summing (4.9) over all periods, assuming a discount rate of 2 percent, gives discounted global benefits of emission reduction $TB(q) = 37.40 \cdot q$ in period 2010-2110. This implies discounted marginal global benefits of 37.40 US\$ per ton CO_2. This figure is in line with results by Plambeck and Hope (1996) who report that their best estimates of marginal global benefits of emissions reduction in a regional scenario fall within the range of 10 to 48 US\$ per ton CO_2.

In a final step, we have to allocate global benefits from abatement to the various world regions based on the assumption that $TB_i(q) = s_i \cdot TB(q)$ where s_i is the share of region i. We consider 12 regions: USA, Japan, European Union (EU-15), other OECD countries (O-OECD), Eastern European countries (EE), former Soviet Union (FSU), energy exporting countries (EEX), China, India, dynamic Asian economies (DAE), Brazil and 'rest of the

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[6] Given our interpretation of γ_D, damages equal $\gamma_D \cdot Y_t$ for a doubling of concentrations. Hence, we can impose $\gamma_1 = 1 - 2 \cdot \gamma_2$ and estimate γ_2. OLS gives $\gamma_2 = 1.497$ with standard error 0.011 (t-value: 136.2) and adjusted R^2=0.998, indicating an almost perfect fit.

world' (ROW). In the following, we use the abbreviations in brackets.[7] The allocation is a difficult task since no source of regional benefit estimates (reduced regional damage costs) is available that exactly matches with our regions. However, two sources come relatively close to our regional specification: Fankhauser (1995) and Tol (1997). Both estimate monetized damages for a doubling of CO_2 concentrations for various world regions, including damages due to increased mortality rates, species and ecosystem losses, changes in agricultural yields, sea level rise and extreme weather events. However, due to the large uncertainties involved, regional estimates vary substantially between both sources. Thus, we use both sources to derive regional shares of global benefits from emission reduction as displayed in Table 4.1.[8]

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[7] EU-15 comprises the 15 countries of the European Union as of 1995. O-OECD includes among other countries Canada, Australia and New Zealand. EE includes for instance Hungary, Poland, and Czech Republic. EEX includes for example the Middle East Countries, Mexico, Venezuela and Indonesia. DAE comprises South Korea, Philippines, Thailand and Singapore. ROW includes for instance South Africa, Morocco and many countries in Latin America and Asia. For details, see Babiker et al. (2001).

[8] Since Fankhauser´s and Tol´s regional specifications do not completely match with ours, some adjustment for our purposes is needed. Fankhauser's estimates have been used for industrialized countries, whereas for developing countries further disaggregation was based on information from the study of Tol. Because of space limitations, the interested reader is referred to the original papers of Fankhauser and Tol, and for the details of our adjustment to our empirical background paper (Dellink et al. 2003) that is available upon request from the authors.

Table 4.1 Emissions, Benefit and Abatement Cost Parameters*

Regions	Emissions in 2010 (Gton)	Share of global benefits s_i	Abatement cost parameter α_i	Abatement cost parameter β_i
USA	2.42	0.226	0.0005	0.00398
Japan	0.56	0.173	0.0155	0.18160
European Union	1.4	0.236	0.0024	0.01503
Other OECD Countries	0.62	0.035	0.0083	0
Eastern European Countries	0.51	0.013	0.0079	0.00486
Former Soviet Union	1	0.068	0.0023	0.00042
Energy Exporting Countries	1.22	0.030	0.0032	0.03029
China	2.36	0.062	0.00007	0.00239
India	0.63	0.050	0.0015	0.00787
Dynamic Asian Economies	0.41	0.025	0.0047	0.03774
Brazil	0.13	0.015	0.5612	0.84974
Rest of the World	0.7	0.068	0.0021	0.00805
World	11.96	$\sum s_i = 1$		

4.3.4.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:

$$AC_{it}\left(q_{it}\right) = \tfrac{1}{3} \cdot \alpha_i \cdot \left(q_{it}\right)^3 + \tfrac{1}{2} \cdot \beta_i \cdot \left(q_{it}\right)^2 \qquad\qquad (4.10)$$

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[9]. Second, we replace q_{it} by $q_i/100$ in (4.10) 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 $\alpha_i = 0$ in this case and re-estimate β_i for OOE. All estimates are displayed in the last two columns in Table 4.1. Fourth, in our model abatement means emission reduction with respect to BAU-emissions. Thus, we

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[9] In the specification of the STACO model all market values are expressed in billion US$ of 1985 using the deflator provided by US-OMB (2002). This applies to damages, benefits and abatement costs.

allocate total initial emissions of 11.96 gigatons (see Table 4.1) to the 12 regions, using the shares of Ellerman and Decaux (1998). This gives the numbers in the second column in Table 4.1. This implies that we assume not only global emissions to grow linearly with d_E (see equation 4.2) but also regional emissions, however, according to their shares in global emissions.

In order to derive total abatement costs of region i, $TAC_i(q_i)$, we sum (4.10) 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 Chapter 3, Figure 3.3.

4.3.5. Payoff Function

Using the information of Sections 4.3.3 and 4.3.4, gives the following payoff function:

$$\pi_i = TB_i(q) - TAC_i(q_i) \tag{4.11}$$

Since we consider 12 world regions, this gives rise to 4096 different membership strategy vectors in the first stage of the coalition formation game. 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 $\sigma_i = 0$, the set of coalition structures, C, comprises 'only' 4084 different coalition structures. For each coalition structure, we compute valuations according to the assumption of the second stage of the coalition formation game that coalition members jointly maximize the aggregate payoff to their coalition (see Section 4.2). For coalition structure c = (c^S, 1,...,1), $\sum_{i \in c^S} MTB_i(q) = MTAC_i(q_i)$ holds for a member i of coalition c^S in equilibrium and for a singleton j $MTB_j(q) = MTAC_j(q_j)$. Thus, joining coalition c^S has the advantage that own abatement efforts are matched by other members, implying higher benefits, but also higher abatement costs. The relation of the benefit and cost effect determines whether a coalition is stable, which is checked in Section 4.4.

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. This implies that if regions form a coalition, and thereby increasing their abatement efforts, this is not offset by a reduction of abatement efforts by outsiders. In other words, in our model no leakage effects occur. According to theory (Carraro and Siniscalco, 1998; and Finus, 2003), this is the most favorable condition for forming stable coalitions. Nevertheless, as will be apparent from subsequent sections, cooperation proves very difficult.

Finally note that in the context of our empirical model, individual rationality is a necessary condition for internal stability of a coalition and hence a necessary condition under open but also under exclusive membership. Individual rationality implies that 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 cannot be stable, regardless of the membership rule.[10]

4.4. Results of the Base Case

4.4.1.Introduction

From the previous discussion it is evident that in particular the estimation of benefits from global abatement is associated with some uncertainty. This concerns primarily the level of damages (that translates into the level of benefits from abatement) represented by the parameter γ_D. Hence, we discuss first the 'base case' value of $\gamma_D = 0.027$ in Section 4.4 and then conduct a sensitivity analysis in Section 4.5 where we consider different levels of this value.

In order to gain insight in the fundamental features of our model, we discuss first three benchmark scenarios in subsection 4.4.2: 1) the *singleton coalition structure*, implying no cooperation. 2) The *grand coalition*, implying full cooperation. 3) The *Kyoto coalition* that constitutes partial cooperation. Here we assume that the members of the original Kyoto Protocol (before the USA withdrew from the Protocol) form a coalition, which includes USA, Japan, the European Union (EU-15), other OECD countries (O-OECD), Eastern European countries (EE) and the former Soviet Union (FSU). Subsequently, we report on results of our stability check (subsection 4.4.3).

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[10] A proof is available upon request from the authors.

4.4.2. Benchmark Scenarios

a) Singleton Coalition Structure

Table 4.2 reports results if each region acts by itself, corresponding to the 'classical' Nash equilibrium with no cooperation. In equilibrium, marginal abatement costs are equal to marginal benefits for each region. Annual global emission reduction amounts to only 4.6 percent. This implies a global stock of CO_2 of 1,561 gigatons in 2110. This is about 2.5 times of the pre-industrial level. 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 3.3 in Chapter 3 and Table 4.1, Section 4.3) and marginal benefits from abatement (see Table 4.1, Section 4.3) between regions. For instance, USA has a relatively flat marginal abatement cost curve. Hence, in the absence of cooperation, USA has an incentive to reduce annual emissions by 6.7 percentage because of her high marginal benefits from abatement. A similar argument applies to China that has an even flatter marginal abatement cost curve, though lower marginal benefits from abatement compared to USA. In contrast, regions like Brazil and dynamic Asian economies (DAE) have virtually no incentive at all to conduct emission reductions by themselves because of steep marginal abatement cost curves and low marginal benefits from abatement.

Table 4.2 Singleton Coalition Structure (Nash Equilibrium)

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Net benefits	Marginal abatement costs	Marginal benefits
	Gton (over 100 years)	% 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
Japan	1	1.4	2	357	354	6.5	6.5
EU-15	7	4.7	24	488	464	8.8	8.8
O-OECD	2	3.1	1	71	71	1.3	1.3
EE	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
China	15	6.6	16	128	112	2.3	2.3
India	3	5.3	3	103	101	1.9	1.9
DAE	1	1.3	0	52	51	0.9	0.9
Brazil	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

* EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

b) Grand Coalition

Table 4.3 displays results for the grand coalition that corresponds to the 'classical' global optimum with full cooperation. In equilibrium, marginal abatement costs are equal across countries and amount to 37.4 US$/ton - a value that is in the range of many other empirical studies (e.g., Weyant 1999). At the aggregate level, the reduction of annual emission reductions amount to 21.4 percent, exceeding those in the singleton coalition structure by a substantial amount. Nevertheless, the effect on the final stock of CO2 is only moderate - a feature reminiscent also to most computable general equilibrium models: it amounts to a reduction of only 5.5 percentage compared to the singleton case and 6.9 percent compared to BAU. The reason is that the airborne fraction of CO2-emissions that remains in the atmosphere is only 64 percent and the annual natural removal rate of 0.86 percent levels off differences between both scenarios over a period of 100 years. However, the gains from cooperation are considerable: the total payoff (benefits minus abatement costs) in the grand coalition is 6,031 billion US$, which implies a gain of 208 percent compared to the singleton

coalition structure. This figure highlights the relevance of cooperation in the case of climate change.

A closer inspection of individual regions reveals that, in terms of total emission reduction, China, USA and India have to contribute more than other regions to a globally optimal solution due to their flat marginal abatement cost curves. For Eastern European countries (EE) and China 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 Table 4.3, column 6. Those regions have to contribute much to cooperation but benefit only little in the form of reduced damages. Therefore, it is clear that the grand coalition is not stable. Moreover, a more detailed analysis considering the last column of Table 4.3 reveals that all regions, except Japan and the European Union (EU-15), have an incentive to leave the grand coalition. Considering the absolute amount of the gains from leaving the grand coalition suggests that most regions face a strong free-rider incentive.

Table 4.3 Grand Coalition (Global Optimum)*

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Net benefits	Marginal abatement costs	Incentive to leave coalition
	Gton (over 100 years)	% of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	US$/ton	bln US$ over 100 years
USA	38	15.7	513	2,169	1,656	37.4	23.6
Japan	4	6.5	63	1,653	1,590	37.4	-123.8
EU-15	16	11.5	229	2,262	2,033	37.4	-180.1
O-OECD	10	16.5	127	331	203	37.4	109.6
EE	10	19.6	130	125	**-6**	37.4	124.9
FSU	19	19.3	242	647	405	37.4	178.1
EEX	12	10.2	188	288	99	37.4	169.9
China	96	40.6	1,348	594	**-754**	37.4	1133.2
India	22	33.8	295	479	184	37.4	245.8
DAE	10	25.1	155	239	84	37.4	142.1
Brazil	1	5.5	12	147	135	37.4	10.0
ROW	19	26.5	250	652	401	37.4	185.1
World	256	21.4	3,553	9,584	6,031		-

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

* Last column: gain from leaving coalition if all other regions remain in coalition, EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

c) Kyoto Coalition

Table 4.4 displays results for the Kyoto coalition. According to our assumption, this implies that the first six regions (indicated in italics in Table 4.4) jointly maximize the aggregate payoff to their coalition and therefore marginal abatement costs of these regions are equal. The annual global emission reduction 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 3,140 bln US$, 60 percent higher than in the Nash equilibrium.

However, regardless of the membership rule, the Kyoto coalition is not stable since internal stability is violated. First, individual rationality is violated for three coalition members: other OECD countries (O-OECD), Eastern European countries (EE) and the former Soviet Union (FSU) would be worse off than in the singleton coalition structure as indicated by bold faced numbers in Table 4.4, column 6. Second, 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 4.4. This result

together with our finding that the USA will already conduct relative high abatement without cooperation (see Table 4.2) 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.[11]

Table 4.4 Kyoto Coalition*

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

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

* Last column: gain from changing membership strategy if all other regions stick to their membership strategy; EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

Not surprising, all six outsiders are better off than in the Nash equilibrium since they benefit from the abatement efforts of the Kyoto coalition. More surprising is the fact that none of the outsiders has an incentive to join the coalition, which follows from the negative number in the last column in Table 4.4. 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.

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[11] It should be pointed out that our analysis does not consider permit trading. However, at the time of the withdrawal of the USA, it was still under discussion whether a permit trading system will be established at all and whether trade will be unrestricted.

4.4.3.Stability Analysis

We checked all 4084 coalition structures for stability under open membership, exclusive membership with majority voting and exclusive membership with unanimity voting with an algorithm programmed with the software package Matlab. We found no non-trivial coalition structure that is stable under open membership.[12] Whereas more than 800 coalition structures are externally stable (under open membership), only 14 coalition structures are internally stable. Thus, it seems that the main problem of cooperation is internal instability due the presence of strong free-rider incentives to leave a coalition. Nevertheless, under exclusive membership and majority voting at least one out of the 14 internally stable coalitions is externally stable of which the results are displayed in Table 4.5.

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[12] 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.

Table 4.5 Coalition between Former Soviet Union, Brazil and Rest of the World*

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Net benefits	Marginal abatement costs	Incentive to change membership strategy
	Gton (over 100 years)	% of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	US$/ton	bln US$ over 100 years
USA	16	6.7	53	511	458	8.5	61.4
Japan	1	1.4	2	390	387	6.5	45.0
EU-15	7	4.7	24	533	509	8.8	76.1
O-OECD	2	3.1	1	78	77	1.3	-4.0
EE	1	1.8	0	29	29	0.5	-6.6
FSU	7	7.4	14	153	138	5.6	-1.4
EEX	1	0.7	0	68	67	1.1	-6.0
China	15	6.6	16	140	124	2.3	-49.0
IND	3	5.3	3	113	110	1.9	-8.5
DAE	1	1.3	0	56	56	0.9	-5.2
Brazil	0	1.1	0	35	34	5.6	-0.1
ROW	6	8.9	14	154	140	5.6	-1.5
World	60	5.1	129	2,260	2,131	-	-

Global stock of carbon dioxide by 2110 = 1,559 Gton

* Stable under exclusive membership, majority and unanimity voting. Last column: gain from changing membership strategy if all other regions stick to their membership strategy. EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

From Table 4.5 it is evident that internal stability holds 'at the margin'. Each of the three members (indicated in italics) would only slightly loose by leaving the coalition as shown in the last column. Moreover, each member only slightly gains compared to the singleton coalition structure (see Table 4.2). Of course, non-signatories gain more since they benefit from additional abatement efforts of the coalition without carrying additional abatement costs.

Overall, this coalition only marginally improves upon the singleton case. Global net benefits are 2,131 billion US$ whereas in the singleton coalition structure they are 1,960 billion US$. This implies only an improvement of 8.7 percent, a rather modest contribution to tackle global warming given that the global optimum would imply an improvement of almost 208 percent. In other words, stable partial cooperation can only slightly reduce the gap between the Nash equilibrium and the global optimum - a phenomenon confirmed by all other results

discussed below. The reason is closely related to the fundamental features of coalition formation.

Internal stability will only hold for coalitions that slightly increase their abatement efforts compared to the singleton coalition structure. If abatement efforts were more ambitious, the free-rider incentive would become too strong so that internal stability would fail to hold. For instance, in the context of a coalition between FSU, Brazil and ROW, all three members have relatively high marginal abatement costs compared to marginal benefits from abatement. Hence, these regions increase their abatement efforts only slightly compared to the singleton coalition structure. Consequently, annual global emission reduction is 5.1 percent, which is only slightly higher than in the singleton coalition structure, which amounts to 4.6 percent. Thus, the conjecture would be wrong that stable coalitions are formed by the 'good guys' and outsiders are the 'bad guys'. For instance, Brazil´s annual emission reduction is 1.1 percent in this coalition whereas the outsiders USA, European Union (EU-15) and China reduce their emissions on average by 6.7, 4.7 and 6.6 percent, respectively.

In terms of *external stability,* it is evident that only USA, Japan and EU-15 have an incentive to join the coalition formed by FSU, Brazil and ROW. The reason is that the potential entrants would receive a large portion of the gains from joint cooperation: these regions have high marginal benefits from global abatement compared to their contribution to joint abatement in a coalition (because of relatively steep marginal abatement cost curves). It is exactly for this reason why their application for accession is turned down by a majority of regions in the coalition.

The explanations about internal stability also help to rationalize participation in stable coalitions. Only coalitions including members that agree on low abatement targets and where members exhibit a similar cost-benefit structure are stable (e.g., FSU, Brazil, ROW). High abatement targets would imply a high free-rider incentive. A heterogeneous cost-benefit structure (e.g., including additionally USA, Japan or EU-15) would imply an asymmetric distribution of the gains from cooperation, putting some countries at disadvantage, which have therefore an incentive to leave the coalition.

Of course, by definition, the coalition between FSU, Brazil and ROW is also stable under unanimity voting. However, the following two coalition structures, listed in Table 4.6 and 4.7, are only stable under exclusive membership and unanimity voting, but not under majority voting.

Table 4.6 Coalition between China and Dynamic Asian Economies*

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Net benefits	Marginal abatement costs	Incentive to change membership 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$/ton	bln US$ over 100 years
USA	16	6.7	53	515	462	8.5	253.0
Japan	1	1.4	2	393	390	6.5	157.8
EU-15	7	4.7	24	537	513	8.8	276.2
O-OECD	2	3.1	1	79	78	1.3	5.2
EE	1	1.8	0	30	29	0.5	-1.8
FSU	5	4.9	4	154	149	2.5	23.8
EEX	1	0.7	0	68	68	1.1	3.0
China	20	8.5	28	141	113	3.2	-0.6
India	3	5.3	3	114	111	1.9	10.7
DAE	2	4.1	3	57	54	3.2	-2.9
Brazil	0	0.1	0	35	35	0.6	1.4
ROW	4	5.3	4	155	151	2.5	24.1
World	61	5.1	123	2,277	2,153	-	-

Global stock of carbon dioxide by 2110 = 1,559 Gton

* Stable under exclusive membership and unanimity voting. Last column: gain from changing membership strategy if all other regions stick to their membership strategy; EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

Table 4.7 Coalition between Energy Exporting Countries and China*

Regions	Total emission reduction	Annual emission reduction	Total abatement costs	Total benefits from abatement	Net benefits	Marginal abatement costs	Incentive to change membership strategy
	Gton (over 100 years)	% of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	US$/ton	bln US$ over 100 years
USA	16	6.7	53	524	471	8.5	254.6
Japan	1	1.4	2	400	397	6.5	158.9
EU-15	7	4.7	24	547	523	8.8	278.4
O-OECD	2	3.1	1	80	79	1.3	5.0
EE	1	1.8	0	30	30	0.5	-2.0
FSU	5	4.9	4	156	152	2.5	23.5
EEX	2	1.8	3	70	66	3.4	-4.4
China	21	8.8	31	144	112	3.4	-0.3
India	3	5.3	3	116	113	1.9	10.2
DAE	1	1.3	0	58	57	0.9	1.5
Brazil	0	0.1	0	35	35	0.6	1.4
ROW	4	5.3	4	158	154	2.5	23.8
World	62	5.2	127	2,317	2,190	-	-

Global stock of carbon dioxide by 2110 = 1,558 Gton

* Stable under exclusive membership and unanimity voting. Last column: gain from changing membership strategy if all other regions stick to their membership strategy; EE=Eastern European countries, EEX energy exporting countries, DAE=dynamic Asian economies.

From Table 4.6 and 4.7, it is evident that most observations and conclusions from above also apply for a coalition between China and dynamic Asian economies (DAE) and a coalition between energy exporting countries (EEX) and China.[13] First, internal stability for coalition members only holds at the margin. Second, both coalitions only marginal improve upon the singleton coalition structure in terms of abatement and global net benefits. Third, USA, Japan and the European Union (EU-15) are those regions with the strongest incentive to join the coalition, which can only be 'neutralized' by unanimity vote.

Viewed together, three important conclusions emerge from the stability analysis of the base case. *First*, not surprisingly, our theoretical prediction $C(OM) \subset C(EM-M) \subset C(EM-U)$ is

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[13] It does not seem evident which of the two coalitions will form. On the one hand, China has a slight preference to form a coalition with DAE instead of with EEX. On the other hand, DAE prefers a coalition between China and EEX and EEX prefers a coalition between China and DAE.

confirmed in our empirical analysis. Whereas no non-trivial coalition is stable under open membership, one non-trivial coalition is stable under exclusive membership and majority voting and two other additional coalitions are stable under unanimity voting. However, a more interesting fact is that those additional coalitions are superior in net benefit and environmental terms. The coalition between the former Soviet Union (FSU), Brazil and the 'rest of the world' (ROW), which is only stable under exclusive membership but not under open membership, implies total abatement of 60 gigatons CO_2 over 100 years and total net benefits of 2,131 billion US\$. In contrast, in the Nash equilibrium this is 55 gigatons CO_2 and 1,960 billion US\$. Moreover, additional coalitions that are only stable under exclusive membership and unanimity voting (but not majority voting) constitute a further improvement. Hence, exclusive membership leads to superior outcomes than open membership and unanimity voting leads to superior outcomes than majority voting.

Second, stable coalitions that constitute partial cooperation only marginally close the gap between the Nash equilibrium and the global optimum if this gap is large. As argued above, in our context the gap in net benefits is large in absolute and relative terms since global net benefits in the global optimum are 6,031 billion US\$ and in the Nash equilibrium 1,960 billion US\$. This implies that net benefits are 208 percent higher in the global optimum than in the Nash equilibrium. In contrast, the coalitions between FSU, Brazil and ROW, China and DAE and EEX and China imply only an improvement in net benefits of 8.7, 9.8 and 11.7 percent, respectively.

Third, despite the fact that the coalition between FSU, Brazil and ROW counts one more member than the coalition between China and DAE and the coalition between EEX and China, it is inferior in terms of global net benefits and abatement. This indicates that success of an IEA cannot be inferred from the number of participants. All three conclusions will be confirmed by our sensitivity analysis on which we report in Section 4.5 and where we argue that they are perfectly in line with results obtained by theory.

4.5. Sensitivity Analysis

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 a sensitivity analysis. We believe that the highest uncertainty concerns benefits from global abatement. Hence, we conduct a sensitivity analysis where we uniformly lower or raise the level of benefits from global abatement. That is, we change the base value of $\gamma_D = 0.027$. For instance, lowering global benefits to 50 percent compared to the base case implies $\gamma_D = 0.014$, which is very close to the value estimated by Nordhaus

(1994). Raising this value to 200 and 300 percent implies higher benefits compared to our base case value of $\gamma_D = 0.027$ (100 percent) taken from Tol (1997). Table 4.8 summarizes the results for four scenarios: 50, 100, 200 and 300 percent of $\gamma_D = 0.027$.

First, not only for our base case but also for all scenarios neither the grand coalition structure nor the Kyoto coalition structure is stable regardless of the definition of stability. Although both coalition structures would substantially improve upon the singleton coalition structure, some members have a strong incentive to leave the coalition.

Second, partial cooperation is not stable under open membership for the 50 percent and 100 percent scenario. Only if we raise benefits sufficiently high, one coalition between Japan and European Union (EU-15) is stable under open membership. Also under exclusive membership stability rises with the level of benefits from global abatement. For instance, in the 50 percent scenario only one non-trivial coalition structure is stable under exclusive membership and unanimity voting, three in the 100 percent scenario and four in the 200 and 300 percent scenarios. The reason is that higher benefits imply that regions already conduct higher abatement in the Nash equilibrium so that partial cooperation requires only small additional abatement efforts. Hence, the free-rider incentive in terms of internal stability decreases with the level of benefits.

Third, and closely related to the second point, a conclusion that has been derived from theoretical models under very restrictive assumptions (symmetric countries or heterogeneous countries with only two types of countries) and that has been called a paradox by Barrett (1994, 1997a) is confirmed: *whenever cooperation would be needed most from a global point of view* (the relative gap between Nash equilibrium and the global optimum) *stable partial cooperation achieves only little*. Under each scenario, the gap is large, and regardless of the membership rule, the gap is at best only marginally closed by stable coalitions.

Table 4.8 Sensitivity Analysis*

Scenario	Coalitions	Stability OM (1)	EM (2) M (3)	EM (2) U (4)	Total emission reduction Gton (over 100 years)	Annual emission reduction % of emissions in 2010	Total Abatement costs bln US$ over 100 years	Total benefits from abatement bln US$ over 100 years	Net benefits bln US$ over 100 years
	Singleton coalition structure	X	X	X	34	2.9	36	644	608
	Japan, EU-15	–	–	–	39	3.3	64	736	672
	FSU, Brazil, ROW	–	X	X	38	3.2	43	709	667
50 %	China, DAE	–	–	–	38	3.2	40	708	668
	EEX, China	–	–	–	39	3.2	41	721	679
	Kyoto coalition	–	–	–	70	5.9	298	1,317	1,018
	Grand coalition	–	–	–	172	14.4	1,225	3,211	1,986
	Singleton coalition structure	X	X	X	55	4.6	109	2,069	1,960
	Japan, EU-15C	–	–	–	59	5.0	152	2,208	2,056
	FSU, Brazil, ROW	–	X	X	60	5.1	129	2,260	2,131
100 %	China, DAE	–	–	X	61	5.1	123	2,277	2,153
Base	EEX, China	–	–	X	62	5.2	127	2,317	2,190
Case	Kyoto coalition	–	–	–	107	8.9	865	4,005	3,140
	Grand coalition	–	–	–	256	21.4	3,553	9,584	6,031
	Singleton coalition structure	X	X	X	87	7.3	324	6,485	6,161
	Japan, EU-15	X	X	X	92	7.7	455	6,908	6,453
	FSU, Brazil, ROW	–	X	X	94	7.9	382	7,035	6,652
200 %	China, DAE	–	–	X	95	8.0	369	7,128	6,760
	EEX, China	–	–	X	97	8.1	380	7,251	6,871
	Kyoto coalition	–	–	–	161	13.4	2,490	12,025	9,535
	Grand coalition	–	–	–	377	31.5	10,204	28,205	18,000

* (1) OM = open membership, (2) EM= exclusive membership, (3) M = majority voting, (4) U = unanimity voting; X means stable and – means not stable; scenarios imply 'percentage of the benefit parameter $\gamma_D = 0.027$ '; EEX energy exporting countries, DAE=dynamic Asian economies.

Table 4.8 Sensitivity Analysis (cont.)*

Scenario	Coalitions	Stability			Total emission reduction	Annual emission reduction	Total Abatement costs	Total benefits from abatement	Net benefits
		OM (1)	EM (2)		Gton (over 100 years)	% of emissions in 2010	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years
			M (3)	U (4)					
	Singleton coalition structure	X	X	X	112	9.3	609	12,519	11,910
	Japan, EU-15	X	X	X	119	9.9	857	13,323	12,466
	FSU, Brazil, ROW	–	X	X	121	10.1	716	13,537	12,821
300 %	China, DAE	–	–	X	123	10.2	694	13,746	13,052
	EEX, China	–	–	X	125	10.4	714	13,976	13,262
	Kyoto coalition	–	–	–	203	17.0	4,610	22,751	18,142
	Grand coalition	–	–	–	470	39.3	18,856	52,759	33,903

* (1) OM = open membership, (2) EM= exclusive membership, (3) M = majority voting, (4) U = unanimity voting; X means stable and – means not stable; scenarios imply 'percentage of the benefit parameter $\gamma_D = 0.027$ '; EEX energy exporting countries, DAE=dynamic Asian economies.

Fourth, independent of the stability concept, if there are stable coalitions, they are rather small. However, the number of participants is no indication of the success of cooperation. Not only for the base case the coalition of three members that is formed by former Soviet Union (FSU), Brazil and ROW is inferior to the coalition between China and dynamic Asian economies (DAE) and energy exporting countries (EEX) and China, each comprising only two members, but also in the scenarios 200 and 300 percent. Again, this result is in line with findings of theory (see Finus, 2001, 2003 for details).

Fifth, not only for the base case but also for the other scenarios it is confirmed that exclusive membership leads to superior outcomes than open membership and that under exclusive membership unanimity voting leads to superior outcomes than majority voting.

4.6. Summary and Conclusions

We studied stability of climate change coalitions. We followed the standard assumption in coalition theory that coalition members efficiently choose their abatement levels as to jointly maximize aggregate net benefits to their coalition. We departed from the standard definition of internal and external stability that implies open membership and also considered exclusive membership with two voting schemes: majority voting and unanimity voting. We applied

these different notions of stability to an empirical model, called STACO. This model captures long-run effects of greenhouse gas accumulation but assumes stationary abatement strategies for game theoretic tractability. It covers the period between 2010 and 2110 and comprises twelve world regions, giving rise to 4084 different coalition structures. Thus, though this model is far from being perfect, it improves upon previous studies in that it captures more dynamic aspects of the climate change problem and allows for a more detailed analysis of the strategic interaction of many actors. We conducted several sensitivity analyses (called scenarios) in order to test the robustness of our results.

First, in the case of global warming, the gains from cooperation prove to be large in our model. This does not only hold in absolute but also in relative terms when global net benefits in the global optimum are compared with those in the Nash equilibrium. This stresses the importance of economic and game theoretic analyses on global warming for future research.

Second, neither the grand coalition nor the Kyoto coalition (comprising the countries of the original Kyoto Protocol before the USA withdrew from this agreement) turned out to be stable for all scenarios regardless of the membership rule and voting scheme, though both coalition structures would substantial improve upon the Nash equilibrium. In contrast, those coalitions that turned out to be stable only comprise few members and only marginally improve upon the Nash equilibrium in terms of global net benefits, global emissions and stock of greenhouse gases. This result provided some rationales why it proves so difficult to achieve a high participation in the Kyoto Protocol and to agree on ambitious and effective abatement targets. The more countries accede to an agreement and/or the higher are abatement targets, the more difficult it becomes to control free-riding. Thus, as long as no major changes of the underlying economic incentive structure occur, it seems that only moderate progress can be expected in near future in the context of climate change. However, it has to be pointed out that our pessimistic conclusion is based on two assumptions. Dropping these assumptions is closely related to possible policy measures that may foster stable and effective cooperation and that we would like to analyze in future research.

One option is to drop the assumption of no transfers and include various transfer schemes in the stability analysis as for instance in Buchner and Carraro (2003) and Bosello et al. (2003). This may comprise 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 in the case of 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 help to balance different interests between countries (see, e.g., Botteon and Carraro, 1997; and Barrett, 1997a). In particular, we expect a higher

participation, which also allows reaping higher efficiency gains from cooperation because stable coalitions can be formed by countries that are more heterogeneous.

Another option is to drop the assumption of joint welfare maximization that 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, it is likely that better results may be achieved if members settle for less ambitious abatement targets and/or if abatement burdens are allocated more equally (though cost-inefficiently). If the effect on participation is strong enough, this may well compensate for inefficiencies. For instance, theoretical work by Endres and Finus (2002), Finus and Rundshagen (1998a) and Finus (2004) provide explanations why in many IEAs abatement targets are specified as inefficient uniform emission reduction quotas and signatories agree on the lowest common denominator (resulting from unanimity voting) in terms of the joint abatement level. These extensions could be further steps in including public choice aspects in the analysis of international treaty formation that may help to rationalize inefficient designs of many actual IEAs.

Third, we confirmed a theoretical result that has been derived under very restrictive assumption: whenever the degree of externality - measured as the relative difference between the Nash equilibrium (singleton coalition structure) and the global optimum (grand coalition) - is large, partial cooperation is either not stable or achieves only little. Only if this difference is small enough, more progress can be expected. In our model, this difference became smaller when we (uniformly) raised benefits from global abatement. Then regions already conduct a substantial amount of abatement without any cooperation, additional abatement requirements within a coalition are relatively small and hence free-riding is less of a problem. From a policy point of view, this suggests that the success of mitigating the global warming problem is closely related to the perception of environmental damages of governments and societies. Thus, measures that enhance environmental consciousness may foster cooperation in the future.

Fourth, large stable coalitions may prove to be inferior compared to small stable coalitions both in economic and environmental terms. This suggests that a high participation in an IEA does not necessarily imply its success, as frequently publicized by politicians and the media. Only a comparison of net benefits of an agreement with an appropriate benchmark (Nash equilibrium or business as usual scenario) allows us to draw sound conclusions.

Fifth, stability proves generally very difficult under open membership rule. We find only for some of our scenarios one coalition that is stable under open membership. In contrast, some of the coalitions that are externally unstable under open membership turn out to be stable

under exclusive membership. Those additional stable coalitions under exclusive membership generate higher global net benefits and a lower stock of greenhouse gases. It turns out that unanimity voting leads to better outcomes than majority voting.

From a theoretical point of view, this suggests not only that a modification of the stability concept of internal and external stability is a fruitful route for research, but also that previous results may have been overly pessimistic. From an applied point of view, the results are interesting in two respects. First, almost all past IEAs have no provision to restrict membership. Hence, it may be worthwhile to think whether to adopt an exclusive membership rule, which is typical for club good agreements, as for instance NATO and European Union, also for pure public good agreements like those on climate change in the future. Second, exclusive membership requires some degree of consensus between coalition partners to form a coalition. At first glance, intuition suggests that the higher the degree of consensus needed to come to a decision, the less likely and successful will be an agreement. However, a closer inspection reveals that when the free-rider problem is explicitly accounted for this conclusion has to be questioned. This qualification is confirmed in the literature that analyzes bargaining on environmental policy levels (e.g., Endres, 1997; Endres and Finus, 2002; and Finus and Rundshagen, 1998a) and is also confirmed by our model that analyzes the effect of membership rules on the formation of stable coalitions. In both cases, consensus agreements are associated with more stability that is a basic prerequisite for any successful agreement. Hence, our results provide a further rationale for the frequent application of consensus voting and in particular for unanimity voting as applied in many international organizations and agreements.

Appendix 4A

Table 4A1 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 4.1 in section 4.3	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)
$M_{pre-ind}$	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 4.1 in section 4.3	-	own calculation based on Fankhauser (1995) and Tol (1997)
α_i	abatement cost parameter of region i	see Table 4.2	-	own calculation based on Ellerman and Decaux (1998)
β_i	abatement cost parameter of region i	see Table 4.2	-	own calculation based on Ellerman and Decaux (1998)
γ_D	scale parameter of damage and benefit function	0.027	-	Tol (1997)

Chapter 5. Permit Trading and Stability of International Climate Agreements[*]

Abstract

We analyze the implication of different allocation schemes of CO2-emission permits for stability and the success of international climate agreements. Our model combines a game theoretical with an empirical module that comprises 12 world regions and captures important dynamic aspects of the climate change problem. We consider seven different permit allocation schemes. Two 'pragmatic schemes' allocate permits according to a uniform emission reduction, five 'equitable schemes' allocate permits based on some normative criteria frequently discussed in the literature. It turns out that permit trading can raise participation and the success of climate agreements, but pragmatic schemes are superior to equitable ones.

5.1. Introduction

Emission permits have been proposed as an efficient instrument to tackle national but also international environmental problems. Recently, this market-based instrument has gained increasing attention in the context of the Kyoto Protocol, aiming at controlling global warming. Since greenhouse gas emission affects all countries, it can be expected that a sufficient high participation in permit trading will guarantee a well-functioning market. However, there has been much debate about the distributional effects of different permit allocation schemes. Rose et al. (1998) took a prominent lead in this discussion, classifying different allocation schemes, clarifying their motivation and analyzing their impact on different countries. The discussion initiated many other papers (e.g., Kverndokk, 1995; and Böhringer et al., 2002) dealing with various notions of fair allocations of permits. It is recognized that not only efficiency but also fairness aspects may play an important role for the participation and success of a global warming treaty. However, this literature only studies the impact of different allocation schemes on net abatement costs of individual participants (abatement costs plus/minus the outlay/receipt from permit trading). Hence, not much can be concluded about whether and which countries have an incentive to join an international environmental agreement (IEA) and whether such a treaty will be self-enforcing. In order to analyze participation and stability, two more steps are necessary.

First, not only abatement costs but also benefits from joint abatement policies have to be taken in consideration. Only this gives a complete picture of the basic incentives to participate in an agreement. That is, we can test whether cooperation is not only globally but also individually rational. We call a treaty individually rational if each participant receives a net benefit exceeding that in the non-cooperative status quo. As shown for instance in Eyckmans et al. (1994) and Germain and van Steenberghe (2003), not all permit allocation schemes that are deemed to be fair guarantee individual rationality to all participants. For instance, a permit allocation based on per capita may appear to be fair ('one-man-one vote'), but leads to very large transfers from industrialized to developing countries that may violate the interests of donors.

Second, even though individual rationality may be seen as a necessary condition for cooperation, it is by no means a sufficient condition. Since abatement constitutes a public good, countries may be better off not participating in an individually rational IEA, saving abatement costs and benefiting from the efforts of signatories. Consequently, in the light that there is no supranational institution that can enforce a global treaty, IEAs must but also be self-enforcing. We check this with the concept of internal and external stability which has been widely applied in the game theoretical literature on IEAs (e.g., Barrett, 1994; and Carraro and Siniscalco, 1993). Different from this literature, however, we combine our game

theoretical analysis with an empirical model that captures twelve world regions. That is, we neither model heterogeneity in a stylized way as for instance in Finus and Rundshagen (1998a) and Hoel (1992), nor do we consider stylized transfer rules as for instance in Botteon and Carraro (1997) and Eyckmans and Tulkens (2003).

The objective of this paper is to test whether stable coalitions exist under various permit allocation schemes and if this is the case whether they improve upon the non-cooperative outcome. We consider two 'pragmatic scenarios' that allocate permits according to a uniform emission reduction and five 'equity scenarios' that allocate permits based on some normative criteria frequently discussed in the literature. Different from Bosello et al. (2003), Eyckmans and Finus (2003) and Weikard, Finus and Altamirano-Cabrera (2006) that test stability of outcome-based allocation rules, we consider allocation based-rules. It turns out that permit trading can improve upon the success of self-enforcing climate agreements but pragmatic are superior to equity schemes. Thus, moral motives may not always be a good guide for the design of effective and self-enforcing treaties.

In the following, we introduce the game theoretical and empirical module in Section 5.2. We motivate our permit trading schemes and discuss some fundamental features in Section 5.3 and report about results of our stability analysis in Section 5.4. Section 5.5 wraps up with a summary and draws some conclusions.

5.2. The model

5.2.1. Game theoretical module

Coalition formation is modeled as a two-stage game. In the first stage, countries or regions ($i \in I=\{1,...,N\}$) decide on their membership strategy; in the second stage, they choose their abatement strategies. In the first stage, we assume that countries have two membership strategies: strategy $\sigma_i = 0$ means 'I do not want to join the agreement' and $\sigma_i = 1$ means 'I want to become a member of a climate treaty'. 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). Hence, a vector of announcements $\sigma = (\sigma_1, \sigma_2, ..., \sigma_N)$, $\sigma \in \Sigma$, leads to coalition structure c = (s, 1,..., 1), $c \in C$, with s either a non-trivial coalition if at least two countries have announced $\sigma_i = 1$ or s = {i} if either all countries have announced $\sigma_i = 0$ or only one country has announced $\sigma_i = 1$. Hence, there exist 4096 different membership vectors but 'only' 4084 different coalition structures in the

context of twelve players (regions).[1] If s = {i}, this is called the 'singleton coalition structure' and if s = I, this is called the 'grand coalition structure'.

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

$$\pi_i = B_i(\sum_{i=1}^{N} q_i) - C_i(q_i),$$

(5.1)

assuming a concave benefit function from global abatement, B_i, and a convex abatement cost function from individual abatement, C_i. For a given coalition structure c, we assume that non-signatories ($\sigma_i = 0$) pursue their self-interests, maximizing π_i with respect to q_i, taking the abatement level of all other countries as given. Assuming an interior equilibrium, this leads to the following first-order condition:

$$B_i'(\sum_{i=1}^{N} q_i) = C_i'(q_i) \quad \forall i \notin s,$$

(5.2)

where primes denote derivatives. In contrast, signatories ($\sigma_i = 1$) are assumed to maximize the aggregate welfare of their coalition. This leads to the following first order conditions:

$$\sum_{i \in s} B_i'(\sum_{i=1}^{N} q_i) = C_i'(q_i) \quad \forall i \in s.$$

(5.3)

The simultaneous solution of the first order conditions of non-signatories and signatories leads to abatement vector $q^*(c)$. This abatement vector can be interpreted as a partial Nash equilibrium between coalition s and the singleton players (Chander and Tulkens 1997). Hence, in equilibrium, $C_i'(q_i^*) = C_j'(q_j^*)$ for all i and j that belong to s. That is, the abatement vector of the coalition is not only optimal from a cost-benefit perspective, but also efficient for the coalition. Of course, this does not extend to outsiders. Consequently, the grand coalition structure (s = I), representing full cooperation, chooses a globally optimal abatement vector and the singleton coalition structure (s={i}), representing no cooperation, corresponds to the 'classical' Nash equilibrium. Any other coalition structure may be seen as partial cooperation.

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[1] This should not be confused as meaning that the mapping of membership strategies into coalition structures would not be unique.

If $q^*(c)$ is unique for all $c \in C$, then the payoff vector $\pi(q^*(c))$ with $\pi_i(q^*(c)) = B_i(\sum_{i=1}^{N} q_i^*(c)) - C_i(q_i^*(c))$ is unique in the second stage. In subsection 5.2.3, we will argue that this is indeed the case and that $q^*(c)$ lies in the interior of the abatement space. At this stage, it suffices to notice that $\pi(q^*(c))$ represents the case without permit trading. In the case of permit trading, payoffs have to be modified. For simplicity, we assume that permits are only traded among cooperating countries, i.e., among coalition members (see section 5.5 for a discussion of this assumption). Hence, a coalition member's payoff can be written as

$$\tilde{\pi}_i(q^*(c), \overline{q}_i(t)) = \pi_i(q^*(c)) - p \cdot (\overline{q}_i(t) - q_i^*(c)), \tag{5.4}$$

where p is the permit price and $\overline{q}_i(t)$ is the assigned abatement resulting from some allocation under a particular permit trading system $t \in T$. The second term on the right hand side of equation (5.4) is positive if a country is a permit seller ($\overline{q}_i(t) < q_i^*(c)$) and negative if a country is a permit buyer ($\overline{q}_i(t) > q_i^*(c)$). The price of permits is equal to marginal abatement costs in equilibrium and follows immediately from the first order conditions of signatories in (5.3). Thus, the 'final' payoff $\tilde{\pi}_i$ in (5.4) can be interpreted as the payoff from cooperation without transfers, π_i, plus or minus a transfer that depends on the allocation of abatement, $\overline{q}_i(t)$. In section 5.4, we will discuss various permit schemes that determine $\overline{q}_i(t)$. At this stage, it suffices to notice that because $\pi(q^*(c))$ is unique also $\tilde{\pi}_i(q^*(c), \overline{q}_i(t))$ is unique for each coalition structure $c \in C$ and any permit scheme $t \in T$.

Taken together, payoffs to country i depend on the coalition structure $c \in C$ determined in the first stage of the game and on abatement strategies $q \in Q$ and the permit trading systems $t \in T$ chosen in the second stage of the game, $\pi_i(c,q,t)$. Since abatement q follows from the assumption of joint welfare maximization of coalition members and the allocation of permits follows from the assumption about a particular permit trading system, we can thus define stability of coalition structure c as follows:

Stable Coalition Structures. *Coalition structure $c \in C$ resulting from announcement $\sigma \in \Sigma$ is called stable if for all $i \in I$, $\sigma_i^* \neq \sigma_i'$: $\pi_i(\sigma_i^*, \sigma_{-i}^*) \geq \pi_i(\sigma_i', \sigma_{-i}^*)$ assuming some permit trading scheme $t \in T$ and that $q \in Q$ follows from the assumption of joint welfare maximization of coalition members.*

Obviously, our definition implies that a coalition structure is called stable if membership strategies constitute a Nash equilibrium. This definition is similar to the concept of internal

and external stability: in equilibrium, no signatory has an incentive to leave the coalition by changing its announcement from $\sigma_i^* = 1$ to $\sigma_i' = 0$ (internal stability) and no non-signatory has an incentive to join the coalition by announcing $\sigma_i' = 1$ instead of $\sigma_i^* = 0$ (external stability). The advantage of our definition is that existence of an equilibrium is guaranteed. The reason is that the singleton coalition structure can always be supported as a Nash equilibrium: suppose all countries announce $\sigma_i = 0$, then no single country can change this coalition structure by unilaterally changing its membership strategy. The advantage of the other definition is that it allows separating stability into two dimensions. Hence, when discussing stability in the following, we distinguish between internal and external stability.

It is evident that the definition of stable coalition structures implies voluntary participation since signatories can leave their coalition if they find it more attractive to free-ride and non-signatories can join the agreement if this pays.

5.2.2. Empirical module

In this section, we explain our empirical module - called STACO-model. Since the model has been laid out in much detail in Finus, Altamirano-Cabrera and van Ierland (2004), we briefly describe here only its main features. The main idea of STACO is to calibrate the following payoff function:

$$\pi_i(q) = \sum_{t=1}^{T}(1+r_i)^{-t}(B_{it}(q_t) - C_{it}(q_{it})),$$ (5.5)

where the philosophy behind the model comprises three items. First, the model should reflect important dynamics of climate models. Therefore, STACO considers a period of 100 years, starting in 2010 and bases its calibration on the widely known DICE-model of Nordhaus (1994) for the development of global emissions and concentration. Second, in order to make the model interesting for a game theoretical analysis, there should be a sufficient number of different players. Therefore, STACO uses abatement cost estimates of Ellerman and Decaux (1998) for twelve world regions. For global benefits and regional benefits from abatement (in the form of reduced damages), STACO uses estimates of Fankhauser (1995) and Tol (1997).

Third, the model must be simple enough to be tractable for a game theoretical analysis. Therefore, STACO assumes stationary abatement strategies, fits the parameters to this specification, leading to the following discounted payoff function:

$$\pi_i(q) = \gamma_i \mu_B \delta_b \sum_{i=1}^{N} q_i - \delta_c \left[\tfrac{1}{3} \cdot \alpha_i \cdot q_i^3 + \tfrac{1}{2} \cdot \beta_i \cdot q_i^2 \right], \tag{5.6}$$

where q_i is the total abatement over 100 years, $q_i = \sum_{t=1}^{100} q_{it}$. The global benefit parameter is μ_B, the regional benefit parameter is γ_i, representing the shares of the different world regions in global benefits, $0 \le \gamma_i \le 1$, $\sum_{i=1}^{N} \gamma_i = 1$ and α_i and β_i are regional abatement cost parameters. The parameters δ_b and δ_c capture discounting in STACO; in the case of δ_b it further includes the decay of greenhouse gases. In our 'standard case' we assume a discount rate of 2 percent.[2] Note that $\mu_B \delta_b$ represents global marginal benefits. It turns out that $\mu_B \delta_b = 37.4$ US$ per ton of carbon, a figure that is much in line with other studies (e.g., Plambeck and Hope 1996). The regional parameters reflect differences of twelve world regions: USA, Japan (JPN), European Union (EU-15), other OECD countries (O-OECD), Eastern European countries (EE), former Soviet Union (FSU), energy exporting countries (EEX), China, India, dynamic Asian economies (DAE), Brazil and 'rest of the world' (ROW). We use the abbreviations in brackets in the following.[3] The parameters are listed in the Appendix 5A in Table 5A1 and their implications are visualized in Figure 3.1 (see Chapter 3) and Figure 5.1 below.

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[2] For a discount rate of 2 percent, $\delta_B = 1385$ and $\delta_C = 43.1$ in STACO. The parameter represents damages in terms of a loss of GDP for a doubling of greenhouse gas concentration, expressed in percentages. We take (meaning a 2.7 percent loss) from Tol (1997). In section 4, these assumptions will be subject to a comprehensive sensitivity analysis.

[3] EU-15 comprises the 15 countries of the European Union as of 1995. O-OECD includes among other countries Canada, Australia and New Zealand. EE includes for instance Hungary, Poland, and Czech Republic. EEX includes for example the Middle East Countries, Mexico, Venezuela and Indonesia. DAE comprises South Korea, Philippines, Thailand and Singapore. ROW includes for instance South Africa, Morocco and many countries in Latin America and Asia.
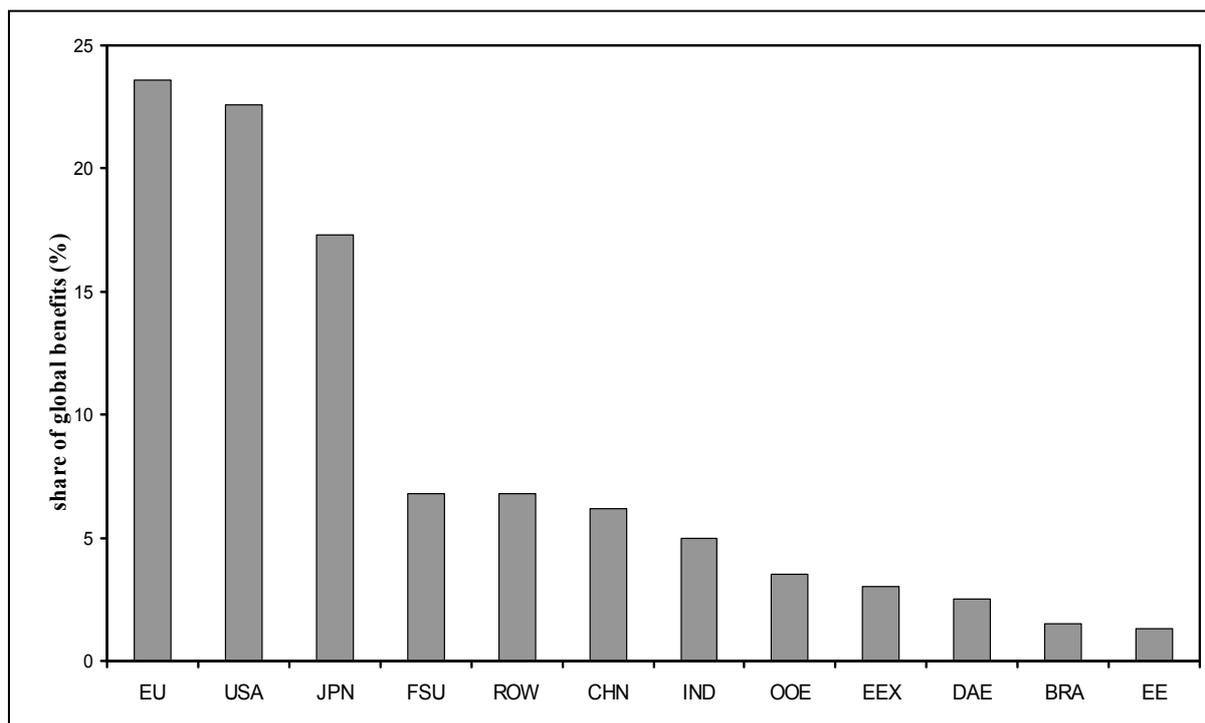
Figure 5.1   Regional benefits from global abatement.

Figure 5.1 lists regions in descending order of regional benefit shares. It is evident that the large industrialized regions are the main beneficiaries of global abatement whereas EEX, DAE and Brazil receive the smallest share of global benefits.

As we note in Chapter 3, subsection 3.6.3, marginal abatement costs vary widely: China and USA have the flattest curves whereas Brazil as well as Japan have the steepest. Roughly speaking, those regions with low initial emissions (e.g., Brazil and Japan) face steep marginal abatement cost curves (see Table 5A.1 in Appendix 5A) since cheap abatement options have already been exploited and substitution to more effective abatement technologies is expensive. For regions with high initial emissions (e.g., China and USA) just the opposite holds.

5.2.3. General features of the model

In this section, we discuss some general features of our model, relating to the game theoretical and the empirical module.

First, in subsection 5.2.1, we pointed out that a unique abatement vector for each coalition $c \in C$ guarantees a unique payoff vector. Considering the empirical specification of the payoff function (see equation (5.6)), it is evident that regions have a dominant strategy

because the first order conditions of signatories are $\mu_B \delta_b \sum_{i \in s} \gamma_i = \delta_c (\alpha_i \cdot q_i^2 + \beta_i \cdot q_i)$ and those of non-signatories are $\mu_B \delta_b \gamma_i = \delta_c (\alpha_i \cdot q_i^2 + \beta_i \cdot q_i)$. Thus, uniqueness is evident. An interior solution follows from two pieces of information. a) $C_i'(q_i)$ is an increasing function, $C_i'(q_i = 0) = 0$ and $\sum_{i \in s} B_i' = \mu_B \delta_b \sum_{i \in s} \gamma_i \geq B_i' = \mu_B \delta_b \gamma_i > 0$, $q_i^* > 0$ $\forall i \in I$ and for any coalition structure. Notice that this implies that even in the singleton coalition structure, corresponding to the 'classical' Nash equilibrium, some abatement is undertaken compared to the business-as-usual scenario, and hence $e_i^{BAU} > e_i^{Nash}$ $\forall i \in I$, where e_i^{BAU} is defined as emission level in the business-as-usual scenario and e_i^{Nash} as emission level in the Nash equilibrium. b) Generally, we can choose a sufficient high upper bound q_i^{max} to guarantee an interior solution. However, in our model abatement means to reduce emissions from the business-as-usual emission level, e_i^{BAU}. Hence, it seems sensible to require $q_i^{max} \leq e_i^{BAU}$. Since it follows from $\mu_B \delta_b \sum_{i \in s} \gamma_i = \delta_c (\alpha_i \cdot q_i^2 + \beta_i \cdot q_i)$ that q_i^* takes on the largest value if s=I (corresponding to the 'classical' global optimum), we only have to check whether $q_i^*(s = I) \leq e_i^{BAU}$ holds for all $i \in I$. In our model, it turns out that this is indeed the case.

Second, in our model, superadditivity holds. That is, whenever a country j joins coalition s, so that coalition structure changes from c to $\tilde{c}$, aggregate welfare of countries $s \cup \{j\}$ increases, $\sum_{i \in s} \pi_i(c, t) + \pi_j(c) < \sum_{i \in s \cup \{j\}} \pi_i(\tilde{c}, t)$. The reason is simple. First, the aggregate payoff to coalition s and $s \cup \{j\}$ is not affected by the kind of permit trading scheme: permit trading only affects individual payoffs of coalition members through transfers but transfers add up to zero. (Recall that non-signatories are not involved in trading.) Second, outsiders $I \setminus \{s \cup \{j\}\}$ have a dominant strategy. Hence, they will not change their abatement level in $\tilde{c}$ compared to c. Hence, if we let q^s, $q^{s \cup \{j\}}$ and q_j denote the abatement vector of signatories before and after country j joined coalition s and abatement of country j, respectively, then $\max_{q^s} \sum_{i \in s} \pi_i + \max_{q_j} \pi_j < \max_{q^{s \cup \{j\}}} \sum_{i \in s \cup \{j\}} \pi_i$ must hold.

Third, in our model, cooperation generates positive externalities. That is, whenever a country j joins coalition s, so that coalition structure c changes to $\tilde{c}$, outsiders $k \notin s \cup \{j\}$ gain $\pi_k(c) < \pi_k(\tilde{c})$. From the first order conditions of signatories, it is evident that abatement of each member increases because the sum of marginal benefits increases from $\mu_B \delta_B \sum_{i \in s} \gamma_i$ to $\mu_B \delta_B \sum_{i \in s \cup \{j\}} \gamma_i$. Hence, global abatement increases, outsiders' benefits increase from c to $\tilde{c}$ but their abatement costs remain the same.

Fourth, superadditivity together with positive externalities imply that global welfare is raised if participation is gradually increased. Nevertheless, membership matters. That is, global welfare may well be different in two coalitions s_1 and s_2 that are of the same size but comprise different members.

Fifth, in the Introduction we mentioned that an agreement must be individually rational and self-enforcing to be stable. Evidently, we check the self-enforcing part through Definition 1 of stable coalition structures. Less evident is that this automatically implies to check also for individual rationality. The reason is that internal stability implies individual rationality (but not vice versa). Suppose coalition s is not individually rational for member i, then member i can leave the agreement and because of the positive externality property (see item 3 above), he will be (strictly) better off than in the singleton coalition structure (provide $s \setminus \{i\}$ comprises at least two members).

Sixth, generally, the advantage of participating in a coalition is that this increases global abatement. Moreover, own abatement efforts are matched by others. This increases benefits from global abatement but also increases abatement costs. The relative size of both effects determines whether it pays to join a coalition. As a tendency, the higher participation in an agreement, the less attractive it becomes to join a coalition and the more attractive it becomes to leave a coalition due to the strict concavity of the payoff function. Therefore, stable coalitions are usually only small.

Seventh, participation in a stable agreement will also depend on membership and on the permit trading system. Since countries have different benefit and cost functions, joint welfare maximization may imply a very asymmetric distribution of the gains from cooperation. For instance, a coalition member, say i, with a flat marginal abatement cost function will have to contribute more to abatement than a member, say j, with a steep marginal abatement cost function. If i has also lower marginal benefits than j, then i may well be worse off from cooperation or at least receives a low payoff. Consequently, it may pay country i to free-ride. This may be different if country i receives a transfer from country j which may be accomplished via a permit trading system that allocates a sufficient amount of permits to country i. In our model, a region i is for instance EE, DAE, China and India and a region j for instance EU-15 and Japan.

5.3. Fundamentals about permit trading

5.3.1. Motivation of permit schemes

In section 5.2.1, we observed that payoffs in a coalition structure c are affected by the global abatement level $\sum_{i=1}^{N} q_i^*(c)$ and the individual abatement level $q_i^*(c)$, $\pi_i = B_i(\sum_{i=1}^{N} q_i^*(c)) - C_i(q_i^*(c))$. This holds for non-signatories. For signatories, payoffs also depend on the assigned abatement level $\overline{q}_i(t)$ that follows from the allocation of permits under some permit scheme t, $\tilde{\pi}_i = \pi_i - p \cdot (\overline{q}_i(t) - q_i^*(c))$. Noting that emission permits of region i, $\overline{e}_i$, mean to allocate a fraction $0 \le \lambda_i \le 1$ of the total amount of permits $\sum_{i \in s} \overline{e}_i$, to each member i, $\overline{e}_i = \lambda_i \sum_{i \in s} \overline{e}_i$, $\sum_{i \in s} \lambda_i = 1$, and recalling that abatement is defined as $q_i = e_i^{BAU} - e_i$ in our model, $\sum_{i \in s} \overline{e}_i = \sum_{i \in s} e_i^*$ with $\sum_{i \in s} e_i^* = \sum_{i \in s} e_i^{BAU} - \sum_{i \in s} q_i^*$, then the allocation of abatement can be expressed as follows:

$$\overline{q}_i(t) = e_i^{BAU} - \lambda_i \left(\sum_{i \in s} e_i^{BAU} - \sum_{i \in s} q_i^*(c) \right) . \qquad (5.7)$$

Thus, different permit schemes $t \in T$ can be related to different weights λ_i. In the literature, several schemes have been proposed of which we consider seven in this paper. We only briefly comment on these schemes and refer the reader to a more extensive discussion of their motivation to Cazorla and Toman (2000) and Rose et al. (1998). The first two schemes are called 'pragmatic schemes', the next five are called 'equitable schemes'. The names that we attach to each scheme are shown in the first row and the mathematical specifications of weights are displayed in the second row in Table 5.1. For the grand coalition, weights (expressed as percentage) are displayed for each region in the subsequent rows. This gives a first idea of the relative impact of different schemes in terms of weights, though it has to be pointed out that weights are different in other coalition structures. The base data for computations of weights is provided in Appendix 5A, Table 5.A.2.

Table 5.1   Permit schemes and shares in the grand coalition

Regions	Pragmatic schemes		Equitable schemes				
	Quota BAU	Quota Nash	Egalitarian	Historical responsibility	Ability to pay	Ability to pollute	Energy efficiency
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
USA	20.2	19.8	4.8	1.9	0.5	1.6	9.8
Japan	4.7	4.8	1.9	8.2	0.3	2.8	26.8
EU-15	11.7	11.7	5.8	3.3	0.6	3.4	18.4
O-OECD	5.2	5.3	2.2	7.4	1.1	2.9	8.2
EE	4.3	4.5	1.9	9.0	4.4	3.0	2.1
FSU	8.4	8.3	4.5	4.6	8.2	3.6	1.3
EEX	10.2	10.6	24.9	3.7	14.8	16.7	3.6
China	19.7	19.4	20.9	1.9	18.5	7.2	1.2
India	5.3	5.4	17.8	7.3	37.0	23.1	2.0
DAE	3.4	3.5	3.2	11.1	3.2	6.4	6.4
Brazil	1.1	1.1	3.0	35.2	3.6	18.6	16.0
ROW	5.9	5.8	9.1	6.5	7.8	10.6	4.3
Total	100	100	100	100	100	100	100

Note: All figures are expressed as a percentage.

Pragmatic schemes

Our pragmatic schemes belong to so-called sovereignty rules because they do not much interfere with the status quo. Both schemes assume that all members receive emission permits that represent the same percentage from some base emission level. This implies to allocate uniform emission reduction quotas to each member. Such a scheme has been applied in the Helsinki Protocol on Sulfur Reduction in Europe and in many other IEAs. However, different from these treaties, in our model such quotas can be traded as intended under the Kyoto Protocol. 'Quota BAU' (scheme 1) assumes base emissions in the business-as-usual scenario, e_i^{BAU}; 'Quota Nash' (scheme 2) assumes base emissions in the classical Nash equilibrium, e_i^{Nash}, corresponding to those in the singleton coalition structure. Both emission levels may be interpreted as the status quo before an agreement is signed. The alternative assumptions allow us to check whether our results are sensitive to the choice of the base-line emission level.

From Table 5.1, we observe that weights between scenario 1 and 2 differ only slightly. This is because the Nash equilibrium implies only a minor emission reduction from BAU-emissions (see Table 5A.2 in Appendix 5A). Since base line emissions are strongly

concentrated in USA and China, those regions receive the highest weights. We now turn to our 'equitable schemes'.

Equitable schemes

'Egalitarian' (scheme 3) allocates emission permits on a per capita basis. This rule acknowledges that all men should have the same right to emit: 'one man one vote'. Evidently, energy exporting countries (EEX), China and India, receive the highest shares in the grand coalition since a large portion of total population lives in these regions.

'Historical responsibility' (scheme 4) allocates permits inversely to BAU-emissions because those countries that have contributed to current greenhouse gas concentration should contribute more to mitigate this problem. Thus, weights under this scheme are the mirror image of 'Quota BAU', and therefore Brazil and dynamic Asian economies (DAE) receive high weights.

'Ability to pay' (scheme 5) allocates permits inversely to welfare levels measured as gross domestic product (GDP). This rule argues that wealthier nations should take on more responsibility in global climate change control than poorer nations. However, this rule may also be seen as a vehicle of development aid through environmental policy by allocating more permits to poorer nations. Again, those regions that receive high shares of emission permits are those mentioned under the 'Egalitarian scheme' and are mainly developing countries.

The scheme 'Ability to pollute' (scheme 6) is similar in spirit to 'Historical responsibility', except that weights are not based on emissions but on emissions per capita. It has also some connection to 'Egalitarian' where weights are based on population. Thus, this scheme may be defended by arguing that every man has the same responsibility for preserving the climate system. Since the USA has the highest emission per capita ratio, they receive the lowest weight. In contrast, due to low current emissions and high population density, developing countries receive high weights under this scheme.

'Energy efficiency' (scheme 7) allocates emission permits inversely to the emission/GDP ratio. It therefore rewards regions with 'advanced environmental technology' like Japan and European Union (EU-15) but gives low weights to China, India and Eastern European countries (EE) that have 'dirty industries'.

5.3.2.Illustration of permit schemes: Some fundamental relations

In this subsection, we illustrate some of the implications of the seven different permit trading schemes in Table 5.2. As a reference point, we also display the base case of no permit trading. Again, we choose the grand coalition to illustrate some fundamental relations. For each scenario, the gains from cooperation are measured in relation to the singleton coalition structure, corresponding to the classical Nash equilibrium. Since the payoff to a region can be interpreted as its payoff without trading plus or minus a transfer (see Section 5.2.1), we also display transfers as implied by the various permit schemes. A positive number means to pay a transfer (permit buyer) and a negative number means to receive a transfer (permit seller). In order to gain some insights about the dimension of trading, we also display total transfers, that is, the sum of all positive or negative numbers. Moreover, in order to get an idea about the distribution of the gains from cooperation, we compute the standard deviation of the gains from cooperation.

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Table 5.2 Gains and transactions under various permit schemes: Grand coalition

Regions	No permit trading		Pragmatic schemes				Equitable schemes									
			Quota BAU (1)		Quota Nash (2)		Egalitarian (3)		Historical responsibility (4)		Ability to pay (5)		Ability to pollute (6)		Energy intensity (7)	
	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers	Gain	Trans-fers
USA	1,241	-	721	520	577	664	-4,709	5,950	-5,716	6,957	-6,200	7,441	-5,815	7,056	-2,941	4,182
Japan	1,236	-	926	310	976	260	-30	1,266	2,160	-923	-596	1,832	286	950	8,703	-7,467
EU-15	1,569	-	1,051	518	1,037	531	-1,006	2,574	-1,917	3,486	-2,857	4,426	-1,862	3,430	3,370	-1,801
O-OECD	133	-	17	115	45	87	-1,029	1,162	767	-634	-1,421	1,554	-785	918	1,068	-936
EE	-33	-	-68	35	-24	-9	-936	904	1,487	-1,520	-63	31	-561	528	-860	827
FSU	269	-	189	81	179	90	-1,190	1,460	-1,165	1,434	196	74	-1,483	1,752	-2,289	2,559
EEX	38	-	-475	513	-330	368	4,710	-4,672	-2,746	2,784	959	-922	1,811	-1,773	-2,786	2,824
China	-866	-	820	-1,686	698	-1,564	1,233	-2,099	-5,424	4,558	679	-1,545	-3,563	2,696	-5,696	4,830
India	83	-	378	-295	378	-294	4,765	-4,682	1,002	-919	11,411	-11,328	6,499	-6,416	-826	910
DAE	33	-	88	-55	116	-83	30	3	2,845	-2,813	-2	35	1,177	-1,145	1,150	-1,117
Brazil	103	-	27	76	45	58	691	-588	12,141	-12,038	921	-817	6,283	-6,180	5,327	-5,223
ROW	265	-	397	-133	375	-110	1,542	-1,278	637	-372	1,044	-780	2,082	-1,818	-149	414
Total	4,071	-	4,071	2,168	4,071	2,058	4,071	13,319	4,071	19,219	4,071	15,393	4,071	17,330	4,071	16,546
Standard deviation	651	-	442	-	399	-	2491	-	4,450	-	3,886	-	3,446	-	3,787	-

Note: All figures are expressed in billion US$.

From Table 5.2 the following observations are interesting:

First, the total gain from cooperation in the social optimum is with 4,071 billion US$ large given the fact that the global payoff in the Nash equilibrium is only 1,960 billion US$.

Second, the standard deviation of the gains from cooperation is generally large. However, there are significant differences: The two pragmatic schemes show the lowest standard deviation and some of the equitable schemes have a very high standard deviation, exceeding that without permit trading to a large extent. The large spread of the gains also shows up in large transfers implied by the various permit trading schemes. Obviously, the equity schemes imply a major reshuffle of the gains from cooperation through permit trading, but most of them replace the asymmetry without trading through another asymmetry that is even larger.

Third, neither the base case of no permit trading nor any of the permit schemes implies that cooperation is profitable for all participants. There are always at least two regions that are worse off than in the Nash equilibrium. For the equity schemes, individual rationality is sometimes severely violated for almost half of all regions. For the base case, it is not surprising that individual rationality is violated for EE and China because their marginal benefits and abatement costs are far below average levels. Hence, these regions contribute above average to global pollution control but benefit only below average. Obviously, none of the permit schemes simultaneously repairs this deficiency for these two regions, letting alone the violation of individual rationality of other regions.

Fourth, even though we can immediately conclude that the grand coalition is not a stable coalition structure because individual rationality is violated under all schemes, it may nevertheless be possible to form smaller coalitions that are individually rational. Nevertheless, also for smaller coalitions stability may be a problem as will be apparent from the next section

5.4. Stability analysis

In this section, we present results of our stability analysis. We start with the 'standard case' in Section 5.4.1, reflecting the parameter values as reported and discussed in Section 5.3. In Section 5.4.2, we report on the results of our sensitivity analysis.

5.4.1.Standard case

For each scenario, we test all 4084 coalition structures for stability with an algorithm programmed in Matlab. In the base case without permit trading, it turns out that more than 1000 coalition structures are externally stable but only 14 coalition structures are internally stable. None of the 13 non-trivial coalition structures (i.e., including a coalition of at least two members) that are internally stable are also externally stable and hence no non-trivial coalition structure is stable. On the one hand, this stresses that internal stability is the main problem of stability and therefore we focus in particular on this part of stability in the following discussion. On the other hand, this stresses the strong free-rider incentives in general, but, in particular, in the context of heterogeneous regions.

Under the scenario 'Quota-BAU', this changes somehow. Now 28 coalition structures are internally stable of which two are also externally stable. The first coalition structure includes a coalition between the European Union (EU-15) and China and the second a coalition between India and the 'Rest of the World' (ROW). In order to explain the driving forces of permit trading, we exemplarily have a closer look at the coalition between EU-15 and China in Table 5.3, though similar relations are also true for other stable coalitions.

Table 5.3 Coalition between the European Union and China: No permit trading and permit trading under the Quota BAU scenario

Regions	Total emission reduction		Marginal abatement costs	Payoffs (without permit trading)	Payoffs (with permit trading)	Transfers	ICM* (without permit trading)	ICM* (with permit trading)
	gton (over 100 years)		US$/ton	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years	bln US$ over 100 years
	q_i^*	$\overline{q}_i$		π_i	$\tilde{\pi}_i$			
USA	16	-	8.5	683	683	-	137.8	-132.6
Japan	1	-	6.5	559	559	-	107.9	-25.0
EU-15	8	20	11.1	733	595	137	-268.6	-131.3
O-OECD	2	-	1.3	111	111	-	-13.5	-52.3
EE	1	-	0.5	42	42	-	-19.4	-40.8
FSU	5	-	2.5	215	215	-	-13.7	-64.2
EEX	1	-	1.1	97	97	-	-21.3	-139.2
China	46	34	11.1	-6	131	-137	118.0	-19.3
India	3	-	1.9	160	160	-	-30.2	-11.2
DAE	1	-	0.9	81	81	-	-18.1	-33.5
Brazil	0	-	0.6	50	50	-	-0.4	-18.7
ROW	4	-	2.5	217	217	-	-14.3	-24.1
World	87	-	-	2,942	2,942	-	-	-

Note: * ICM means incentive to change membership measured as $\pi_i(\sigma_i', \sigma_{-i}^*) - \pi_i(\sigma_i^*, \sigma_{-i}^*)$. See Section 5.2.1.

From Table 5.3, it is evident that without permit trading the coalition between the EU-15 and China (indicated in italics in the first column) is not internally stable because China would gain by leaving this coalition (indicated in the second last column). Clearly, without transfers, EU-15 is the main beneficiary in this coalition at the expenses of China. Because China is a cheap provider of abatement, also USA and Japan have an incentive to join this coalition (indicated in the second last column) and therefore this coalition would also not be externally stable.

With permit trading, the situation changes. Under the 'Quota BAU' scenario, China receives a sufficient amount of emission permits ($\overline{q}_i$ is low; see equation 5.7) that can be sold to EU-15. Thus, China receives a large transfer of 137 billion US$ as indicated in the column 'Transfer'. Thus, whereas before there was a slack of enforcement power on the side of EU-15 and lack on the side of China without permit trading, this asymmetry is now somehow mitigated with permit trading, as this is evident from the last column. Now China would

loose from leaving the coalition. Also no outsider has an incentive to join the coalition. In particular, USA and Japan have no interest anymore in joining this coalition because transfers to China would exceed their gains from cooperation.

For the other coalitions and permit trading schemes, results are summarized in Table 5.4.

Table 5.4 Stable coalition structures

	Scenario	Number of internally stable coalitions	Stable coalitions	Global emission reduction	Global payoff
(i)	singleton coalition	-	stable	55	1,960
(ii)	no permit trading	14	no stable coalitions	-	-
(iii)	(1) quota BAU	28	{EU-15, China}	87	2,942
			{India, ROW}	60	2,107
	(2) quota Nash	53	{EU-15, EE, India}	68	2,372
				61	2,151
			{Japan, India}		
(iv)	(3) egalitarian	3	no stable coalitions	-	-
	(4) historical responsibility	1	no stable coalitions	-	-
	(5) ability to pay	0	no stable coalitions	-	-
	(6) ability to pollute	1	no stable coalitions	-	-
	(7) energy efficiency	1	no stable coalitions	-	-
(v)	grand coalition	-	not stable	256	6,031

Notes: Global emission reduction = gigatons over 100 years. Global payoff = billion US dollar over 100 years. Stable coalitions means internally and externally stable. Scenarios 1 and 2 correspond to the' pragmatic schemes' and scenarios 3 to 7 to the 'equitable schemes'.

In Table 5.4, the singleton coalition structure, which is stable by definition, and the grand coalition structure, which is not stable under any scenario, are listed as benchmarks to measure the success of stable coalition structures. Also the reference case without permit trading is listed. It is evident that under the pragmatic schemes the number of internally stable coalition structures is higher than in the base case without permit trading but under the equity schemes this is substantially lower. This confirms the conjecture from the grand coalition in

Section 5.3.2 that equity schemes may remove an asymmetry but replace it by a different and even stronger asymmetry. Different degrees of asymmetry also show up in terms of stable coalition structures (internally and externally stable coalition structures). Only under the pragmatic schemes, we find stable coalition structures. Those stable coalition structures improve upon the non-cooperative situation in environmental and welfare terms, though they close the gap between no and full cooperation only to a small extent. The results also confirm that membership matters and that from the number of participants success cannot be inferred. For example, the coalition between EU-15 and China is more successful than any other stable coalition, though the coalition between EU-15, Eastern European countries (EE) and India counts one more member.

5.4.2. Sensitivity analysis

A typical feature of empirical work is that results depend on assumptions about policy scenarios and on parameter values, which are subject to some uncertainty. In terms of policy scenarios, we considered above two pragmatic and five equity allocation schemes of permits. It is evident that a much longer list of schemes could be generated and checked for stability. We refrain from this exercise. However, given that the two pragmatic schemes perform rather well whereas all five equity schemes perform badly for our model, one may wonder whether a combination of a pragmatic and an equity rule would perform better. Thus, we tested a combination of every of the two pragmatic schemes with every of the five equity schemes. We consider apart from a 50%/50% allocation rule of permits, also a 25%/75% and 75%/25% rule.[4] Surprisingly, we find no non-trivial coalition structure that is stable. Apparently, the equity rules introduce too much asymmetry, or, put differently, the asymmetry of the equity schemes cannot be sufficiently balanced by the pragmatic schemes. Thus, the superiority of the pragmatic schemes over the equity schemes in our model is confirmed by our sensitivity analysis.

In terms of parameters and given the large number of parameters that enter our model, some selection is necessary for a sensitivity analysis. We believe that the highest uncertainty concerns benefits from global abatement and discounting. Hence, in terms of benefits, we conduct a sensitivity analysis where we uniformly raise the level of benefits from global abatement. That is, we raise the base value of the global benefit parameter μ_B from 100 to 200 and 300 percent.[5] In terms of the discount factor, we recall that our 'standard case'

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[4] This means that we tested 30 additional scenarios.

[5] Recall, $\mu_B = 0.027$ in the base case and hence 200 (300) percent implies $\mu_B = 0.054$ ($\mu_B = 0.081$) which means a substantial increase in the valuation of the benefits from a reduction of greenhouse gases. This is certainly an optimistic view with respect to the recognition of environmental benefits by governments.

assumed a discount rate of 2 percent. This is roughly in line with Weitzman (2001) who suggests that if a constant discount rate has to be chosen, in the context of global warming, then a discount rate of 2 percent or less is appropriate to capture long-term effects. This means that we are at the upper bound. Hence, we test also for a discount factor of 1 percent and - in order to get a more complete picture of the driving forces - consider additionally also a discount rate of 3 percent. It is evident that discounting affects not only benefits but also abatement costs. In line with more sophisticated models, a lower (higher) discount rate means in our model STACO to put a higher (lower) weight on benefits compared to abatement costs because of the long terms effects of climate change. More specifically, a change in the discount rate affects the benefit parameter δ_B and the cost parameter δ_C in STACO. Since both parameters are level parameters (see equation 5.6); as this is also true for μ_B), only the change of the relation δ_B / δ_c is important. Hence, a discount rate of 1 percent has the same effect as raising the global benefit parameter μ_B from 100 to 120 percent and a discount rate of 3 percent has the same effect as lowering the global benefit parameter μ_B from 100 percent to 85 percent.

Hence, taken together, our sensitivity analysis compares our standard scenario, which is the 100 percent scenario, with a 85, 120, 200 and 300 percent scenario. Table 5.5 summarizes the results that confirm our qualitative results from above.

Table 5.5 Sensitivity analysis

% parameter μ_B	of Coalitions	Scenarios				Total emission reduction	Global payoff
		No permit trading	(1)	(2)	(3)-(7)	gton (over 100 years)	bln US$ (over 100 years)
	Singleton coalition structure	x	x	x	x	50	1,493
	Coalition Japan, EU-15	-	-	-	-	53	1,567
	Coalition India, ROW	-	x	-	-	54	1,607
85 %	Coalition Japan, India	-	-	x	-	55	1,641
	Coalition EU-15, EE, India	-	-	x	-	62	1,814
	Coalition EU-15, China	-	x	-	-	78	2,253
	Grand coalition	-	-	-	-	234	4,656
	Singleton coalition structure	x	x	x	x	55	1,960
	Coalition Japan, EU-15	-	-	-	-	59	2,056
100 %	Coalition India, ROW	-	x	-	-	60	2,107
Base	Coalition Japan, India	-	-	x	-	61	2,151
Case	Coalition EU-15, EE, India	-	-	x	-	68	2,372
	Coalition EU-15, China	-	x	-	-	87	2,942
	Grand coalition	-	-	-	-	256	6,031
	Singleton coalition structure	x	x	x	x	62	2,655
	Coalition Japan, EU-15	x	-	-	-	67	2,784
	Coalition India, ROW	-	x	-	-	67	2,850
120 %	Coalition Japan, India	-	x	x	-	69	2,909
	Coalition EU-15, EE, India	-	-	-	-	77	3,199
	Coalition EU-15, China	-	x	-	-	98	3,962
	Grand coalition	-	-	-	-	284	8,053

Note: 'x' means stable and '–' means not stable. First column refers to 'percentages of the benefit parameter' μ_B. The 85 and 120 percent scenario correspond to a discount rate of 3 and 1 percent, respectively, as explained in the text. Scenarios 1 and 2 correspond to the' pragmatic schemes' and scenarios 3 to 7 to the 'equitable schemes'.

Table 5.5 Sensitivity analysis (cont.)

% of parameter μ_B	Coalitions	Scenarios				Total emission reduction	Global payoff
		No permit trading	(1)	(2)	(3)-(7)	gton (over 100 years)	bln US$ (over 100 years)
	Singleton coalition structure	x	x	x	x	87	6,161
	Coalition Japan, EU-15	x	-	-	-	92	6,453
	Coalition India, ROW	-	x	-	-	93	6,588
200 %	Coalition Japan, India	-	x	x	-	95	6,720
	Coalition EU-15, EE, India	-	-	-	-	105	7,343
	Coalition EU-15, China	-	x	x	-	133	9,045
	Grand coalition	-	-	-	-	377	18,000
	Singleton coalition structure	x	x	x	x	112	11,910
	Coalition Japan, EU-15	x	-	-	-	119	12.466
	Coalition India, ROW	-	x	-	-	119	12,704
300 %	Coalition Japan, India	-	x	x	-	122	12,950
	Coalition EU-15, EE, India	-	-	-	-	135	14,094
	Coalition EU-15, China	-	x	x	-	169	17,280
	Grand coalition	-	-	-	-	470	33,903

Note: 'x' means stable and '−' means not stable. First column refers to 'percentages of the benefit parameter' μ_B. The 85 and 120 percent scenario correspond to a discount rate of 3 and 1 percent, respectively, as explained in the text. Scenarios 1 and 2 correspond to the' pragmatic schemes' and scenarios 3 to 7 to the 'equitable schemes'.

First, the grand coalition, though it would raise global welfare substantially compared to no cooperation, is not stable under all scenarios.

Second, without permit trading, there is now one stable coalition structure in the 120, 200 and 300 percent scenarios that involves a coalition between Japan and EU-15.[6] This suggests that a sufficient high recognition of the benefits from controlling global warming may improve

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[6] It turns out that 120 percent is the lower benchmark for which this change occurs.

upon the prospects of cooperation – a conjecture confirmed for the pragmatic permit trading schemes. However, this coalition only slightly improves upon the non-cooperative outcome: both regions have steep marginal abatement costs and therefore only marginally increase abatement efforts above non-cooperative levels.

Third, pragmatic permit trading schemes are superior to equitable schemes for all scenarios. Apart from the singleton coalition structure, there is no stable coalition structure under any equitable scheme but two or three under the pragmatic schemes. Thus, our conclusion from above is confirmed that moral motivations (i.e., equity concerns) may not always be a good guide for successful treaty-making.

Fourth, in case there are stable coalition structures, they involve only small coalitions and only marginally improve upon the non-cooperative outcome in terms of global welfare and global emission reduction. Thus, even though a cleverly designed permit trading scheme may balance some asymmetries between coalition members, it cannot totally overcome strong free-rider incentives.

5.5. Summary and conclusions

We studied the effect of permit trading on the stability of global climate agreements with a model that combines a game theoretical with an empirical module. The game theoretical module models coalition formation as a two-stage game in which regions choose their participation in an agreement in the first stage and their abatement strategies in the second stage. Apart from membership, payoffs depend on the permit trading scheme, implying different initial allocations of emission allowances. The empirical module provided benefit and costs estimates for twelve world regions. Though it captures long-run effects of greenhouse gas accumulation over 100 years, it assumes stationary abatement strategies for game theoretical tractability.

We considered seven different permit trading schemes that were divided into two categories: 'pragmatic' and 'equitable' schemes. Pragmatic schemes are closely related to the current status quo and allocate permits according to uniform emission reductions from some base emission level. We considered emissions in the business-as-usual scenario without abatement and those in the Nash equilibrium as base lines. Equitable schemes could be motivated by different notions of fairness that have been proposed in the literature as for instance 'historical responsibility' or 'ability to pay'. From the many results we would like to mention three key results.

First, the gains from partial and full cooperation would be very large in terms of global welfare but also measured in environmental variables like global emission reduction. However, the gains are quite unevenly distributed because of the large heterogeneity between regions. Depending on the permit scheme, this inequality can be mitigated, as for instance the pragmatic schemes do. However, the equitable schemes frequently replace one type of asymmetry by introducing another asymmetry, implying large transfers from one group of countries to another group. For instance, a scheme that allocates permits on a per capita basis implies large transfers from industrialized to developing countries.

Second, the large asymmetries under the equitable rules found for full cooperation also showed up for partial cooperation, implying that there was no stable coalition under equitable schemes. In contrast, some coalitions are stable under the pragmatic schemes. Thus, our findings do not support the conjecture that equity can enhance the success of agreements. Of course, this finding cannot claim generality. Nevertheless, it provides an indication that equity principles itself might not be able to offset strong-free-rider incentives. In fact, designing permit trading schemes based on pragmatic principles may appear to be less fair but more successful in mitigating the climate problem.

Third, even cleverly designed permit trading schemes that reduces the disparity of the allocation of the gains from cooperation cannot overcome strong free-rider incentives. In our model, only small coalitions turned out to be stable that improve upon the status quo, though not much. Nevertheless, it became evident that the number of participants is not a good indicator for the success of treaties, membership may be even more important. This suggests that when designing a permit scheme for future agreements, identifying key players and inducing the participation of those players should receive a high priority.

For future research, we would like to mention four items among many other possibilities. First, we could drop the assumption of joint welfare maximization within a coalition. The assumption implies that ambitious abatement targets are implemented. This translates into instability of large coalitions because of high free-rider incentives. Overall, it is likely that better results may be achieved if members settle for less ambitious abatement targets. If the effect on participation is strong enough, this may well compensate for modest abatement targets (Finus and Rundshagen 1998a). Second, we could drop the assumption that permits are only traded among coalition members. This would closely resemble the clean development mechanism under the Kyoto Protocol where signatories can also buy certified emission reductions from non-signatories. Obviously, this option could reduce abatement costs of signatories and thus increase their welfare. However, this option also increases welfare of non-signatories through transfers. Thus, it is not evident whether such an option will raise self-enforcing participation and the success of treaties. However, there is no doubt

that a consistent treatment of this issue will complicate the analysis substantially because the determination of optimal abatement levels will have to consider all strategic aspects associated with world wide trade. Third, though we already considered a substantially larger number of actors than most climate models, twelve regions is nevertheless a small number compared to the total number of countries world wide. From the theory of public goods, we expect that a larger number of actors would pronounce free-riding problems. That is, our aggregation into 12 world regions means an optimistic view to the possibilities of self-enforcing cooperation. However, currently, the problem of such an extension is the lack of less aggregated empirical data. Fourth, we limited the decision about participation to a one-shot decision for simplicity. A more realistic and interesting assumption would allow for the possibility that decisions can be revised at various points in time. It is evident that this would also require giving up the assumption of stationary abatement strategies in order to render the analysis relevant. On the one hand, this would allow accounting for a change of benefit and abatement parameters over time which seems important in the context of a long time horizon. On the other hand, we expect that already for a setting with 'only' twelve heterogeneous players, this would constitute a great computational challenge as results for symmetric players and simple payoff functions in Rubio and Ulph (2003) indicate.

Appendix 5A

Table 5A1 Emissions, benefit and abatement cost parameters*

Regions	Emissions in 2010 (Gton)	Share of global benefits γ_i	Abatement cost parameter α_i	Abatement cost parameter β_i
1 USA	2.42	0.226	0.0005	0.00398
2 Japan	0.56	0.173	0.0155	0.18160
3 European Union (EU-15)	1.4	0.236	0.0024	0.01503
4 Other OECD Countries (O-OECD)	0.62	0.035	0.0083	0
5 Eastern European Countries (EE)	0.51	0.013	0.0079	0.00486
6 Former Soviet Union (FSU)	1	0.068	0.0023	0.00042
7 Energy Exporting Countries (EEX)	1.22	0.030	0.0032	0.03029
8 China	2.36	0.062	0.00007	0.00239
9 India	0.63	0.050	0.0015	0.00787
10 Dynamic Asian Economies (DAE)	0.41	0.025	0.0047	0.03774
11 Brazil	0.13	0.015	0.5612	0.84974
12 Rest of the World (ROW)	0.7	0.068	0.0021	0.00805
World	11.96	1	-	-

Note: Input data in STACO-model as described in Finus et al. (2004).

Table 5A2   Base data for allocation of permits

Regions	Emissions in BAU scenario (I)	Emissions in Nash scenario (I)	Population (II)(IV)	GDP (III)(IV)	GDP per capita (V)	Emissions per capita (BAU-scenario) (VI)	Emissions per unit of GDP (BAU-scenario) (VII)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	(gton)	(gton)	(million of habitants)	(billion 1985 US$)	(thousand 1985 US$)	(tons per habitant)	(tons per 1985 US$)
USA	2.4	226	305	8,845	29.0	79	0.03
Japan	0.5	55	124	5,584	44.9	45	0.01
EU-15	1.4	133	375	9,579	25.5	37	0.01
O-OOE	0.6	60	142	1,902	13.4	44	0.03
EE	0.5	51	120	405	3.4	43	0.13
FSU	1	95	287	501	1.8	35	0.20
EEX	1.2	121	1,602	1,650	1.0	8	0.07
China	2.4	221	1,340	1,021	0.8	18	0.23
India	0.6	61	1,145	458	0.4	6	0.14
DAE	0.4	40	207	972	4.7	20	0.04
Brazil	0.1	13	190	774	4.1	7	0.02
ROW	0.7	66	584	1,119	1.9	12	0.06
WORLD	11.9	1,140	6,421	32,810	-	-	-

Notes: (I) STACO calculations (Finus et al., 2004). (II) Level of population in 2010 calculated from table 2.1 of World Bank (2002). (III) Level of GDP in 2010 calculated from DICE model and table 1.1 of World Bank (2002). (IV) Data aggregated into STACO's 12 regions following Babiker et al. (2001). (V) Computed from column 3 and 4. (VI) Computed from column 1 and 3. (VII) Computed from columns 1 and 4.

Chapter 6. Do Abatement Quotas Lead to More Successful Climate Coalitions?[*]

Abstract

This paper studies the effect of different treaty designs on the success of international environmental agreements (IEAs). We analyze the standard assumption of an efficient abatement scheme and three uniform abatement quota schemes. Apart from analytical results, the analysis is supported by simulations based on the STACO model. It turns out that quota agreements where the members decide by majority or unanimity voting are particularly successful in overcoming free-rider incentives within an IEA. Finally, our results provide a rationale for the application of uniform abatement quotas in IEAs.

6.1. Introduction

Casual empirical evidence has already shown that existing international environmental agreements (IEAs) depart from a globally optimal solution typically in three respects. Firstly, not all countries that are responsible for negative transboundary spillovers participate in IEAs. A typical example is the Kyoto Protocol on the reduction of greenhouse gases that cause global warming. Neither the USA, a major current emitter of greenhouse gases, nor major future emitters such as China and India, have accepted quantified emission reductions under this agreement.

Secondly, total abatement of the coalition is below coalitional optimal levels. For framework conventions (such as the Vienna Convention preceding the Montreal Protocol on CFC-reductions, the Framework Convention on Climate Change (FCCC) preceding the Kyoto Protocol on greenhouse gases reduction or the Convention Long Range Transboundary Pollution (LRTAP) preceding the Helsinki and Oslo Protocols on sulfur reductions) this is evident as they are mere declarations of intentions without abatement obligations. However, this suboptimality is also true for other conventions and it is supported by empirical studies, suggesting that emission reduction targets are not much higher than in the absence of these agreements. Examples are studies on the Montreal Protocol (Murdoch and Sandler 1997b), the Helsinki Protocol (Murdoch and Sandler 1997a), the Oslo Protocol (Finus and Tjøtta 2003), and the Kyoto Protocol (Böhringer and Vogt 2004).

Thirdly, emission reduction efforts are not cost-effectively allocated. Abatement obligations are often specified as uniform emission reduction quotas, even though countries face different marginal abatement costs. The list of examples is long and includes the Helsinki Protocol, which suggested a 30 percent reduction of sulfur emissions from 1980 levels by 1993. Moreover, the "Protocol Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes" signed in Sofia in 1988 called on countries to *uniformly* freeze their emissions at 1987 levels by 1995 and the "Protocol Concerning the Control of Emissions of Volatile Organic Compounds or Their Fluxes" signed in Geneva in 1991 required parties to reduce 1988 emissions by 30 percent by 1999. Also the original abatement obligations of the Kyoto Protocol resembled a uniform emission reduction for many signatories, though the subsequent implementation of a permit trading system later promises to mitigate this inefficiency.

In the game theoretical literature on IEAs, the first type of deficiency has received much attention. The first papers showing that only small coalitions are self-enforcing go back to Barrett (1994) and Carraro and Siniscalco (1993). Later papers have addressed the problem of heterogeneous payoff functions and considered possibilities to mitigate free-rider problems

for instance with various transfer schemes (e.g. Barrett 1997a, 2001; Botteon and Carraro, 1997; Carraro, 1997; Hoel and Schneider, 1997; Eyckmans and Finus, 2006; and Weikard, Finus and Altamirano-Cabrera, 2006), different permit allocation schemes (e.g. Altamirano-Cabrera and Finus, 2006) or the possibility to form multiple coalitions (e.g. Carraro, 2000; Bosello et al., 2003; Finus and Rundshagen, 2003a; Pintassilgo, 2003; and Eyckmans and Finus, 2006). However, all of these papers share the assumption that total abatement within a coalition is chosen optimally. The second type of deficiency has been addressed by Barrett (2002) and Finus (2004) in models that capture the trade-off between participation and the total level of abatement implemented within a coalition. They demonstrate that there maybe a rationale to implement a coalitional abatement level below optimal levels because this is compensated by higher participation. Both papers are stylized models assuming symmetric players. The third deficiency (and to some extent also the second deficiency) has been addressed by papers that consider uniform emission reduction quotas that follow from a bargaining process. Hoel (1992) was probably the first to point out that uniform emission reduction quotas are not cost-effective. Endres (1997) and Eyckmans (1999) introduced a bargaining model where countries put forward proposals for uniform emission reduction quotas and either agree on the lowest or median country proposal. Both papers also consider a bargaining process on a uniform emission tax. For the lowest proposal, it is shown that the bargaining outcome under the quota regime may be superior to the tax regime from an environmental and welfare point of view. Later papers have confirmed the superiority of the quota over the tax regime for the lowest proposal in a repeated game framework when stability is also considered (e.g. Finus and Rundshagen, 1998b; and Endres and Finus, 2002) and the analysis is extended to more than two countries (Finus and Rundshagen, 1998a).

This paper follows the tradition of the literature that considers uniform emission reduction quotas. It differs from the previous literature in three respects. Firstly, the analysis is not based on a stylized model restricted to only two countries and/or a special type of asymmetry between countries. This means however that not all results can be derived analytically. Therefore, we complement our analysis with simulations, using an empirical climate model called *sta*bility of *co*alitions or STACO model (Finus et al., 2006). STACO captures benefit and abatement cost functions from greenhouse gas emission reduction for 12 world regions. Secondly, stability is not tested in a repeated game framework. Instead, coalition formation is explicitly modeled and stability is tested with the concept of internal and external stability introduced by d´Aspremont et al. (1983) and frequently used in the literature that deals with the first type of deficiency mentioned above. Thirdly, for the three quota agreement designs (that differ in the assumptions how coalition members agree on the level of a uniform quota) we additionally consider the possibility that quotas can be traded.

In what follows, Section 6.2 describes the model of coalition formation, proves some general results and points to some fundamental relations for which no analytical results can be derived. Section 6.3 describes the calibration of our empirical (STACO) model. Section 6.4 reports and discusses results of our simulations based on the model described in Section 6.2. Section 6.5 summarizes the main conclusions and points to some issues for future research.

6.2. Coalition Formation Process

In the tradition of recent approaches in coalition theory (Bloch, 2003; and Yi, 2003), we model coalition formation as a two-stage game. In the first stage, regions $i \in N = \{1,...,n\}$ decide on their membership in a coalition. This stage is modeled in the tradition of the cartel formation game of d´Aspremont et al. (1983) that has recently been named open membership single coalition game (Finus and Rundshagen, 2003a; and Yi 2003). This entails that regions can freely choose between two membership strategies: 'I sign the agreement' and 'I do not sign the agreement'. Those regions that choose the first strategy become members of coalition $k \in K$ (where K denotes the set of all possible coalitions) and those that choose the second strategy remain singletons. If all regions announce 'I do not sign the agreement' or all regions make this announcement except one, then k is a trivial or singleton coalition. If two or more regions announce 'I sign the agreement', k is a non-trivial coalition which is called the grand coalition if all regions make this announcement. In the context of our empirical model STACO with 12 regions there are 4096 different announcement vectors (2^n) and 4084 different coalitions ($2^n - n$).[1]

In the second stage, the regions choose their equilibrium abatement strategy which we denote by q_i^*. The abatement vector $q^* = (q_1^*,...,q_n^*)$ leads to payoff vector $\pi^* = (\pi_1^*,...,\pi_n^*)$ with $\pi_i^* := \pi_i(q^*)$ where $\pi_i(\bullet)$ is the payoff function of region i

$$\pi_i(q) = B_i(\sum_{j=1}^{n} q_j) - C_i(q_i) , \qquad\qquad (6.1)$$

where $B_i(\sum_{j=1}^{n} q_j)$ are the benefits from global abatement (which is the sum of individual abatement, $q_j, \forall j \in I = \{1,...,n\}$), $C_i(q_i)$ are abatement costs from individual abatement q_i, and q is the vector of abatement levels. The strategy space is compact, $q_i \in [0, e_i^{BAU}]$, where

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[1] There are n different announcement vectors where only one region announces "I sign the agreement" which leads to the same coalition as when all regions announce "I do not sign the agreement".

e_i^{BAU} is the business-as-usual (BAU) emission level. Benefit functions are continuous and concave and cost functions are continuous and strictly convex. As will be evident from Section 6.3, STACO assumes linear benefit functions, thus $B_i' > 0$ and $B_i'' = 0$ with primes denoting first and second derivates respectively. We introduce this assumption already in this section and make it throughout the paper since it eases some of the subsequent proofs.

In subsection 6.2.1, we consider several rules of how the abatement vector q^* is derived. At this stage, it suffices to know that any of these rules we consider $r \in R$, assigns a unique vector q^* to every possible coalition $k \in K$ and hence a unique payoff vector π^*. Therefore, for a given rule, we write $\pi^*(q^{*r}(k))$. Consequently, for any given rule $r \in R$, the game can be solved by backward induction. Following d'Aspremont et al. (1983), we define a stable coalition as a coalition where no member in coalition k has an incentive to leave this coalition (internal stability) and no non-member has an incentive to join coalition k (external stability).[2] More formally, a coalition k is called stable (and denoted by k^*) if and only if it is:

internally stable: $\forall\, i \in k^* : \pi_i^*(q^{*r}(k^*)) \geq \pi_i^*(q^{*r}(k^* \setminus \{i\}))$

$$(6.2)$$

externally stable: $\forall\, i \notin k^* : \pi_i^*(q^{*r}(k^*)) \geq \pi_i^*(q^{*r}(k^* \cup \{i\}))$.

Note that, by definition, the singleton coalition is internally stable and the grand coalition is externally stable. Moreover, the singleton coalition can always be supported by an announcement that makes it externally stable (and hence stable) and hence the existence of a stable coalition is guaranteed. The reason is that if all regions announce that they do not want to be part of the agreement, then no single region can initiate a different coalition by unilaterally changing its membership strategy.

6.2.1. Agreement Designs I

We consider different rules about how players choose their abatement strategy in the second stage. This can be interpreted as different designs of an agreement which we describe in the following.

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[2] Note that this definition basically corresponds to a Nash equilibrium in membership strategies.

Reference Design

The standard assumption in the literature on coalition formation (Bloch, 2003; and Yi, 2003), which has also been applied in environmental economics, is that the coalition *k* acts like a single player and derives its abatement vector by maximizing the aggregate payoff to coalition *k*, given the abatement levels of outsiders:

$$\max_{q_i, i \in k} \sum_{i \in k} \left(B_i(\sum_{j \in k} q_j + \sum_{\ell \notin k} q_\ell) - C_i(q_i) \right),$$ (6.3)

whereas single players just maximize their own payoff, given the abatement levels of all other players:

$$\max_{q_i, i \notin k} B_i(q_i + \sum_{j \neq i} q_j) - C_i(q_i).$$ (6.4)

The standard assumption can be interpreted as an unconstrained optimization within coalition *k*. That is, abatement levels are efficiently chosen within coalition *k* because, in equilibrium, marginal abatement cost of each member of *k* is equal to the sum of marginal benefits of coalition *k* (assuming an interior solution). Consequently, if *k* is the grand coalition (k=N), the equilibrium abatement vector $q^{*RD}(k)$ (where the superscript RD stands for 'Reference Design') is globally optimal. It also means that if *k* is a singleton coalition (k={i}), then $q^{*RD}(k)$ corresponds to abatement in the Nash equilibrium. Substitution of q^{*RD} in the payoff functions gives payoffs $\pi(q^{*RD}(k))$.

Joint Quota

The first alternative assumption that we consider is labeled 'Joint Quota' and implies a constrained optimization. Coalition members still jointly maximize the aggregate payoff to coalition *k*, but under the constraint that each member of *k* has to reduce emissions by the same uniform rate ω. The reference point of this joint uniform emission quota is assumed to be emissions in the Nash equilibrium, e_i^{Nash}. Taking already account of the specification of our empirical model, which defines abatement q_i in terms of emission reduction from emissions in the business-as-usual scenario, e_i^{BAU}, we have $q_i(\omega) = e_i^{BAU} - (1-\omega)e_i^{Nash}$. The constrained optimization implies for coalition *k*:

$$\max_{\omega} \sum_{i \in k} \left(B_i(\sum_{j \in k} q_j(\omega) + \sum_{\ell \notin k} q_\ell) - C_i(q_i(\omega)) \right), \tag{6.5}$$

given the abatement of outsiders. Of course, for single regions that are not members of *k*, this alternative assumption has no effect and hence for them (6.4) is valid. Moreover, note that if *k* is a singleton coalition, then (6.4) and (6.5) are equivalent. The constraint implies that abatement is no longer efficient within coalition *k* ($\#k \geq 2$) provided the members of *k* have different abatement cost functions - which is the case in our numerical application see section 3. We denote $\omega^{*JQ}(k)$ the solution of (6.5) and the implied abatement vector including the solution of (6.4) for a given coalition *k* by $q^{*JQ}(k)$ (where the superscript 'JQ' stands for 'Joint Quota') with associated payoffs $\pi(q^{*JQ}(k))$.

Quota Proposals

The second and third alternative that we consider are called proposals. We assume that each member *i* in coalition *k* makes a proposal for a uniform quota ω_i under the assumption that this quota is implemented in all regions in *k*, given the abatement levels of all outsiders. Hence, proposal ω_i is derived from

$$\max_{\omega_i} B_i(\sum_{j \in k} q_j(\omega_i) + \sum_{\ell \notin k} q_\ell) - C_i(q_i(\omega_i)) . \tag{6.6}$$

Again, the reference level for uniform emission reductions are Nash equilibrium emissions e_i^{Nash} and hence $q_i(\omega_i) = e_i^{BAU} - (1 - \omega_i)e_i^{Nash}$. Moreover, singletons just perform (6.4). The solution of (6.6) for each member in *k*, leads to a set of proposals $\{\omega_1^*(k),...,\omega_k^*(k)\}$. There are certainly many ways to determine which of the proposals is implemented. We consider here two prominent solutions inspired by the public choice literature. The first solution assumes that members agree on the *median quota proposal*, $\omega^{*MQP}(k) := med\{\omega_1^*(k),...,\omega_k^*(k)\}$. This is equivalent to majority voting over a uniform quota. The second solution assumes that members agree on the lowest quota proposal, $\omega^{*LQP}(k) := min\{\omega_1^*(k),...,\omega_k^*(k)\}$. This is equivalent to unanimity voting over a uniform quota. We denote the equilibrium abatement vector for all players for a given coalition *k* that is implied by $\omega^{*MQP}(k)$ and the solution of (6.4) by $q^{*MQP}(k)$ (where the superscript MQP stands for 'Median Proposal Quota') with associated payoffs $\pi(q^{*MQP}(k))$, implied by $\omega^{*LQP}(k)$ and $q^{*LQP}(k)$ (where the superscript LQP stands for 'Lowest Quota Proposal) with

associated payoffs $\pi(q^{*LQP}(k))$. Note that both abatement vectors imply that abatement is not cost-efficient within non-trivial coalition k ($\#k \geq 2$) if regions have different abatement cost functions.

6.2.2. Properties I

For the determination of stable coalitions via backward induction a necessary condition is the existence of an equilibrium abatement vector for every coalition $k \in K$ in the second stage and a convenient condition is that this equilibrium is unique, giving rise to a unique payoff vector for every coalition $k \in K$. For our empirical specification of the payoff function (where we assume a linear benefit function), these conditions hold.

Proposition 1

For each agreement design $r \in \{RD, JQ, MQP, LQP\}$ considered in subsection 6.2.1 and for each coalition $k \in K$ there exists a unique abatement vector $q^{*r}(k)$.

Proof: See Appendix 6B1.

One reason for the popularity of majority and in particular unanimity voting in international negotiations is the fact that these decision rules possess the property that truthtelling is a dominant strategy. That is, under both decisions rules, regions have no incentive to put forward a biased proposal in order to influence the decision in its favor. For the lowest common denominator decision rule (i.e. unanimity voting), this observation has been made by Eyckmans (1999) and proved by Endres and Finus (2002) in the context of two players. In our context with $n > 2$ players, this property also holds and this is also the case for the median decision rule (i.e. majority voting).

Proposition 2

Assume that coalition members make a proposal for a uniform emission reduction quota to be implemented within coalition k. Suppose coalition members agree on the median or on the lowest quota proposal, then coalition members will reveal their true preferences.

Proof: See Appendix 6B2.

It is clear that each of the four agreement designs leads to a different abatement vector $q^{*r}(k)$ for each coalition $k \in K$. However, for a given coalition $k \in K$, general conclusions

about the relation between aggregate abatement under the four scenarios are difficult to derive and only possible in a few cases. For instance, no general relation between aggregate abatement under the 'Reference Design', 'Joint Quota' and 'Median Quota Proposal' holds. That is, $\sum_{i=1}^{n} q_i^{*RD}(k) <> \sum_{i=1}^{n} q_i^{*JQ}(k)$, $\sum_{i=1}^{n} q_i^{*RD} <> \sum_{i=1}^{n} q_i^{*MQP}$ and $\sum_{i=1}^{n} q_i^{*JQ}(k) <> \sum_{i=1}^{n} q_i^{*MQP}$ is possible. However, the following can be established.

Proposition 3

Consider all non-trivial coalitions $k \in K$, $\#k \geq 2$.

a) Under each agreement design, $r \in \{RD, JQ, MQP, LQP\}$, total abatement is higher than in the Nash equilibrium.

b) Under the design 'Joint Quota' total abatement is at least as high as under the design 'Lowest Quota Proposal', i.e. $\sum_{i=1}^{n} q_i^{*JQ}(k) \geq \sum_{i=1}^{n} q_i^{*LQP}(k)$.

c) Under the design 'Median Quota Proposal' total abatement is at least as high as under the design 'Lowest Quota Proposal', i.e. $\sum_{i=1}^{n} q_i^{*MQP}(k) \geq \sum_{i=1}^{n} q_i^{*LQP}(k)$.

Proof: See Appendix 6B3.

Note, however, that even if total abatement is higher under one agreement design than under another for a given coalition $k \in K$, conclusions about the performance of stable coalitions in terms of aggregate abatement would be premature. The reason is that, even if for example $\sum_{i=1}^{n} q_i^{*MQP}(k) \geq \sum_{i=1}^{n} q_i^{*LQP}(k)$ holds for all $k \in K$, $\#k \geq 2$, a coalition that is stable under the agreement design 'Lowest Quota Proposal' may not be stable under the design 'Median Quota Proposal'. For instance, suppose only small coalitions are stable under 'Median Quota Proposal' but larger coalitions are stable under 'Lowest Quota Proposal', the latter design may be superior in terms of global abatement. That is, there may well be a trade-off between ambitious abatement targets and stable participation. In order to get more information on this trade-off, simulations are required that we conduct with our empirical model STACO.

Similar relations may also hold for global welfare. For a given coalition $k \in K$, it holds for instance that global welfare under 'Joint Quota' is higher than under 'Lowest Quota Proposal'. Nevertheless, if only small coalitions are stable under the former design and large coalitions are stable under the latter design, the superiority maybe reversed – a possibility that

is confirmed by our simulations on which we report in Section 6.4. As indicated above, one reason for this apparent counterintuitive result is that high abatement may not only generate a high global welfare but may also increase the incentives of regions to leave a coalition. Another reason is related to the condition of profitability. We call an agreement *profitable* if all members of coalition k receive at least their payoff in the Nash equilibrium. It can be shown that profitability is a necessary condition for internal stability in our model and hence a necessary condition for a coalition to be stable.

Proposition 4

For each agreement design $r \in \{ RD, JQ, MQP, LQP \}$ a coalition $k \in K$ is internally stable if and only if it is profitable.

Proof: See Appendix 6B4.

However, for all agreement designs, except for the 'Lowest Quota Proposal', profitability may be violated for some coalitions $k \in K$, which, in the numerical application, is particularly true for large coalitions. This is illustrated in Section 6.4 where further explanations are provided. At this stage, it suffices to establish profitability for the 'Lowest Quota Proposal' along the lines in Endres and Finus (2002) that we adopt for the case of $n \geq 2$.

Proposition 5

For each coalition $k \in K$, the implementation of the 'Lowest Quota Proposal' leads to a profitable agreement.

Proof: See Appendix 6B5.

6.2.3. Agreement Design II and Properties II

Until now, we assumed that the uniform quotas derived from the agreement design 'Joint Quota', 'Median Quota Proposal' and 'Lowest Quota Proposal' cannot be traded. This implies an efficiency loss. Therefore, we consider the possibility of trading. In particular, we assume that the total abatement level within coalition $k \in K$ as derived for the three different quota agreement designs in subsection 6.2.1 is fixed and that the members of k can trade quotas among each other but not with outsiders. Assuming a competitive quota trading market, which may also be called a permit market, trade will take place until marginal

abatement costs within coalition k are equalized. The price for permits will be equal to the marginal abatement costs in equilibrium.

Whereas the payoff of a coalition member $i \in k$ without trading is $\pi_i(q^{*r}(k)) = B_i(\sum_{j \in k} q_j^{*r}(k) + \sum_{\ell \notin k} q_\ell^{*r}(k)) - C_i(q_i^{*r})$, the payoff with trading is now given by $\pi_i(q^{*r}(k), q_i^{**r}(k)) = B_i(\sum_{j \in k} q_j^{*r}(k) + \sum_{\ell \notin k} q_\ell^{*r}(k)) - C_i(q_i^{**r}) - p(q_i^{*r}(k) - q_i^{**r}(k))$ where $q_i^{*r}(k)$ is abatement without trading and $q_i^{**r}(k)$ is abatement after trade has taken place and $p = C_i'(q_i^{**r}) = C_j'(q_j^{**r})$ for all $i, j \in k$ is the price for permits. Note that $\sum_{j \in k} q_j^{*r}(k) = \sum_{j \in k} q_j^{**r}(k)$ because total abatement of the coalition is fixed, total abatement of non-members in k, $\sum_{\ell \notin k} q_\ell^{*r}(k)$, is the same with and without trading because for non-members nothing changes, and hence total abatement as well as benefits with and without trading are the same. Since trading is voluntarily and hence constitutes a win-win situation for all coalition members, $\pi_i(q^{*r}(k)) \leq \pi_i(q^{*r}(k), q_i^{**r}(k))$ for all members $i \in k$. For regions $\ell \notin k$, nothing changes. Taken together, we can conclude the following:

Proposition 6

Suppose uniform quotas under the design 'Joint Quota', 'Median Quota Proposal' and 'Lowest Quota Proposal' can only be traded among coalition members $k \in K$, then

   a)   coalition $k \in K$ is internally stable without trading if and only if it is internally stable with trading;
   b)   coalition $k \in K$ is externally stable with trading if and only if it is externally stable without trading.

Proof: Follows immediately from definition (6.2) of stability and the discussion above.

Proposition 6 suggests that if internal stability is the main problem for forming large stable coalitions, then trading may lead to larger stable coalitions. In particular in the context of the provision of a public, external stability may seem less of a concern because the incentive to join a coalition means a higher participation. Of course, whether 'more' internal but 'less' external stability translates into more successful coalitions in terms of global abatement and global welfare can only be investigated via numerical simulations on which we report in section 6.4.

Note finally that for the 'Reference Design' the possibility of trading has no effect because marginal costs with coalition k are already equalized for the abatement vector q^{*RD}. Moreover, Propositions 1 to 5 directly carry over to the case of trading (with appropriate adjustment in notation) because the starting point for trading are the quotas determined without trading (see Appendix 6B).

6.3. Benefit and Cost Functions of the STACO model

The calibration of payoff function (6.1) is based on the STACO-model (*sta*bility of *co*alitions model). Since the model has been laid out in much detail in Finus et al. (2006), we only briefly describe the main features here. The philosophy behind STACO comprises three items. Firstly, the model should reflect the important dynamics of climate models with respect to the accumulation of greenhouse gases and their impacts. Therefore, STACO considers a period of 100 years, starting in 2010. Secondly, in order to make the model interesting for a game theoretical analysis, there should be a sufficient number of different interacting players. Therefore, STACO uses abatement cost estimates for twelve world regions described in Ellerman and Decaux (1998). For global and regional benefits from abatement (in the form of reduced damages), it uses estimates of Fankhauser (1995) and Tol (1997). Thirdly, the model must be simple enough to be tractable for a game theoretical analysis. Therefore, though STACO captures a time of 100 years, it assumes stationary abatement strategies for simplification. The parameters of STACO are calibrated such that they are in line with the widely known DICE-model of Nordhaus (1994) in terms of global emissions and concentrations of CO_2. That, is parameters are calibrated such that they match emissions and concentration in the BAU-scenario in the DICE model (Nordhaus 1994) for our time horizon of 100 years.[3] This leads to the following discounted payoff function:

$$\pi_i(q) = \xi_i \varphi \delta_B \sum_{j=1}^{n} q_j - \delta_c \left[\tfrac{1}{3} \cdot \alpha_i \cdot q_i^{3} + \tfrac{1}{2} \cdot \beta_i \cdot q_i^{2} \right], \tag{6.7}$$

where abatement q_i is the total abatement over 100 years from business-as-usual emissions (BAU-emissions) and where all parameters are non-negative. The global benefit parameter is φ, and the regional benefit parameter is ξ_i, representing the share of a region in global benefits, $0 \le \xi_i \le 1, \sum_{i=1}^{n} \xi_i = 1$; α_i and β_i are regional abatement cost parameters that take on a non-negative value. The regional parameters reflect differences between the twelve world regions: USA, Japan, European Union (EU-15), other OECD countries (O-OECD),

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[3] This is a simplification that neglects the equilibrium path of abatement over time but it seems not so important for our analysis that focuses on coalition formation based on discounted payoffs.

Eastern European countries (EE), former Soviet Union (FSU), energy exporting countries (EEX), China, India, dynamic Asian economies (DAE), Brazil and 'rest of the world' (ROW).[4] The parameters δ_B captures discounting *and* the stock effects of GHG concentrations (retention rate and decay factor, cf. Nordhaus 1994 and Finus et al. 2006), whereas δ_c captures only discounting.

All parameter values are listed in Appendix 6A. In our base case, we assume a discount rate of 2 percent which gives $\delta_B = 1385.2$ and $\delta_c = 43.1$. The global benefit parameter is $\varphi = 0.027$, reflecting a 2.7 percent loss of GDP due to an increase in temperature by 3 degrees Celsius – as in Tol (1997). Since STACO assumes linear benefit functions, regional marginal benefits ($s_i \varphi \delta_B$) as well as global marginal benefits ($\varphi \delta_B$) are constant. For the base case calibration, this means that marginal global benefits are equal to 37.4 US$ per ton of carbon, a figure much in line with other studies (e.g., Plambeck and Hope, 1996). In our sensitivity analysis, we will test the robustness of our results by assuming different discount rates.

In our setting, we assume that the large industrialized regions are the main beneficiaries of global abatement whereas energy exporting countries (EEX), dynamic Asian economies (DAE), Brazil and Eastern European Countries (EE) receive the smallest shares of global benefits. Furthermore we assume that marginal abatement costs vary widely: China and USA have the lowest whereas Brazil and Japan have the highest. On average, abatement in regions that have low current BAU-emissions is costly since further emission reduction is only possible by employing expensive abatement technology. The opposite holds for regions with high current BAU-emission levels (see Appendix 6A).

6.4. Results

6.4.1. General Observations

In this subsection, we discuss some general observations displayed in Table 6.1 that are helpful for the interpretation of subsequent results. We choose the grand coalition (i.e. the coalition where all our 12 regions participate) as a reference point because it represents an

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[4] EU-15 comprises the 15 countries of the European Union as of 1995. O-OECD includes among other countries Canada, Australia and New Zealand. EE includes, among others, Hungary, Poland, and Czech Republic. EEX includes, among others, the Middle East Countries, Mexico, Venezuela and Indonesia. DAE comprises South Korea, Philippines, Thailand and Singapore. ROW includes South Africa, Morocco and many countries in Latin America and Asia. For details, see Babiker et al. (2001).

important benchmark. From Table 6.1, the following conclusions can be drawn for the calibration of our empirical model.

1) The 'Reference Design' implies large global emission reductions. The global gain from full cooperation is large in absolute terms but also in relative terms when considering that global welfare in the Nash equilibrium is 1,960 bln. US$. This stresses that cooperation can have a large impact.

2) Without trading, the quota agreement designs imply a substantial welfare loss compared to the 'Reference Design'. This is particular pronounced for the 'Lowest Quota Proposal'. For this agreement design, abatement is not only cost-ineffective (as this also holds for the other two quota agreement designs) but also global abatement is substantially lower than in the first-best optimum and lower than under 'Joint Quota' and 'Median Quota Proposal' due to the agreement on the lowest common denominator, as suggested by Proposition 3, b) and c). Nevertheless, even the 'Lowest Quota Proposal' implies some emission reduction compared to the Nash equilibrium as suggested by Proposition 3, a).

3) With trading, the welfare loss compared to the first-best optimum can be reduced which holds in particular for 'Joint Quota' and 'Median Quota Proposal'. Now, abatement is no longer cost-ineffective, but only global abatement levels are not optimal.

Table 6.1 Various Agreement Designs for the Grand Coalition

Agreement Design	Grand Coalition				Number of Profitable Coalitions (out of all coalitions)
	Global Abatement (%)	Global Gain (bln. US$)	Violation of Profitability	Violation of Internal Stability	
No Trading					
1) Reference Design	17.6	4,071	EE, China	all except Japan and EU-15	110
2) Joint Quota	12.1	2,629	EEX	All	1,616
3) Median Quota Proposal	13.1	2,605	EEX, Brazil	All	1,538
4) Lowest Quota Proposal	3.7	1,252	-	Japan, O-OECD, EE, FSU, EEX, DAE Brazil	4,084
Trading					
1) Reference Design	17.6	4,071	EE, China	all except Japan and EU-15	110
2) Joint Quota	12.1	3,587	EEX	all except China and India	2,091
3) Median Quota Proposal	13.1	3,743	EEX	all except China and India	1,997
4) Lowest Quota Proposal	3.7	1,385	-	O-OECD, FSU, EEX, Brazil	4,084

Notes: Global accumulated emissions in the BAU-scenario (without abatement) is 1,196 gigatons carbon over the century, total emission reduction in the Nash equilibrium is 55 gigatons corresponding to a 4.6% emission reduction and discounted global welfare is 1,960 bln US$ over the century. 'Global Abatement' is percentage abatement from Nash equilibrium emissions; 'Global Gain' is measured in billion US$ (discounted over the century) with respect to welfare in the Nash equilibrium; 'Violation of Profitability' lists those regions for which profitability as defined in Section 6.3.3 is violated; 'Violation of Internal Stability' lists those regions for which internal stability as defined in Section 6.3.1 is violated; 'Number of Profitable Coalitions' is the number of coalitions for which profitability holds for all coalition members out of the total number of coalitions which is 4,084.

4) The grand coalition comprises regions with very heterogeneous benefit and cost structures. Therefore, for the first three agreement designs, the gains from cooperation are

very asymmetrically distributed and hence this coalition is not profitable to all participants, even with trading. This does not only hold for the grand coalition, but also for some other coalitions as the last column in Table 6.1 suggests. In particular for the 'Reference Design', it is evident that a cost-effective allocation of abatement duties may imply a very asymmetric distribution of the gains from cooperation because only 110 coalitions out of 4,084 coalitions are profitable. For instance, China has to contribute much to a coalitionally optimal solution because of her flat marginal abatement cost curve but benefits only little because of her low marginal benefits. This is similar for Eastern European Countries (EE). Clearly, because trading implies a win-win-situation, profitability improves for the 'Joint Quota' and 'Median Quota Proposal'. The higher numbers of profitable coalitions with trading compared to without trading, in the last column of Table 6.1, confirm this. For the 'Lowest Quota Proposal', this is different. As Proposition 5 suggests, all coalitions are profitable even without trading.

Since profitability is a necessary condition for internal stability according to Proposition 4, it is immediately clear that the grand coalition cannot be stable for the first three agreement designs. The asymmetric distribution of the gains from cooperation shows up in a high number of regions for which internal stability is violated. As Proposition 6 suggests, trading mitigates this problem, but it does not disappear for the grand coalition. However, even the 'Lowest Quota Proposal' with trading is not internally stable because four regions would have an incentive to leave.

6.4.2. Stability Analysis: No Trading

In this subsection, we report on our stability analysis for the four agreement designs, assuming that quotas cannot be traded. Table 6.2 lists all coalitions that are stable under at least one design. Recall that the singleton coalition implies Nash equilibrium emissions and this coalition is stable by definition.

Table 6.2 shows that there is no stable non-trivial coalition under the 'Reference Design'. This is due to the asymmetric distribution of the gains from cooperation and the implementation of ambitious abatement targets in particular within large coalitions of heterogeneous regions, as pointed out in subsection 6.4.1. These factors are responsible for strong free-rider incentives.

In contrast, under the agreement design 'Joint Quota' and 'Median Quota Proposal' one non-trivial coalition comprising India and ROW is stable. Because this coalition is small (and India and Row have a similar cost structure), efficiency losses of the quota agreements are negligible and global welfare is only slightly lower compared to the 'Reference Design'.

Because of its small size, however, this coalition represents only a marginal improvement compared to the singleton coalition. Nevertheless, the result illustrates that (a small) inefficiency loss but a more symmetric distribution of the gains from cooperation may pay off if this is 'rewarded' by higher participation in a stable agreement.[5]

Table 6.2 Stable Coalitions: No Trading

Agreement Design	Coalition Members	Coalitional Abatement (% of Nash emissions)	Global Abatement (% of Nash emissions)	Global Welfare (bln US$)
	singleton coalition*	0.0	0.0	1,960
1) Reference Design	India, ROW	3.5	0.4	2,107
	EU-15, China, India, ROW	14.7	5.4	3,755
2) Joint Quota	India, ROW*	3.2	0.4	2,100
	EU-15, China, India, ROW^E	7.3	3.1	2,941
3) Median Quota Proposal	India, ROW*	3.3	0.4	2,103
	EU-15, China, India, ROW^E	9.7	4.1	3,163
4) Lowest Quota Proposal	India, **ROW***	2.8	0.4	2,088
	EU-15, **China**, India, ROW*	5.0	2.3	2,725

Notes: * denotes stable coalitions; 'E' denotes externally stable coalitions; bold-faced regions are those regions that propose the lowest quota in a given coalition.

Under 'Lowest Quota Proposal' the coalition between India and ROW is also stable, but implies lower global welfare because the implemented quota in this coalition drops from 3.2 and 3.3 percent, respectively, to 2.8 percent (as predicted by Proposition 3). However, an additional, larger and more successful coalition, comprising EU-15, China, India and ROW, is stable. The implemented quota, which is proposed by China, is with 5 percent for the coalition moderate, and substantially lower than those that would be implemented under the other two quota agreements. However, moderation pays off. That is, the participation effect compensates the moderation effect.

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[5] The fact that global welfare under "Median Quota Proposal" is higher than under "Joint Quota" in the two coalitions listed in Table 2 is due to the following reason. Though welfare of a coalition under "Median Quota Proposal" is lower than under "Joint Quota" by definition, in these examples, higher abatement levels of the coalition in the former agreement design induce a positive effect on non-members that compensates the coalitional loss.

Taken together, ranking agreement designs according to global welfare (or global abatement)[6] gives: 1) Lowest Quota Proposal, 2) Median Quota Proposal, 3) Joint Quota Proposal and 4) Reference Design. This allows for the following interpretations and conclusions.

Firstly, the widely made standard assumption in the literature on coalitions, which we called 'Reference Design', underestimates the possibilities for cooperation in the context of free-rider incentives. Secondly, the results provide a rationale for uniform quotas as frequently applied in many IEAs. Despite their inherent inefficiency, they imply a more symmetric distribution of the gains from cooperation and hence make it easier to form stable agreements. Because there is no stable non-trivial coalition under the 'Reference Design', we can conclude that welfare of all regions is higher under the three quota agreements. For coalition members this follows from the fact that stable agreements must be profitable and for non-members from the positive externality implied by higher abatement levels of members compared to the Nash equilibrium (see the proof in Appendix 6B4).

Thirdly, the results provide a rationale for the application of voting rules in international environmental negotiations. Though unconstrained optimization is a first-best solution, and constrained optimization is a second-best solution for a coalition $k \in K$ when abstracting from stability problems, this may no longer hold when agreements have to be self-enforcing. Though majority and, in particular, unanimity voting may depart substantially from an optimal solution, the application of these voting procedures in international environmental negotiations may lead to a more successful treaty. Fourthly, the results question the commonly hold view that unanimity voting, as applied in almost all IEAs, would be an obstacle for more ambitious and successful international environmental policy. Of course, this view is true when abstracting from stability problems because unanimity voting may imply substantially lower abatement targets than in any of the three other agreement designs considered in this paper, as we have seen above. However, it may not be true when considering that often more ambitious targets cannot be implemented as a self-enforcing treaty. In other words, a bird in hand is worth two in the bush.

6.4.3. Stability Analysis: Trading

In this subsection, we discuss the results of our stability analysis with trading. Table 6.3 lists all coalitions that are stable under at least one design. The two coalitions (India and ROW as

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[6] In case of multiple equilibria, we cannot assess which equilibrium will be played. Therefore, we choose the most successful stable coalition under each design. The same results arise when we use the average of all multiple equilibria and assume that all equilibria are equally likely.

well as EU-15, China, India and ROW) that have been found stable under no-trading are included for illustrative purposes and indicated by italics. Recall that the possibility of trading makes no difference for the 'Reference Design' because marginal abatement costs within a coalition already equalize without trading.

Abstracting from stability considerations, Table 6.3 confirms a result observed already for the grand coalition in Table 6.1, namely global welfare is raised through trading. Because the coalitions listed in Table 6.3 comprise fewer members than the grand coalition, also the gains from trade are smaller than in Table 6.1. For instance, consider the coalition between EU-15, China, India and ROW. Without trading, global welfare under 'Joint Quota', 'Median Quota Proposal' and 'Lowest Quota Proposal' was 2,941, 3,163 and 2,725 billion US $, respectively (see Table 6.2) whereas as it is now 3,080, 3,393 and 2,811 billion US $, respectively (see Table 6.3). In this coalition, EU-15 buys quotas (i.e. permits) in the market because of her steep marginal abatement cost curve. In contrast, China is a supplier of quotas because of her flat marginal abatement cost curve. Thus, abatement costs can be reduced through a permit market where gains increase with market size.

Table 6.3 Stable Coalitions: Trading

Agreement Design	Coalition Members	Coalitional Abatement (% of Nash emissions)	Global Abatement (% of Nash emissions)	Global Welfare bln US$
	Singleton coalition*	0.0	0.0	1,960
1) Reference Design	*India, ROW*	*3.5*	*0.4*	*2,107*
	EU-15, China, India, ROW	*14.7*	*5.4*	*3,755*
	Japan, India, ROW[E]	7.8	1.2	2,374
	Japan, EU-15, China, India[E]	16.6	5.9	3,795
	USA, Japan, China, India[E]	14.6	6.3	3,912
	USA, EU-15, China, India[E]	14.8	7.3	4,122
	Japan, EU-15, China, India, ROW[E]	18.6	7.4	4,183
	USA, Japan, EU-15, China, India[E]	17.9	9.3	4,427
2) Joint Quota	*India, ROW[I]*	*3.2*	*0.4*	*2,100*
	EU-15, China, India, ROW[I]	*7.3*	*3.1*	*3,080*
	Japan, India, ROW[I]	3.5	0.5	2,169
	Japan, EU-15, China, India*	6.8	2.8	2,982
	USA, Japan, China, India[I]	5.3	3.4	3,186
	USA, EU-15, China, India[I]	5.9	4.2	3,414
	Japan, EU-15, China, India, ROW[E]	7.1	3.9	3,335
	USA, Japan, EU-15, China, India[E]	9.0	5.3	3,708
3) Median Quota Proposal	*India, ROW[I]*	*3.3*	*0.4*	*2,104*
	EU-15, China, India, ROW[I]	*9.7*	*4.1*	*3,393*
	Japan, India, ROW*	5.1	0.9	2,261
	Japan, EU-15, China, India*	6.7	2.8	2,973
	USA, Japan, China, India*	7.8	3.9	3,307
	USA, EU-15, China, India*	8.0	4.6	3,492
	Japan, EU-15, China, India, ROW[E]	9.4	3.9	3,380
	USA, Japan, EU-15, China, India[E]	7.2	5.3	3,733
4) Lowest Quota Proposal	*India, **ROW**[I]*	*2.8*	*0.4*	*2,088*
	*EU-15, **China**, India, ROW[I]*	*5.0*	*2.3*	*2,811*
	Japan, India, ROW[I]	2.8	0.4	2,130
	Japan, EU-15, **China**, India[I]	2.7	2.2	2,756
	USA, Japan, China, India[I]	3.7	2.5	2,872
	USA, EU-15, China, India[I]	4.6	3.3	3,149
	Japan, EU-15, **China**, India, ROW*	6.3	3.0	3,050
	USA, Japan, EU-15, China, India*	6.6	4.0	3,350

Legend: '*' denotes stable coalitions; bold-faced regions are those regions that propose the lowest quota for a given coalition 'E' denotes externally stable coalitions; 'I' denotes internally stable coalitions.

Including stability considerations, comparing Table 6.3 with Table 6.2 shows that coalition formation is more successful with trading. Within each of the three quota agreement designs, global welfare (and global abatement) of stable coalitions is higher with trading than without. For instance, under 'Median Quota proposal' the only stable coalition between India and ROW generated global welfare of 2,100 billion US $ where global abatement was 0.4 percent. Now with trading, there are four stable coalitions, all of them implying higher global welfare and higher global abatement. From these coalitions, the coalition between USA, EU-15, China, India with 3,492 billion US $ and global abatement of 4.6 percent is the best performing coalition from a global point of view. Similar relations can be observed under 'Joint Quota' and 'Lowest Quota Proposal'.

These improvements can be related to Proposition 6 stating that trade has a positive effect on internal but a negative effect on external stability. For instance, the coalition between EU-15, China, India and ROW was only internally stable (and stable) under 'Lowest Quota Proposal' but not under 'Joint Quota' and 'Median Quota Proposal'. Now with trading, this coalition is still internally stable under 'Lowest Quota Proposal' (as suggested by Proposition 6) and additionally internally stable under 'Joint Quota' and 'Median Quota Proposal'. Under all three designs, this coalition is not externally stable (which is not ruled out by Proposition 6). However, this is no problem because more successful coalitions are stable. Under 'Lowest Quota Proposal' this is for instance a larger coalition including also Japan.

A similar observation can be made for the coalition between India and ROW which was stable under all three quota agreements without trading. Now, with trading, this coalition is still internally stable (as suggested by Proposition 6) but externally unstable. In any case, external instability is rewarded by other more successful (and larger) stable coalitions. Thus, we conclude for our simulations that internal stability seems to be the major problem of forming large stable coalitions and hence trading has a positive effect on the success of coalition formation.

Ranking agreement designs according to global welfare (or global abatement) as previously done gives: 1) Median Quota Proposal, 2) Lowest Quota Proposal, 3) Joint Quota Proposal and 4) Reference Design. This allows for the following interpretations and conclusions.

Firstly, also with trading, unanimity and majority voting lead to superior stable coalitions than under 'Reference Design' (unconstrained optimization) and 'Joint Quota' (constrained optimization). This confirms that there is some rationale for these voting procedures in international politics.

Secondly, between 'Joint Quota Proposal' and 'Lowest Quota Proposal' ranks have changed. With trading, which implies a win-win-situation for all coalition members, the effect of moderation is less important. In other words, trading is an additional instrument which introduces some flexibility for the design of agreements and hence high abatement targets are less of a binding constraint for stable coalition formation.

6.4.4.Sensitivity Analysis

In order to check the robustness of results, we conduct a sensitivity analysis with respect to the parameters of the payoff function. The objective is to check whether the qualitative conclusions we derived above still hold for a parameter variation. The investigation of quantitative results such as equilibrium abatement levels, global welfare and membership in stable coalitions is of less importance to us. Given the large number of parameters that enter our model, it is impossible to explore all parameter variations. Therefore, the sensitivity analysis is restricted to global parameters: the global level of benefits and abatement cost as well as the discount rate.

The analysis is simplified by the fact that a change of the discount rate has the same implications as a simultaneous change of the benefit and cost parameters. To see this, recall that the payoff function in STACO is given by $\pi_i = \xi_i \varphi \delta_b \sum_{i=1}^{n} q_i - \delta_c \left(\alpha_i q_i^3 + \beta_i q_i^2 \right)$. Firstly, consider abatement costs. A higher (lower) discount rate just scales the abatement costs down (up) because we assume a stationary abatement path and, hence, constant abatement costs. That is, the parameter δ_c is the accumulated discount factor and works like a scaling parameter. Secondly, consider benefits. A change of the discount rate has a similar scaling effect captured by the parameter δ_b. However, due to stock effects, most of the benefits of abatement are obtained in the future. Therefore, a change of the discount rate has a stronger scaling effect on benefits than on abatement costs. Hence, an increase of the discount rate has the same effect as lowering benefits and/or increasing abatement costs. Consequently, lowering the discount rate has the same effect as increasing benefits and/or lowering abatement costs. This allows us to focus our sensitivity analysis on the discount rate.

In our base case, we assumed a discount rate of 2%. In our sensitivity analysis, we apply discount rates of 1% and 5%. Hence, a 1% discount rate can be interpreted as a rise in benefits and abatement costs as compared to the base case. Due to the stock effect, benefits rise more than abatement costs. The aggregate effect is the same as scaling up benefits by a factor 1.18. For a 5% discount rate, the aggregate effect is the same as scaling benefits down by a factor 0.62. (For details, see Table 5A2 in Appendix 5A.) Table 5.4 summarizes our findings. This table lists stable coalitions and additionally the grand coalition in order to

evaluate the possible global gains from full cooperation. We may recall that the singleton coalition is stable by definition. Table 5.4 confirms many conclusions derived above.

Table 5.4 Sensitivity Analysis: Stable Coalitions

Agreement Design	Coalition Members	Global Welfare (bln US$)		
		1% discount rate	2% discount rate	5% discount rate
	Singleton coalition	2,582	1,960	877
No Trading				
1) Reference Design	Grand coalition#	7,842	6,031	2,809
2) Joint Quota	India, ROW	2,763	2,100	943
	Grand coalition#	5,992	4,589	2,108
3) Median Quota Proposal	India, ROW	2,767	2,103	944
	Grand coalition#	5,967	4,565	2,087
4) Lowest Quota Proposal	India, **ROW**	2,747	2,088	937
	EU-15, **China**, India, ROW	3,577	2,725	1,230
	USA, China, India, ROW	-	2,828	1,296
	Grand coalition#	4,236	3,212	1,427
Trading				
1) Reference Design	Grand coalition#	7,842	6,031	2,809
2) Joint Quota	Japan, EU-15, China, India	3,914	2,982	1,347
	Grand coalition#	7,223	5,547	2,570
3) Median Quota Proposal	Japan, India, ROW	2,970	2,261	1,020
	Japan, EU-15, China, India	3,910	2,973	1,336
	USA, Japan, China, India	4,352	3,307	-
	USA, EU-15, China, India	4,564	3,492	1,599
	Grand coalition#	7,406	5,703	2,668
4) Lowest Quota Proposal	Japan, EU-15, **China**, India, ROW	4,000	3,050	1,381
	USA, Japan, **EU-15**, China, India	4,369	3,350	1,546
	Grand coalition#	4,412	3,345	1,486

Notes: '#' the grand coalition is not stable under any agreement design; '−' means not stable; bold-faced regions are those regions that propose the lowest quota in a given coalition.

The potential global gain from full cooperation is large for the 'Reference Design'. Though, in absolute terms, the gain is smaller for a higher discount rate and higher for a smaller discount rate than in our base case (see Table 5.1), in relative terms, the gain remains large (more than 200 percent). For the quota agreements, the gain from full cooperation is smaller

due to the departure from a first-best optimization. In particular under the 'Lowest Quota Proposal', the gain is substantially smaller. It is also confirmed for the grand coalition that trading reduces the welfare loss of uniform quotas. Moreover, regardless of the agreement design, the grand coalition is not stable.

Table 5.4 shows that a variation of the discount rate has almost no effect on the set of stable coalitions. Only under 'Lowest Quota Proposal' there is an additional stable coalition between USA, China, India and ROW for a discount rate of 5% if quotas cannot be traded. Table 5.4 also confirms that for each of the three quota agreements, trading leads to stable coalitions that are superior to those without trading. Most importantly, ranking agreement designs according to the coalition with the highest global welfare, gives for no trading: 1) Lowest Quota Proposal, 2) Median Quota Proposal, 3) Joint Quota Proposal and 4) Reference Design and for trading: 1) Median Quota Proposal, 2) Lowest Quota Proposal, 3) Joint Quota Proposal and 4) Reference Design. This is exactly the ranking that we found in our base case, assuming a discount rate of 2%. Thus, all of our qualitative conclusions in previous subsections are confirmed.

6.5. Summary and Conclusions

Coalition formation was modeled as a two-stage game where regions decide upon their membership in the first stage and in the second stage on their abatement levels. Stability was tested based on the concept of internal and external stability. The focus of this paper was on the second stage. For this stage, four agreement designs were investigated. The 'Reference Design' followed the standard assumption in the literature on coalition formation that coalition members maximize the aggregate welfare to their coalition. This implies a cost-effective allocation of abatement duties within a coalition and a coalitional optimal aggregate abatement level. The design 'Joint Quota' made the same assumption, except that all coalition members have to reduce emissions by the same uniform rate. The other two agreement designs assumed a bargaining process where each coalition member makes a proposal for a uniform emission reduction quota. The design 'Median Quota Proposal' assumed that members agree on the median proposal, corresponding to majority voting, the design 'Lowest Quota Proposal' assumed that they agree on the lowest proposal, corresponding to unanimity voting. Additionally, the possibility of trading quotas was considered.

Because not all results could be obtained analytically, we conducted simulations with an empirical model called STACO. This model comprises benefit and abatement cost functions of twelve world regions for the climate change problem and captures a time horizon of one hundred years. The major objective of this paper was to relate different agreement designs to

the success of coalition formation when agreements have to be self-enforcing. In particular, we were interested to find explanations for the popularity of emission reduction quotas despite their cost-ineffective and a rationale for the frequent application of majority and in particular unanimity voting in negotiations leading to the signature and ratification of international environmental agreements.

It became apparent that the 'Reference Design' would lead to large global gains from cooperation if participation in a climate agreement would be high. However, this design implies a very asymmetric distribution of the gains from cooperation because the benefit-cost structure is very heterogeneous across world regions. This is a major obstacle in forming even small stable coalitions. Though the grand coalition is also not stable under the quota agreements, at least smaller coalitions are stable. Though cost-inefficient without trading, they lead to a less asymmetric distribution of the gains from cooperation. The reason is that all members reduce their emissions by the same percentage and the reduction is conducted from non-cooperative emission levels that already reflect the different interests across regions.

Among the quota agreement designs, it is not the 'Joint Quota' that performs best but the designs derived from proposals with majority and unanimity voting. Without trading, unanimity voting is particular successful. It implements substantially lower abatement targets than majority voting and those that are implemented under the design 'Joint Quota', but this is compensated by higher participation. Only if quotas can be traded majority voting will lead to better outcomes than unanimity voting which still leads to better outcomes than 'Reference Design' and 'Joint Quota'. With trading, moderate abatement targets are less of a binding constraint for successful cooperation.

Apart from the positive aspects of our analysis, there is also a normative dimension. Firstly, the standard assumption in the literature on coalition formation which we have called 'Reference Design' clearly underestimates the possibilities of cooperation. This suggests a critical review of this assumption, given that it also does not reflect what is actually going on in international negotiations. Secondly, allowing for the possibility of trading quotas among coalition members after quotas have been agreed upon, as in the Kyoto Protocol, improves the prospects of cooperation.

These results lead us to consider two issues for future research. The first issue involves studying the effects if trading would not be restricted to members but includes outsiders of a coalition. For a given coalition, welfare of insiders would increase even more than with restricted trading but also welfare of outsiders would increase. Hence, the effect of trade on internal stability and external stability is no longer as straightforward as was the case with

restricted trade. Thus, it cannot be ruled out that trading may have a negative effect on the formation of stable and successful coalitions. The second issue would be to analyze the effect of trading if we allow for the possibility that regions already anticipate the possibility that trade takes place when putting forward their proposals. Again, it cannot be ruled out that this leads to lower quota proposal by at least some members who may have a positive or negative effect on the success of coalition formation.

Appendix 6A

Table 6A1 Regional Emission, Benefit and Abatement Cost Parameters*

Regions	Emissions in 2010 (Gton)	Share of global benefits ξ_i	Abatement cost parameter α_i	Abatement cost parameter β_i
1 USA	2.42	0.226	0.0005	0.00398
2 Japan	0.56	0.173	0.0155	0.18160
3 European Union (EU-15)	1.4	0.236	0.0024	0.01503
4 Other OECD Countries (O-OECD)	0.62	0.035	0.0083	0
5 Eastern European Countries (EE)	0.51	0.013	0.0079	0.00486
6 Former Soviet Union (FSU)	1	0.068	0.0023	0.00042
7 Energy Exporting Countries (EEX)	1.22	0.030	0.0032	0.03029
8 China	2.36	0.062	0.00007	0.00239
9 India	0.63	0.050	0.0015	0.00787
10 Dynamic Asian Economies (DAE)	0.41	0.025	0.0047	0.03774
11 Brazil	0.13	0.015	0.5612	0.84974
12 Rest of the World (ROW)	0.7	0.068	0.0021	0.00805
World	11.96	1	-	-

* Input data of STACO-model as described in Finus et al. (2006). Emissions in 2010 are BAU-emissions.

Table 6A2: Global Parameters

Parameter	Discount rate		
	1 %	2 %[1]	5 %
δ_B	2389.8	1385.2	395.7
φ	0.027	0.027	0.027
δ_C	63.0	43.1	19.8
$\delta_B\varphi$ [2]	64.5	37.4	10.7

[1] Base case; [2] this figure is equal to global marginal benefits.

Appendix 6B

The proofs assume throughout payoff function (6.1), with strictly concave abatement cost functions but linear benefit functions. The latter assumption could be removed, but at the expenses of longer and more complicated proofs.

6B1. Proof of Proposition 1

Existence and uniqueness follow from the fact that payoff functions that are maximized for each agreement design as described in subsection 6.2.1 are strictly concave and the benefit functions are linear implying dominant equilibrium strategies. A sufficient condition for strict concavity is that the second order derivatives are negative over the entire domain of the variable. This is obvious for the reference scenario that solves problems (6.3) and (6.4) in the text but can also be easily check for the other agreement design. That is, one shows that problem (6.5) in the text from which a joint quota $\omega^{*JQ}(k)$ is derived, and problem (6.6) in the text from which quota proposals $\omega_i^*(k)$ are derived are strictly concave with respect to a uniform quota. This is an important property of which we will make use below.

For trading, which implies that coalition members minimize $C_i(q_i^r) + p(q_i^{*r}(k) - q_i^r(k))$ subject to a fixed total abatement level within coalition k where $q_i^{*r}(k)$ denotes abatement before trading (see subsection 6.2.3), existence and uniqueness follow from the fact that this function is strictly convex with respect to q_i^r, as is easily confirmed, and the strategy space is compact and convex.

It is important to note for all following proofs that singleton's optimal abatement level is independent of coalition $k \in K$ and follows in all cases from (6.4) in the text.

Note that for the empirical calibration of payoff function (6.1), which is given by (6.7) in the text, an interior solution cannot just be assumed but has to be checked in the computations.

6B2. Proof of Proposition 2

From Appendix 6B1 we know that payoff functions are strictly concave in proposals $\omega_i(k)$. Let $\omega^{*MQP}(k) := med\{\omega_1^*(k),...,\omega_k^*(k)\}$ and the median player be player j, $\omega^{*MQP}(k) = \omega_j^*(k)$. Because $\omega_j^*(k)$ maximizes $\pi_j(q(\omega_j(k)))$, any other proposal $\hat{\omega}_j(k) \neq \omega_j^*(k)$ by j implies $\pi_j(q(\hat{\omega}_j(k))) < \pi_j(q(\omega_j^*(k)))$ by single-peakedness. Consider a

player $i \in k$ with $\omega_i^*(k) < \omega_j^*(k)$. Suppose this player proposes instead $\hat{\omega}_i(k) \neq \omega_i^*(k)$. Then this has no effect if $\hat{\omega}_i(k) < \omega_j^*(k)$ and will reduce his payoff if $\hat{\omega}_i(k) \geq \omega_j^*(k)$ by single-peakedness of payoff function because then $\omega^{*MQP}(k) < \hat{\omega}^{MQP}(k)$. Similar arguments apply for a player k with $\omega_k^*(k) > \omega_j^*(k)$.

For $\omega^{*LQP}(k) := min\{\omega_1^*(k),...,\omega_k^*(k)\}$ similar arguments hold. Let player j's proposal be accepted, $\omega^{*LQP}(k) = \omega_j^*(k)$. This player has no incentive to propose an other proposal by single-peakedness of payoff functions. Consider a player i with $\omega_i^*(k) > \omega_j^*(k)$. Suppose this player proposes instead $\hat{\omega}_i(k) \neq \omega_i^*(k)$. Then this has no effect if $\hat{\omega}_i(k) \geq \omega_j^*(k)$ and will reduce his payoff if $\hat{\omega}_i(k) < \omega_j^*(k)$ by single-peakedness because then $\omega^{*LQP}(k) > \hat{\omega}^{LQP}(k)$. Because we assume that proposals are made without the information that quotas maybe traded afterwards, trade has no effect on the proposals.

6B3. Proof of Proposition 3

a) Irrespective of the agreement design, singletons perform (6.4) in the text, which leads to the F.O.C. $B_i' = C_i'$ for all $i \notin k$. This condition also holds for all $i \in N$ in the Nash equilibrium. Because of constant marginal benefits, this condition leads to dominant abatement levels. That is, singletons choose abatement level q_i^{*Nash} irrespective of the abatement level of other players. Now consider that a coalition $k \in K$, $\#k \geq 2$ forms.

For the "Reference Design", this implies that members $i \in k$ perform (6.3) in the text with F.O.C. $\sum_{i \in k} B_i' = C_i'$. Because $\sum_{i \in k} B_i' > B_i'$ and C_i' is an increasing function, $q_i^{*RD}(k) > q_i^{*Nash}$ for all $i \in k$, $k \in K$, $\#k \geq 2$, is true.

For the quota agreements, we write the F.O.C. of singletons in an alternative way:

$$B_i' \left(\partial \sum\nolimits_{j \in I} q_j / \partial q_i \right) \left(\partial q_i / \partial \omega_i \right) = C_i' \left(\partial q_i / \partial \omega_i \right),$$ (6B1)

recalling that $q_i(\omega_i) = e_i^{BAU} - (1 - \omega_i)e_i^{Nash}$ and noting that $\left(\partial \sum\nolimits_{j \in I} q_j / \partial q_i \right) = 1$ because of a global pollutant and that the solution of (6B1) is $\omega_i^{*Nash} = 0$.

For "Median Quota Proposal and "Lowest Quota Proposal", proposals of members $i \in k$ are derived from (6.6) in the text, which give rise to the following F.O.C.:

$$B_i'\left(\partial \sum_{j \in I} q_j \Big/ \partial \sum_{\ell \in k} q_\ell\right)\left(\partial \sum_{\ell \in k} q_\ell \Big/ \partial \omega_i\right) = C_i'\left(\partial q_i / \partial \omega_i\right), \tag{6B2}$$

noting that $\partial \sum_{j \in I} q_j \Big/ \partial \sum_{\ell \in k} q_\ell = 1$. Because $B_i'\left(\partial \sum_{\ell \in k} q_\ell \Big/ \partial \omega_i\right) > B_i'\left(\partial q_i / \partial \omega_i\right)$ it follows from (6B1) and (6B2) that for the solution of (6B2), $\omega_i^*(k)$, $\omega_i^*(k) > \omega_i^{*Nash} = 0$ for all $i \in k$, $k \in K$, $\#k \geq 2$ since $C_i'' > 0$. Hence, regardless of which proposal $\omega_i^*(k)$ is implemented in coalition k (i.e. regardless whether $\omega^{*MQP}(k) := med\{\omega_1^*(k),...,\omega_k^*(k)\}$ or $\omega^{*LQP}(k) := min\{\omega_1^*(k),...,\omega_k^*(k)\}$), abatement levels of all members $i \in k$ will be higher than in the Nash equilibrium. For the "Joint Quota", coalition members $k \in K$ perform (6.5) in the text which leads to the solution $\omega^{*JQ}(k)$. Since $\omega^{*JQ}(k) \geq \omega^{*LQP}(k)$ as proofed under b) below, and given that we just showed $\omega^{*LQP}(k) > \omega_i^{*Nash} = 0$, $\omega^{*JQ}(k) > \omega_i^{*Nash} = 0$ for $k \in K$, $\#k \geq 2$, follows.

b) $\omega^{*JQ}(k)$ can be interpreted as the maximum of the sum of $\#k$ single-peaked functions of the members of coalition k and proposals $\omega_i^*(k)$ for all $i \in k$ as the maxima of the $\#k$ single-peaked functions. Let proposals $\{\omega_1^*(k),...,\omega_k^*(k)\}$ be sorted according size, $\omega_1^*(k) \leq \omega_i^*(k) \leq \omega_k^*(k)$, then $\omega^{*JQ}(k) \in [\omega_1^*(k),...,\omega_k^*(k)]$ with $\omega^{*LQP}(k) = \omega_1^*(k)$ for the "Lowest Quota Proposal" and therefore $\omega^{*JQ}(k) \geq \omega^{*LQP}(k)$ for all $k \in K$ (with strict inequality if $\omega_1(k) \neq \omega_k(k)$).

c) Follows simply from the fact that $\omega^{*MQP}(k) := med\{\omega_1^*(k),...,\omega_k^*(k)\} \geq \omega^{*LQP}(k) := min\{\omega_1^*(k),...,\omega_k^*(k)\}$ for all $k \in K$ (with strict inequality if $\omega_1(k) \neq \omega_k(k)$). Because the total abatement level is fixed for trading, conclusions at the aggregate level also imply for trading.

6B4. Proof of Proposition 4

From Proposition 3a it is known that for each coalition $k \in K$, $\#k \geq 2$, total abatement under each agreement design is strictly higher than in the Nash equilibrium. Because players $i \notin k$ have dominant strategies, it follows that for every $k \in K$, $\#k \geq 2$, the payoff of these players is strictly higher than in the Nash equilibrium (because benefits are strictly higher and costs the same) and hence payoffs of all players $i \notin k$ are (strictly) profitable. That is, non-

members benefit from the positive externality derived from higher abatement of coalition $k \in K$ compared to the Nash equilibrium, as shown under 6B3 Hence, a coalition can only be internally stable if and only if all coalition members $i \in k$ receive a profitable payoff (otherwise they just leave their coalition). If $\#k = 1$, the singleton coalition is profitable (and internally stable) by definition.

Since trading has no influence on the payoff of non-members of coalition k (the outside option of a coalition member when leaving), conclusions are also valid for trading.

6B5. Proof of Proposition 5

Since $\omega_i^*(k)$ maximizes a coalition member's payoff, $\omega_i^*(k) \geq \omega_1^*(k) = \omega^{*LQP}(k) > \omega_i^{*Nash} = 0$ for all $k \in K$, $\#k \geq 2$, as shown above with associated payoffs $\pi_i(\omega^{*LQP}(k))$ and $\pi_i(\omega^{*Nash}(k))$, respectively, $\pi_i(\omega^{*LQP}(k)) > \pi_i(\omega^{*Nash}(k))$ for all $k \in K$, $\#k \geq 2$, must hold by the strict concavity of payoff functions with respect to $\omega_i(k)$ as explained under 6B1 above. If $\#k = 1$, the singleton coalition is profitable by definition.

Since trading implies a win-win situation for all coalition members, the proof also applies to trading.

Chapter 7. The Influence of Political Pressure Groups on the Stability of International Climate Agreements*

Abstract

This paper examines the effects of political pressure groups (lobbies) on the size and stability of international climate agreements. We consider two types of lobbies, industry and environmentalists. We show the potential effects of lobbying using the STAbility of COalitions (STACO) model. We find that although lobby contributions may help to stimulate international cooperation, the resulting stable agreement does little to tackle climate change. Finally, we observe that, contrary to intuition, a member of a stable agreement can collect industry contributions.

7.1. Introduction

With few exceptions, studies on the size and stability of international environmental agreements (IEAs) tend to treat the participants in international negotiations as monolithic and benevolent governments that truly represent the common interests of their nation (e.g. Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1997a). Even though this approach has yielded many important insights, it ignores the fact that governments often have interests not in line with those of their domestic constituents. Moreover, it does not consider that the incentives embodied in elections and other political control systems may ultimately determine what these governments can and will do at the international negotiation tables. These ideas have long been recognized by political scientists and public choice scholars. [1]

In a representative democracy, national political actors influence the policy decisions of their representatives – including positions in international negotiations – in many ways. First, the citizens may influence the international bargaining through the electoral process. A government's proposals at international negotiations should be acceptable to its domestic constituents because this, at the end, will help it to win elections (Morrow, 1991). Second, political pressure groups (or lobbies), such as business associations and environmental NGOs, are able to affect the behavior of politicians by providing information, by financing election campaigns, or by bringing environmental concerns to the forefront of the minds of the voters (Olson, 1965; Grossman and Helpman, 2001). These political factors play an important role when the national representatives meet at the international level to decide, for instance, whether or not they will participate in an IEA.

Game theoretical studies on the formation and stability of IEAs have pointed out that strong free-rider incentives exist and that these prevent agreements from being effective (e.g. Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994, 1997a; Jeppesen and Andersen, 1998). These studies assume that governments maximize a welfare function. Governments, then, only care about the aggregated welfare level of their countries. Welfare maximization, hence, is the main force that drives environmental policy decisions. However, recent events in the international policy arena have illustrated the fact that lobby groups try to affect environmental policy-making, both at the national and the international level. [2] In recent

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[1] See Persson and Tabellini (2000), for an extensive review of this literature.

[2] In 2002, the Competitive Enterprise Institute (CEI), a conservative lobby group in the USA, intended to discredit the USA's Environmental Protection Agency report on global warming. Moreover, in 2003, the CEI sued other government climate research bodies that produced evidence for global warming (The Observer, 2003). In 2005, Scientific Alliance, a British lobby group linked to Exxon Mobile, published a report challenging current views about potential effects of climate change (The Guardian, 2005).

years, industry and environmentalist lobbies have been very active in this respect, and often their interests have conflicted with each others.

The aim of this paper is to develop a model in which government's decision about IEA participation and abatement policies are influenced by lobby groups. In our model, lobby groups organize a collective action to influence government decisions. We model this by means of contributions that reflect the willingness to pay of the lobby to change the government's policies in their favor. In this respect, our paper is in the tradition of the literature that studies the influence of interest groups on policy-making; see Persson and Tabellini (2000) for an overview. Most of these studies focus on the role of producer groups in the determination of trade policies. In this area, the political contributions approach of Grossman and Helpman (1994, 1995 and 1996) is a standard model. Grossman and Helpman study the effect of lobby contributions on trade policies. They consider that policy-makers are self-interested and seek to maximize the sum of lobby contributions and the welfare of the median voter in order to increase their chances to be reelected.

The political contributions approach has further been applied to study environmental policy-making (e.g. Fredriksson, 1997; Aidt, 1998; Conconi, 2003; Fredriksson *et al.,* 2005). Fredriksson (1997) studies the influence of lobby groups on environmental tax policy and shows that there is a relation between the strength of lobby activities and the deviation from an optimal pollution tax. Aidt (1998) analyzes the effect of environmentalist and industry lobbies on environmental policy in the presence of production externalities. Aidt shows that lobby groups, through the competitive political process, are important to internalize production externalities. Conconi (2003) analyzes the effect of environmentalist lobbies on the determination of trade and environmental policies for large countries linked by trade and transboundary pollution problems. Conconi's results show that the impact of lobby groups on environmental policy depends on the trade policy regime, the type of decision-making process (if it is unilateral or cooperative) and the size of the transboundary environmental spillovers. Fredriksson *et al.* (2005) analyze and empirically test the effect of environmentalist lobby groups and degree of democracy on environmental policy-making. Their empirical analysis shows, for OECD countries, that there is an effect of lobby actions on policy-making. However, this effect is likely to occur in countries with sufficiently high levels of political competition.

Although there is a large literature on lobby groups and international policy-making, the analysis of the potential effects of lobbying on the formation and stability of IEAs has not been examined in detail – with the exception of Haffoudhi (2005a). Haffoudhi studies the impact of lobby groups on the size and stability of IEAs. She finds that, for homogeneous countries, a global agreement would be sustained by means of industry lobby contributions.

Our paper takes a similar approach. First, as in Grossman and Helpman (1994) and Haffoudhi (2005a), we assume that lobbies try to influence government's policy decisions but we abstract from the election process. We assume that lobbies' influence is represented by prospective contributions that enter into the government's political revenue function and are made conditional on a change of government's policy decisions. Second, different from Grossman and Helpman (1994), we do not model lobbying as a menu auction, where exogenously given lobby groups offer contribution schedules to policy-makers. We assume, instead, following Felli and Merlo (2005) and Haffoudhi (2005a), that given the set of existing lobbies, governments choose the lobby from which it will receive contributions. Third, different from Haffoudhi (2005a), we consider an empirical model with heterogeneous world regions. Finally, following Hillman and Ursprung (1992, 1994), we consider two model variants where governments consider the contributions from supergreen and green environmentalist lobby groups. Supergreens are concerned about global environmental damages, whereas greens are only concerned about the environmental impacts that affect their own region.

This paper is the first to study the effect of lobbying on the size and stability of IEAs with an empirically meaningful model. It extends previous work in two directions. First, we analyze coalition formation in IEAs from a public choice perspective. We extend the literature on IEAs to include political pressure (modeled by means of prospective lobby contributions) on governments' decisions when signing an agreement. Second, we demonstrate the potential impacts of lobbying with the help of the STAbility of COalitions (STACO) model introduced by Dellink *et al.* (2004). STACO combines an empirical climate change module with a game theoretical module on coalition formation. This allows us, with appropriate modifications, to study the impact of the pressure from lobby groups on the stability of climate coalitions and the resulting environmental and economic effects. We test for stability using the concept of internal and external stability (d'Aspremont *et al.*, 1983). A coalition is said to be stable if no other region wants to accede to the coalition (external stability) and no member region wants to leave the coalition (internal stability).

The results form our analysis show that although lobby contributions help to stabilize an ICA, the stable agreement does not help much in tackling climate change. Furthermore, we find that, contrary to intuition, a member of a stable agreement may collect industry contributions. However, we provide a sufficient condition for governments, upon joining a coalition, to get engaged with the environmentalist lobby.

The next section presents our analytical framework. Section 7.3 describes the empirical calibration of the payoff function including the lobby contribution schemes. Section 7.4 presents and analyzes the main results. Finally, Section 7.5 summarizes and concludes.

7.2. Analytical framework

We set up a model of coalition formation with lobby contributions. In the model, governments in each region $i \in N$ seek to maximize their own political revenue considering the pressure from lobby groups. We model lobby pressure as prospective contributions that reflect the willingness to pay of a lobby to influence the government's policy decisions in their favor. Contributions, thus, represent the monetary value assigned to all lobbying activities that influence the government's decisions. The political revenue function has two components. First, it is a function of the regional net benefits of climate policy. This may include the net benefits of participating in an IEA to tackle climate change – hereafter called 'international climate agreement' (ICA). Second, political revenue depends on the contributions from lobby groups. We assume that only two groups of citizens overcome the problems involved with organizing a lobby (e.g. organizational costs and free-riding) described by Olson (1965) and actually form lobby groups. Hence, following a common assumption in the literature (see Grossman and Helpman 1996, Aidt 1998 and Conconi 2003), we assume a given number and identity of the lobby groups. In particular, we consider that two lobby groups, environmentalist (E_i) and industry (I_i), are active in region i. Lobby groups are indexed by $h_i \in \{E_i, I_i\}$. Furthermore, we consider two types of environmentalists, supergreens (S) and greens (G), thus $E_i \in \{S_i, G_i\}$.

The political revenue function of government i, π_i, reflects the benefits and costs of greenhouse gases' abatement and the prospective contributions, L_{h_i}, from lobby group h_i, that chooses to support the government's policy. Hence, either industry or environmentalists, but not both, support a chosen policy. The political revenue function is :

$$\pi_i(q_i) = B_i(q) - C_i(q_i) + \rho_i \cdot L_{h_i}(q_i), \tag{7.1}$$

where B_i are the total discounted benefits from global abatement $q = \sum_{i \in N} q_i$, and C_i are the total discounted abatement costs from regional abatement q_i. We assume that B_i is concave, i.e. $\partial B_i / \partial q_i > 0$ and $\partial^2 B_i / \partial q_i^2 \leq 0$, C_i is strictly convex, i.e. $\partial C_i / \partial q_i > 0$ and $\partial^2 C_i / \partial q_i^2 > 0$, and that $q_i \in [0, e_i^{BAU}]$ where e_i^{BAU} is the emission level in the Business-as-usual scenario with no abatement. The parameter $\rho_i \geq 0$ captures the relative weight of contributions compared to net benefits from abatement. For simplicity we assume that $\rho_i = \rho_j = \rho$ for all $i, j \in N$. Finally, $L_{h_i} \geq 0$, represents the total discounted contributions

from a regional lobby and we assume that for the environmentalist lobby $\partial L_{E_i} / \partial q_i > 0$, $\partial^2 L_{E_i} / \partial q_i^2 \leq 0$, and for the industry lobby $\partial L_{I_i} / \partial q_i < 0$, $\partial^2 L_{I_i} / \partial q_i^2 < 0$.

We model the formation of ICAs as a two-stage game of cartel formation. At the first stage, regions decide on membership. At the second stage, regions choose their abatement strategies. At the first stage, we assume that regions can choose between two membership strategies: to sign or not to sign an ICA. Those who sign an ICA become signatories, i.e. members of a coalition K. If no region or only a single region signs the ICA, then K is not effective and the singleton coalition structure emerges. If K = N the grand coalition emerges. In our empirical setting with 12 heterogeneous players (regions), the game renders $2^{12} - 12 = 4084$ different coalition structures.

Non-signatory governments choose their abatement level such that it maximizes their political revenue – i.e. it maximizes expression (7.1). Signatory governments choose their abatement levels taking into account the net benefits of fellow coalition members; additionally each government also includes the lobby contributions it can collect. Thus, the ICA commits coalition members to account for the externalities that accrue to their coalition. By contrast, lobby contributions are considered to be a regional issue. Hence, coalition members maximize

$$\sum_{i \in K} \left[B_i (q) - C_i (q_i) \right] + \rho \cdot L_{h_i} (q_i). \tag{7.2}$$

We follow the standard assumption in coalition formation: the coalition plays non-cooperatively, behaving like a single player, against non-signatories. The Nash equilibrium of the resulting abatement game gives a unique abatement vector.[3]

We consider the situation without lobby contributions as our base case, $L_{h_i} = 0$. In the base case, each government makes its abatement decisions considering only the net benefits from abatement. When governments receive contributions, abatement is influenced both by the net benefits from abatement (the first two terms on the right-hand side of (7.1) for non-signatories and the terms between square brackets in (7.2) for signatories) and the possibility of receiving, domestically, a lobby contribution – the last term on the right-hand side of (7.1) and (7.2). We assume that a lobby pays contributions for any abatement policy q_i the

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[3] This type of equilibrium has been called a Partial Agreement Nash equilibrium by Chander and Tulkens (1997).

government adopts in favor of this lobby. In particular, we assume that the environmentalist lobby pays a contribution when government's abatement is strictly higher than the equilibrium level of abatement in the base case, q_i^g. In contrast, the industry lobby pays a contribution when government's abatement is strictly lower than q_i^g. Governments maximize their political revenue considering that the two lobbies are willing to make a contribution. Then, they choose the abatement level that renders the largest political revenue and consequently they choose which lobby to accept a contribution from. The governments choose

$$\text{Max}\left\{ B_i(q_i^{E^*}) - C_i(q_i^{E^*}) + \rho_i \cdot L_{E_i}(q_i^{E^*}), B_i(q_i^{I^*}) - C_i(q_i^{I^*}) + \rho_i \cdot L_{I_i}(q_i^{I^*}) \right\} \qquad (7.3)$$

where $q_i^{E^*}$ and $q_i^{I^*}$ are the equilibrium levels of abatement with environmentalist and industry contributions, respectively. Thus, we assume that only one lobby will be successful in influencing the decision of the government. In (7.3) governments only consider the benefits of their own abatement taking the abatement of other regions as given.

Inspection of the first order conditions of our model reveals that lobby contributions always affect the abatement decisions of singletons and coalition members. In our base case, without contributions, the payoff function is $\pi_i^o(q_i) = B_i(q) - C_i(q_i)$. Then, the first order condition of a government as a singleton is

$$\partial B_i(q) / \partial q_i = \partial C_i(q_i) / \partial q_i . \qquad (7.4)$$

In the base case a coalition member maximizes $\sum_{i \in K} \pi_i^o(q_i)$

$$\partial \sum_{i \in K} B_i(q) \bigg/ \partial q_i = \partial C_i(q_i) / \partial q_i . \qquad (7.5)$$

From (7.1) we obtain the first order condition for a singleton with lobby contributions

$$\partial \left(B_i(q) + \rho_i \cdot L_{h_i}(q_i) \right) \bigg/ \partial q_i = \partial C_i(q_i) / \partial q_i . \qquad (7.6)$$

From (7.2) we obtain the first order condition for a coalition member

$$\partial \left(\sum_{i \in K} [B_i(q)] + \rho_i \cdot L_{h_i}(q_i) \right) \bigg/ \partial q_i = \partial C_i(q_i) / \partial q_i . \qquad (7.7)$$

Comparing (7.6) and (7.7) with (7.4) and (7.5) we observe that lobby contributions enter as an extra term on the marginal benefits side (left-hand side of these expressions). Hence, as long as $\partial L_{h_i}(q_i)/\partial q_i > 0$ the abatement levels of singletons and coalition partners will be different from the corresponding levels in the base case. Furthermore, comparing expressions (7.5) and (7.7) we observe that lobby contributions disturb efficiency for coalition members. Clearly, the marginal contributions term ($\partial L_{h_i}(q_i)/\partial q_i$) causes coalition members to move away from the efficient level of abatement – obtained from the maximization of the coalitional net benefits from abatement.

7.3. Calibration of the model

In this section, we describe the main features of the calibration of the empirical module of the STAbility of COalitions (STACO) model – see Dellink *et al.* (2004) and Finus *et al.* (2006) for a detailed description of the calibration. STACO has been used to examine effects of exclusive membership (Finus *et al.*, 2005), permit trading (Altamirano-Cabrera and Finus, 2006) and surplus sharing (Weikard, Altamirano-Cabrera and Finus, 2006) on the stability of ICAs. STACO calculates payoffs (in terms of net benefits) for each region and each coalition structure. These payoffs are used to check for stability. The regions considered are USA, Japan, European Union (EU-15), other OECD countries (O-OECD), Eastern European countries (EE), former Soviet Union (FSU), energy exporting countries (EEX), China, India, dynamic Asian economies (DAE), Brazil and "rest of the world" (ROW).[4] STACO considers a time horizon of 100 years starting in 2010, focuses on abatement of CO_2 emissions, and uses a uniform 2% discount rate for the calculation of the net present value of the net benefits of abatement. We adopt the same specification. In Section 7.4.2 we present a sensitivity analysis varying the discount rate. Finally, we assume stationary abatement strategies, i.e. a constant abatement level over the time horizon of our model.

7.3.1. The Benefit function

In STACO, the calibration of the benefit function is based on a linear approximation of the damage cost function of the DICE model (Nordhaus, 1994). We assume that the benefits of global abatement are derived from reduced environmental damages caused by CO_2 emissions

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[4] EU-15 comprises the 15 countries of the European Union as of 1995. O-OECD includes among others Canada, Australia and New Zealand. EE includes, among others, Hungary, Poland, and Czech Republic. EEX includes, among others, the Middle East Countries, Mexico, Venezuela and Indonesia. DAE comprises South Korea, Philippines, Thailand and Singapore. ROW includes South Africa, Morocco and many countries in Latin America and Asia. For details, see Babiker *et al.* (2001).

and that each region receives a share of the global benefits. The resulting (discounted) regional benefit function, $B_i(q)$, is expressed as

$$B_i(q) = \mu_i \cdot \delta_B \cdot q \tag{7.8}$$

where μ_i is the share of the benefits ($\sum_{i \in N} \mu_i = 1$) that a region receives from global abatement $q = \sum_{i \in N} q_i$ and δ_B is a parameter that captures the discounting of benefits of abatement and the stock effects of CO_2 emissions.[5] This parameter δ_B represents the global marginal benefits in STACO. From 7.8 follows that the regional marginal benefits are constant and equal to $\mu_i \delta_B$. The regional parameters for the benefit function are listed in Appendix 7A, Table A.1. With constant marginal benefits, the coalition and the singletons have dominant abatement strategies (Folmer and van Mouche, 2000). That is, the abatement strategies of a region or a coalition are independent of other regions. Thus, there are no leakage effects in our model. The literature on the stability of IEAs recognizes that a setting with linear benefit function offers the most favorable conditions for forming stable coalitions (Carraro and Siniscalco, 1993; Finus, 2001 and 2003).

7.3.2. The Abatement costs function

For the specification of the abatement cost function we rely on estimates from the EPPA model (Ellerman and Decaux, 1998). The regional (discounted) abatement costs are given by

$$C_i(q_i) = \delta_C \left[\frac{1}{3} \xi_i q_i^3 + \frac{1}{2} \zeta_i q_i^2 \right] \tag{7.9}$$

where ξ_i and ζ_i are regional parameters and δ_C captures the discounting of abatement costs.[6]

The regional parameters for the abatement cost function are listed in Appendix 7A, Table 7A1. In our setting, the large industrialized regions are the main beneficiaries of global abatement whereas energy exporting countries, the dynamic Asian economies and Brazil receive the smallest share of global benefits. The marginal abatement costs vary widely:

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[5] We use the calibration suggested by Dellink *et al.* (2004) and Finus *et al.* (2006) who use $\delta_B = 37.4 \ \$/ton$.

[6] As in Dellink *et al.* (2004) and Finus *et al.* (2006), we use $\delta_C = 43.1 \ \$/ton$

China and USA have relatively flat curves whereas Brazil and Japan have relatively steep curves.

7.3.3. Lobby payoffs and contributions

In this subsection, we specify the lobby contribution functions. We assume that the environmentalist lobby contributions are related to the increase of environmental benefits as a result of the regional abatement policy. Thus, the environmentalist lobby contributes if the government decides to increase abatement above the benchmark level, q_i^g, that would be chosen by the government in the absence of lobby contributions. Following Hillman and Ursprung (1992 and 1994), we assume that the environmentalist lobby may be either supergreen or green. A supergreen lobby is concerned (by self-interest, aesthetic or altruistic motives) about global environmental impacts of regional environmental policies. A green lobby is concerned only about the regional environmental impacts of the regional abatement polices.

The contribution function for a *supergreen* lobby S_i is

$$
L_{S_i} = \begin{cases} \varepsilon \cdot \delta_B \left(q_i - q_i^g \right) & \text{for } q_i \geq q_i^g \\ 0 & \text{for } q_i < q_i^g \end{cases}.
$$
(7.10)

The contribution function for a *green* lobby G_i is

$$
L_{S_i} = \begin{cases} \varepsilon \cdot \mu_i \cdot \delta_B \left(q_i - q_i^g \right) & \text{for } q_i \geq q_i^g \\ 0 & \text{for } q_i < q_i^g \end{cases}.
$$
(7.11)

In (7.10) and (7.11), ε is a parameter ($0 < \varepsilon < 1$) that reflects the strength of the willingness to pay of environmentalist lobbies for increased abatement. The parameter δ_B is included in these expressions because lobby contributions, for consistency, have to be discounted in order to be included in the political revenue function of singletons and coalition members – see expressions (7.1) and (7.2). Moreover, we assume that environmentalist contributions are linked to the benefits from abatement and that the stock effects of CO_2 emissions are also recognized by the environmentalist lobby. Hence, the discount factor of the benefit function is applied.

For further calculations and analysis, we need to determine q_i^g. We find the singleton coalition structure to be the unique stable coalition in the base case. Hence, the corresponding abatement levels serve as the reference abatement levels (q_i^g) to determine contributions. It is clear from (7.10) and (7.11) that the more the actual abatement exceeds q_i^g the higher the contributions of both types of environmentalist lobbies.

Next, we assume that the industry is always harmed by the abatement decision of the government, given that the abatement costs are usually carried by the industry. Industry contributions are linked to the discounted costs saved when abatement levels are lower than q_i^g. Thus, considering expression (7.5) and that the industry uses the same discount rate δ_C for contributions and abatement, we get:

$$
L_{I_i} = \begin{cases} \delta_C \left\{ \dfrac{\xi_i}{3} \left[\left(q_i^g\right)^3 - q_i^3 \right] + \dfrac{\zeta_i}{2} \left[\left(q_i^g\right)^2 - q_i^2 \right] \right\} & \text{for } q_i \leq q_i^g \\ 0 & \text{for } q_i > q_i^g \end{cases}
\tag{7.12}
$$

From expression (7.12) it is clear that an industry lobby pays higher contributions the more the actual abatement level is below the government's benchmark decision without lobby contributions.

7.4. Results and sensitivity analysis

In this section, we present the results from our analysis for the base case, we examine the implication of lobby contributions and provide a sensitivity analysis. For the base case, we find that all regions undertake some abatement effort even in the absence of an agreement – i.e. in the singleton coalition structure. The heterogeneity of our regions, in terms of cost-benefit structure (see Appendix 7A, Table 7A1) implies different levels of abatements. For instance, USA undertakes the largest abatement effort in the singleton coalition structure given its low marginal abatement costs and high marginal benefits. Also China undertakes important abatement efforts because it has relatively low marginal benefits and the lowest marginal costs. In contrast, regions like Brazil or the energy exporting countries (EEX), that have high marginal cost and low marginal benefits have little incentive to abate.

7.4.1.Main results and stability analysis

The results of this section are obtained assuming that the relative weight of contributions compared to social welfare ρ is equal to 1. Hence, we assume that governments weight both the net benefits from abatement and the lobby contributions equally. We change this assumption in the sensitivity analysis of section 7.4.2. As preliminary results from our analysis we highlight two features of our setting. First, from the first order conditions presented in Section 7.2 we know that $\partial B_i(q)/\partial q_i = \partial C_i(q_i)/\partial q_i$ for our base case and that $\partial\left(B_i(q)+\rho_i\cdot L_{h_i}(q_i)\right)/\partial q_i = \partial C_i(q_i)/\partial q_i$ for the case with lobby contributions. Considering our empirical calibration (see Section 7.3) these conditions imply that a region, acting as a singleton, has a higher abatement level than in the base case if it receives contributions from the environmentalist lobby and has a lower abatement level than in the base case if it receives contributions from the industry lobby – see Appendix 7B expressions (7B1)-(7B4). Second, the decision of whether or not to take lobby contributions is independent of the decisions of the remaining regions concerning lobby contributions and coalition membership – both for singletons and coalition members. This is a result of the presence of constant marginal benefits – which imply dominant abatement strategies – in our model. Dominant strategies allow us to calculate regional abatement and corresponding lobby contributions without considering the behavior of other regions.

In Table 7.1, we show the results for the singleton coalition structure once we include lobby contributions. We note that the influence of lobbies on abatement levels and net benefits depends mainly on the type of environmentalist lobby. When we consider a supergreen lobby, contributions have a positive effect on global abatement and consequently on global payoff. For the singleton coalition structure, we find an increase in abatement of about 40 % compared to the base case. Global abatement increases even though there are three regions (USA, Japan and EU-15) that receive industry contributions and hence reduce their abatement below the base case levels. However, when we consider a green lobby, contributions have a negative effect on global abatement. There is a decrease of 40 % compared with the base case because all regions take contributions from the industry lobby and reduce their abatement levels below those of the base case.

Table 7.1 Results for singleton coalition structure with lobby contributions (supergreen and green lobbies)

Region	Industry or supergreen lobby contributions			Industry or green lobby contributions		
	Abatement over century	Net benefits over century	Contributions over century [a]	Abatement over century	Net benefits over century	Contributions over century [a]
	(Gton)	(bln $)	(bln $)	(Gton)	(bln $)	(bln $)
USA	11	657	35*	11	273	35*
Japan	0	514	2*	0	221	2*
EU-15	4	696	16*	4	296	16*
O-OECD	4	97	7	1	44	1*
EE	3	34	9	1	17	0*
FSU	8	185	11	3	85	3*
EEX	3	83	8	0	39	0*
China	31	106	58	9	75	11*
India	7	133	14	2	64	2*
DAE	2	69	6	0	32	0*
Brazil	0	45	0	0	20	0*
ROW	7	186	11	2	86	3*
World	80	2,804	176	34	1,252	73

Note: a) regions indicated with an * are receiving industry contributions, otherwise they receive environmentalist contributions.

In the base case, a region, acting as a singleton, chooses the abatement level (q_i^g) that maximizes government's net benefits from abatement – see expression (7.4). From expressions (7.10)-(7.12), and for all $\rho > 0$, we know that any compromise in the abatement level of the government (i.e. for any $q_i \neq q_i^g$) will be rewarded with a contribution from one of the lobbies. When $q_i < q_i^g$, the industry makes a contribution that compensates for the foregone benefits from a lower abatement level. Whereas, when $q_i > q_i^g$, the environmentalist makes a contribution compensating for the additional abatement costs resulting from increased abatement. Hence, for all regions, any abatement level different from q_i^g results in a higher payoff than in the base case. It is always better, then, to change the abatement decision and collect contributions.

In Figure 7.1, we present a schematic representation of the shape of the political revenue function – expression (7.1) – of the governments. From the Figure, we identify which lobby is successful in influencing the government's abatement decisions. The curves depict the political revenue function for a singleton with industry lobby contributions π_i^I, with environmentalist lobby contributions π_i^E and without contributions π_i. It is obvious from

Figure 7.1 that it is always better to accept lobby contributions. The local optima for the payoff with lobby contributions (points A and C) represent a higher payoff than the base case optimum (point B). For the region represented in Figure 7.1, it is better to collect industry contributions – the best local optimum, in terms of political revenue, is point A.

The situation is different for coalition members. A closer inspection of the first order conditions for singletons and coalition members – expressions (7.4)-(7.7) – reveals that a region, acting as a coalition member, will always have a higher abatement level than when acting as a singleton, simply because they take the positive externalities from the abatement of other coalition members into account. When joining a coalition, members have to consider the marginal benefits of their partners. Hence, the left-hand sides of (7.5) and (7.7) increase. These expressions can only hold if there is an increase in the abatement level. Hence in Figure 7.1, the abatement level of the region as a coalition member will correspond to points that are to the right of points A, B and C.

It is less transparent for coalition members which lobby would be successful in influencing the abatement decisions of the government. In our setting, with heterogeneous regions, it is not possible to determine a clear-cut rule analytically. It depends on the identity of the coalition partners, in particular on their marginal benefits. We do, however, find that for our empirical calibration a sufficient condition for a government's switch from taking industry contributions to accept environmentalist contributions is that it forms a coalition with partners whose marginal benefits match or exceed its own marginal benefits. To understand this, first consider a government that as a singleton accepts contributions from the industry (as in Figure 7.1). Its abatement decision is taken following expression (7.6). Then, consider that this government forms a coalition with a region that has the same marginal benefits. Using (7.5), (7.8), (7.9), (7.12) and rearranging terms we obtain

$$\frac{1}{2}\sum_{i\in K}\rho\delta_B\mu_i = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right] \tag{7.13}$$

Note that if the two coalition members have the same marginal benefits (i.e. $\mu_i = \mu_j$, with $i, j \in K$) then (7.13) becomes $\rho\delta_B\mu_i = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right]$ which is the first order condition for a singleton in the base case – see Appendix 7B. Hence, if this region continues to accept industry contributions, it will move to the abatement level of a singleton in the base case – i.e. it chooses q_i^g. This level of abatement, however, gives a lower payoff than accepting environmentalist contributions. Hence, the region will further increase abatement and choose to collect contributions from the environmentalist lobby. Regions accepting industry contributions as singletons do not switch to environmentalist contributions when joining a

coalition unless their abatement level as a coalition member exceeds q_i^g. In the case that a region joins a coalition whose members have an aggregated level of marginal benefits larger than its own, it will increase its abatement level beyond q_i^g and will receive environmentalist contributions.
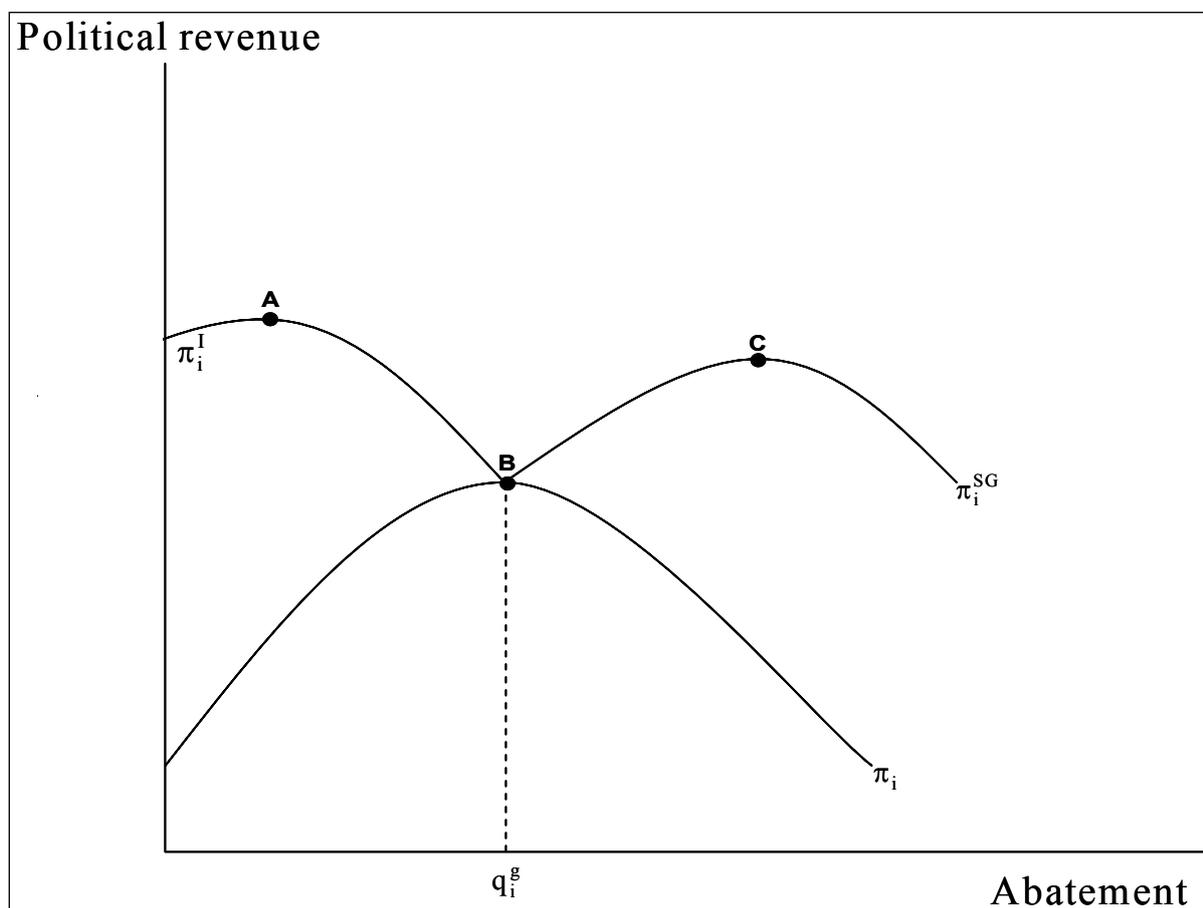

Figure 7.1 Political revenue curves for a representative region as a singleton

We test for stability using the concept of internal and external stability. Internal stability means that no coalition member has an incentive to leave the coalition. External stability means that non-members have no incentives to join the coalition. In the base case we do not find a stable coalition and find that only 14 internally stable coalition structures. This shows that there are strong free-rider incentives. The situation changes once we consider lobby contributions. We notice that lobby contributions help to reach a stable agreement. We find one stable coalition comprising Japan and the European Union (EU-15). This coalition is stable when considering industry and supergreen contributions and when considering industry and green contributions – see Table 7.2.

Table 7.2 Reference and stable coalitions with lobby contributions (no transfers)

Case	Coalition	Global abatement over century (Gton)	Global net benefits over century (bln $)
Base case	singleton coalition*	55	1,960
	{Japan, EU-15}	59	2,056
	grand coalition	256	6,031
With industry and supergreen contributions	singleton coalition*	80	2,804
	{Japan, EU-15}*	83	2,908
	grand coalition	270	6,005
With industry and green contributions	singleton coalition*	34	1,252
	{Japan, EU-15}*	38	1,350
	grand coalition	258	6,031

Note: * stable coalition.

In our base case, the coalition between Japan and EU-15 is internally unstable. The extra benefits that EU-15 would obtain from the augmented abatement level in the coalition would be offset by the increase in its abatement costs. Hence, it will not join the coalition but remain a singleton. Lobby contributions help to make this coalition stable. We find that EU-15 collects industry contributions in the stable coalition. At a first glance this result seems counterintuitive: A region will always increase abatement when joining a coalition. Why, then, would a region sign an agreement with the support of the industry? In the end, an agreement is meant to foster abatement.

A closer inspection of our results reveals why a coalition member receives industry contributions. In the stable coalition, EU-15 indeed increases its abatement level compared to the singleton case (by 50%). Even after the increase, however, this level of abatement is still lower than its base case level. Hence, EU-15 collects industry contributions. Furthermore, we find that at least one coalition member receives industry contributions in about 1,000 of the coalitions that we tested – among these only the coalition of Japan and EU-15 is stable. In these coalitions, the increase in benefits is not sufficient to compensate the increase in abatement costs for some members, even with supergreen contributions. Governments, thus, choose a compromise. They increase their abatement level from the singleton coalition structure but to an extent less than in the base case. Hence, they still can collect from the industry. EU-15 will only change its decision about lobby contributions if it joins a coalition partner with higher marginal benefits (such as USA) or if the coalition with Japan is enlarged. In contrast, upon joining the coalition, Japan changes its decision to take contributions – the marginal benefits of EU-15 clearly exceed those of Japan, see Appendix 7A, Table 7A1. In

the stable coalition, Japan collects contributions either from the supergreen or the green lobby.[7] Because the coalition increases global abatement, both regions have larger benefits and abatement costs. For Japan, the increase in abatement costs is more than compensated by the environmentalist contributions.

We find that the stable coalition does not help much to tackle climate change. From Table 7.2 we observe that the increase in abatement for the stable coalition represents a small improvement with respect to the singleton coalition structure. Furthermore, when there are green and industry contributions, the stable coalition falls short of achieving the abatement level of the singleton coalition structure in the base case – it achieves 30% less abatement. In the coalition of Japan and EU-15, the latter collect industry contributions. Hence, EU-15 has a lower abatement level in this coalition than as singleton in the base case. This counteracts the cooperative efforts of Japan. The stable coalition, then, helps little to reap the gains from cooperation. It does not help to close the gap, in terms of net benefits, between the situation without cooperation (singleton coalition structure) and full cooperation (grand coalition structure). The stable coalition only closes this gap by approximately 2%, either with supergreen and industry contributions or with green and industry contributions.

7.4.2. Sensitivity analysis

We conduct a sensitivity analysis with respect to a selection of parameters from our model. The aim of this exercise is to investigate whether the qualitative results presented in Section 7.4.1 hold for a variation in some of the critical parameters of our model. We focus on three parameters, the strength of environmentalist lobbies' willingness to pay for abatement policies (ε), the relative weight of contributions compared to social welfare (ρ) and the discount rate. Firstly, we analyze the effects of having an environmentalist lobby (supergreen or green) with stronger or weaker willingness to pay (WTP) for increased abatement. We test this through an increase or decrease in the parameter ε. We change ε from 0.1 (its original level) to 0.5 and 0.01 in order to reflect a stronger and a weak WTP respectively. Secondly, we investigate the effect of having a government that is less or more concerned about lobby contributions. We test this through a change in the parameter ρ from 1 (its original level) to 0.5 and 1.5 in order to reflect less or more concern of government about contributions. Third, we investigate a change in the discount rate. Note that in the STACO calibration, discounting enters the benefit and abatement costs functions through parameters δ_B and δ_C respectively. Following our assumption of constant abatement strategies, a change in the discount rate has

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[7] In reality, a switch of this nature is less drastic. For instance, several environmentalist groups in USA, backed by Vice-president Al Gore, in 1997, heavily pushed for the ratification of the Kyoto Protocol. This was clearly a change from the previous (George Bush Sr.) administration.

only a scaling effect on the benefits and abatement costs. Given that the parameter δ_B also captures the stock effects of CO_2 emissions, a change in the discount rate, however, has stronger scaling effects on the benefits than on the abatement costs. In STACO, an increase in the discount rate has a similar effect to having lower benefits or higher abatement costs. Conversely, lowering the discount rate has a similar effect to having higher benefits or lower abatement costs. We can simplify these effects and express the variation of the discount rate as a re-scaling in the benefit function. Then, we perform the sensitivity analysis by changing the discount rate from 2% (its original level) to 1% (that is equivalently to scaling up benefits by a factor of 1.18) and to 3% (that is equivalently to scaling down benefits by a factor of 0.85).

We find that qualitatively, our results are robust to the changes in the parameters described above. Firstly, we find that in stability terms our results are quite robust. The coalition between Japan and EU-15 is stable under all changes of the parameters that we tested – the only exception is when $\rho = 1.5$ – and irrespective of the type of the environmentalist lobby. Secondly, we confirm that the influence of lobbies depends on the type and strength of the environmentalist lobby. When we consider supergreen and industry contributions, both the singleton and stable coalition of Japan and EU-15 achieves better results (in terms of abatement and net benefits) than in the base case. Whereas, when there are green and industry contributions, all singletons are collecting contributions from the industry and the abatement of the stable coalition is below the level of the singleton coalition structure in the base case. Third, we find that the decisions of taking contributions are also robust to a change in the discount rate. Only if the benefits become sufficiently high (as with a discount rate of 1%) do all governments in our regions have an incentive to change its decisions and take environmentalist contributions in the singleton coalition structure and in the stable coalition between Japan and EU-15.

7.5. Summary and conclusions

In this paper, we study the effect of political pressure groups (lobbies) on the size and stability of international climate agreements (ICAs). We study ICAs as a coalition formation process. The formation of ICAs is modeled as a two-stage game in which governments choose their participation at the first stage and their abatement strategies at the second stage – considering both net benefits from abatement and lobby contributions. We assume that there are only two lobbies from which governments obtain contributions: industry and environmentalist. We consider that the level of contributions depends on each lobbies' payoff functions and the abatement strategy chosen by the government. The payoff of an environmentalist lobby depends on the additional abatement efforts undertaken by the

government. We consider two types of environmentalist lobbies, supergreen and green. A supergreen lobby is interested in the global effects of the abatement policies. A green lobby is only interested in the regional effects of abatement policies. We assume that the industry lobby is always harmed if the government increases abatement.

We test stability of ICAs using the definition of internal and external stability. We use the STAbility of COalitions (STACO) model that provides us with benefit and cost estimates for twelve world regions. We incorporate the level of pressure exerted by lobbies into STACO. In our setting, government's political revenue depends on the abatement strategy chosen by a region and the prospective contributions from a lobby. We perform a sensitivity analysis with respect to the parameters that reflect the strength of environmentalist willingness to pay for abatement policies, the intensity of preferences over money with respect to the environmental policy and the discount rate. We find that our main results and conclusions are robust to these changes.

There are three key results from our analysis. Firstly, we find that in the absence of an agreement (i.e. the singleton coalition structure) environmentalist lobby contributions may help to foster abatement efforts. When we consider supergreen and industry lobby contributions, we find that the singleton coalition structure improves upon our base case. There are only three regions that receive industry contributions but this does not offset the global increase in abatement. In contrast, when we consider industry and green lobby contributions, all regions take contributions from the industry. This has a clear detrimental effect for both global abatement and global payoff.

Secondly, we find that even with a supergreen lobby, stable agreements would not achieve much in tackling climate change. We find that lobby contributions help to increase stability in our model (there are no stable coalitions in our base case) but the success of stable coalitions depends on the type of preferences of the environmentalist lobby. There is a stable coalition between Japan and the European Union (EU-15) with environmentalist (supergreen and green) and industry contributions. In both cases, this stable coalition does little to close the gap, in terms of abatement and net benefits, between the situation without cooperation (singleton coalition structure) and full cooperation (grand coalition structure). Furthermore, when there are green and industry lobby contributions, the stable coalition falls short of achieving the abatement level of the singleton coalition structure in the base case.

Thirdly, we find that, contrary to intuition, industry contributions are compatible with ICAs. We observe that in the stable coalition between Japan and EU-15, the latter is taking industry contributions. The government of EU-15 looks for a compromise increasing its abatement upon joining the coalition but remaining below base case levels. Thus, it can still collect

industry contributions and benefit from the increased global benefits as a result of the coalition formation process.

Appendix 7A

Table 7A1 Emissions, Benefit and Abatement Cost Parameters

Regions	Emissions in 2010 (Gton)	Share of global benefits μ_i	Abatement cost parameter ξ_i	Abatement cost parameter ζ_i
1 USA	2.42	0.226	0.0005	0.00398
2 Japan	0.56	0.173	0.0155	0.18160
3 European Union (EU-15)	1.4	0.236	0.0024	0.01503
4 Other OECD Countries (O-OECD)	0.62	0.035	0.0083	0
5 Eastern European Countries (EE)	0.51	0.013	0.0079	0.00486
6 Former Soviet Union (FSU)	1	0.068	0.0023	0.00042
7 Energy Exporting Countries (EEX)	1.22	0.030	0.0032	0.03029
8 China	2.36	0.062	0.00007	0.00239
9 India	0.63	0.050	0.0015	0.00787
10 Dynamic Asian Economies (DAE)	0.41	0.025	0.0047	0.03774
11 Brazil	0.13	0.015	0.5612	0.84974
12 Rest of the World (ROW)	0.7	0.068	0.0021	0.00805
World	11.96	1	-	-

Source: Dellink et al. (2004) and Finus et al. (2006).

Appendix 7B

Following the functional specification of Section 7.3, and expressions (7.1), (7.6), (7.7) and (7.8), we can derive the first order conditions for the singleton coalition structure under different lobby cases. For the case without lobby contributions (i.e. the base case)

$$\rho\delta_B\mu_i = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right]. \tag{7B1}$$

For a singleton receiving only contributions from the supergreen lobby

$$\rho\delta_B\left(\mu_i + \varepsilon\right) = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right]. \tag{7B2}$$

For a singleton receiving only contributions from the green lobby

$$\rho\delta_B\mu_i\left(1 + \varepsilon\right) = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right]. \tag{7B3}$$

For a singleton receiving only contributions from the industry lobby

$$\left(\rho\delta_B\mu_i\right)/2 = \delta_C\left[\xi_i q_i^2 + \zeta_i q_i\right]. \tag{7B4}$$

The left-hand side of (7B1)-(7B4) represents the sum of the marginal benefits and to the marginal contributions, whereas the right-hand side represents marginal abatement costs. From these expressions, we note that a region, acting as a singleton, has a higher abatement level than in the base case if it receives contributions from the environmentalist lobby, and has a lower abatement level than in the base case if it receives contributions from the industry lobby.

Chapter 8. Does strategic voting undermine the success of an international environmental agreement?

Abstract

We study the effect of strategic voting on the success and stability of international environmental agreements (IEAs). We assume that voters elect the government that negotiates an IEA in a framework of two asymmetric countries without transfers. We find that when countries sign an agreement, voters have an incentive to elect their government strategically – voters elect a government that is 'greener' than the median voter in one country and a government that is 'less green' in the other. The resulting IEA improves in terms of abatement upon the case without cooperation. Finally, we find that strategic voting does not undermine the success of IEAs because voters elect 'less green' governments, but because strategic voting makes IEAs unstable.

8.1. Introduction

Game theoretical studies on international environmental agreements (IEAs) point out that these agreements are not especially successful because of free-rider incentives (e.g. Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994 and 1997a; Jeppesen and Andersen, 1998). However, a recent study by Buchholz et al. (2005) explains that there may be another reason for unsuccessful IEAs, namely that voters support candidates whose environmental preferences differ from their own. In particular, voters elect strategically a government that is 'less green' than the median voter. Thus, when governments meet at international negotiations, they bargain for an agreement that does not tackle effectively the environmental problem. Voters choose a 'less green' government because it gives them a better bargaining position to obtain larger net benefits and transfers from participating in an IEA. Political economy scholars have recognized this strategic behavior of the voters in fields such as industrial organization, monetary policy and the provision of public goods. The problem is approached with strategic delegation models – for an overview of this approach see Persson and Tabellini (2000, Chapters 7 and 12). This approach analyzes situations of principals (e.g. voters, owners of firms) delegating their decision power to a representative, or agent (e.g. governments, managers), in order to bargain over an outcome of a policy or market position with a third party. The general result from the strategic delegation framework is that the appointed agents have different preferences than those of the principals. By choosing an agent with different preferences than their own, a principal can obtain a strategic advantage at the bargaining stage.

The strategic delegation approach has been applied to diverse issues that range from industrial organization to international policy-making (e.g. Fershtman and Judd, 1987; Persson and Tabellini, 1992; Dolado et al., 1994; Segendorff, 1998; Buchholz et al., 2005). Fershtman and Judd (1987) study the design of incentive contracts between an owner and a manager of a firm that competes in an oligopolistic market. They show that the owner manipulates the contract in order to choose a manager whose interests are not purely driven by a profit maximization behavior because this gives to the firm a strategic advantage when competing in the market. Persson and Tabellini (1992) analyze, in the context of a two-country, two-period model, the effects of strategic delegation on capital taxation. They find that voters choose a government that has different preferences than their own with respect to taxes on capital. In particular, voters choose a government that is less sensitive to the strategic effects of the tax policy because it helps to mitigate the effects of higher capital mobility on the tax rate. Dolado et al. (1994) study strategic delegation in an international monetary policy game. Their analysis focuses on the incentives that governments have to delegate the control of monetary policy to independent central bankers. They find that governments choose more conservative central bankers (with respect to the output/inflation

ratio) than their own preferences as means to commit to a more restrictive monetary policy. Segendorff (1998) studies the effect of strategic delegation on the bargaining process between two countries for the provision of a transboundary public good. In each country, a principal delegates the task of the negotiations to a selected citizen that is appointed as an agent. Although Segendorff abstracts from the electoral process, the principal can be thought of as the decisive median voter and the agent as the elected government. His analysis shows that the principal has incentives to choose an agent who has a weaker preference for the public good because this will give the principal a better position at the negotiations. Finally, Buchholz et al. (2005) is the only study on the role of strategic voting on IEAs. They study a model of two symmetric countries that produce a transboundary public good (in this case reduction of polluting emissions) that generates a positive reciprocal externality. Buchholz et al. show that voters choose candidates that have a weaker preference for the provision of emission reduction (i.e. they are 'less green') because this gives them a better position when bargaining the terms of the IEA about emissions and monetary transfers. Furthermore, they show that countries are better off (in terms of global emission reduction and payoff) without cooperation than signing an IEA. Finally, they show that in the case of a global pollutant, voters decide to choose a government that does not care at all for the environment. We offer a description of this framework in Section 8.2.

The aim of this chapter is to study the effect of strategic delegation in the success and stability of an IEA. This is the first study to consider the effects of strategic voting on stability of IEAs. This chapter starts with an approach similar to Buchholz et al. (2005). We consider that elected governments gather to discuss the terms of an IEA. These governments represent different types of government, corresponding to the different preferences of voters towards a transboundary environmental problem. We assume that voters elect the type of politician that will represent them at the international negotiations. We differ from the work of Buchholz et al. (2005) in three respects. Firstly, we relax the symmetry assumption and consider two asymmetric countries with no transfers. Secondly, we consider a pure public good – e.g. benefits from abatement of GHGs. Thirdly, we test for stability of the resulting IEA.

The results from our analysis show that when countries act as singletons leakage effects are the main cause for strategic voting. Moreover, we find that when countries sign an IEA, voters always have an incentive to elect their government strategically – voters elect a government that is 'greener' than the median voter in one country and a government that is 'less green' in the other. An interesting characteristic of our setting is that the resulting agreement improves in terms of abatement upon the case without cooperation. Finally, we find that strategic voting does not undermine the success of IEAs because voters elect 'less green' governments, but because strategic voting makes IEAs unstable.

The structure of this chapter is as follows. Section 8.2 describes the main features and results of the model by Buchholz et al. (2005). Section 8.3 presents our framework for strategic voting in the context of a global pure public good assuming two asymmetric countries. Section 8.4 presents and discusses the results of our analysis. Section 8.5 concludes.

8.2. Modeling IEAs and strategic voting for symmetric countries

In this section we provide a summary of the framework of Buchholz et al. (2005). This serves as a basis for developing our model in Section 8.3. The model of Buchholz, Haupt and Peters (henceforth called BHP model) considers two countries (i, j = 1, 2 with i ≠ j) that are symmetric in every respect. Each country faces a tradeoff to produce either environmental quality (i.e. reducing emissions of a transboundary pollutant) or a domestic product. The domestic product in country i is x_i. The economic activities produce an environmental damage (i.e. emissions of a transboundary pollutant) both locally and abroad. Damages are represented by a function $D_i = D(x_i + sx_j)$, where the parameter s, $0 < s < 1$, represents the spillover between regions. Hence, a local pollutant $s = 0$ and a global pollutant $s = 1$ are boundary cases. Environmental damage D_i is measured in physical terms – e.g. tons of emission reduction. The valuation of these damages depends on the preferences of an individual h in country i towards the environment. These preferences are represented by the term θ_i^h. Thus, the monetary value of the environmental damage is given by $\theta_i^h \cdot D(x_i + sx_j)$ and h's payoff V_i^h is

$$V_i^h = x_i - \theta_i^h D(x_i + s x_j) \tag{8.1}$$

By ranking the individuals with respect to their personal valuation, the preference parameter of the median voter of each region θ_i^m and her payoff $V_i^m = x_i - \theta_i^m D(x_i + sx_j)$ can be identified. The election process is modeled in a stylized way considering a majority-rule process where individuals elect a candidate according to their preferences. Hence, the preferences of the median voter characterize those of the winning candidate.

The model analyzes the effect of strategic voting on the outcome of an IEA. It considers a three stage game. In the first stage, citizens in each country elect their government simultaneously. In the second stage, elected governments negotiate over the level of economic activity and transfers. Transfers are defined according to the Nash bargaining solution. If an agreement is reached then it becomes binding, otherwise, countries adopt the

non-cooperative policy (Nash equilibrium). At the third stage, governments determine the non-cooperative policy that constitutes the threat point at the second stage.

The game is solved by backward induction. At the third stage, the potential non-cooperative outcome is determined. This is the threat point in the negotiation stage. At the third stage, the government solves for its optimal policy taking the strategy of the other country as given and ignoring the externalities that are imposed on its neighbor. Thus, country i's government chooses the level of x_{in}^g which maximizes its payoff

$$V_{in}^g = x_{in} - \theta_i^g D\left(x_{in} + s x_{jn}\right) \tag{8.2}$$

where the subscript n indicates the non-cooperative solution and the superscript g indicates a variable corresponding to the government. Buchholz et al. show that as long as $s < 1$ there is a unique Nash equilibrium. Furthermore, they show that the greener the government (i.e. the higher level of θ_i^g) the fewer are the polluting economic activities in country i for a given strategy and government type of country j. It is assumed that the goods $\left(x_{in}^g, x_{jn}^g\right)$ are substitutes, thus any reduction of the polluting activities in one country are offset by an increase in the pollution of the other country. Hence, in this model there are leakage effects.

At the second stage, both countries negotiate an IEA about the levels of economic activity and transfers. The negotiated level of economic activity is obtained by maximizing the aggregated payoff

$$V_{ic}^g + V_{jc}^g = x_{ic} - \theta_i^g D\left(x_{ic} + s x_{jc}\right) + x_{jc} - \theta_j^g D\left(x_{jc} + s x_{ic}\right), \tag{8.3}$$

where the subscript c indicates the outcome of the cooperative case. Transfers are paid from the gains of cooperation. The Nash bargaining solution is, as there are only two symmetric countries, an equal split of the gains of cooperation. The transfer for country i is then

$$T_i = \frac{1}{2}\left[\left(x_{jc} - \theta_j^g D_{jc}\right) - \left(x_{ic} - \theta_i^g D_{ic}\right) + \left(x_{in} - \theta_j^g D_{in}\right) - \left(x_{jn} - \theta_j^g D_{jn}\right)\right]. \tag{8.4}$$

From (8.4) it can be observed that the transfers depend on the governments' preferences over the damages expressed by θ_i^g and θ_j^g.

At the first stage, citizens elect the government by majority voting. Taking the election result of the other country as given, the median voter, indexed by m, in country i supports the government of type θ_i^g which maximizes her payoff including transfers

$$P_{ic}^m = x_{ic}\left(\theta_i^g, \theta_j^g\right) - \theta_i^h D\left(x_{ic}\left(\theta_i^g, \theta_j^g\right) + s x_{jc}\left(\theta_i^g, \theta_j^g\right)\right) + T_i\left(\theta_i^g, \theta_j^g\right). \tag{8.5}$$

Buchholz et al. show that a 'greener' government achieves a lower level of environmental damage in its own country. However, having a greener government weakens the position of the country at the bargaining stage. This results in a lower payoff. In equilibrium, the median voter in each country chooses a government that cares less about the environment than the median voter (i.e. $\theta_i^g < \theta_i^m$) in order to receive a larger share of the gains of cooperation, and to transfer the costs of emission reduction to the other country. The resulting level of environmental damage is suboptimal.

The median voter behaves strategically even in the case *without* cooperation. Though there are no transfers available in this case, the leakage effect between both countries drives the result. A country that does not participate in the IEA is better off by having a less green government, because then the reduction of polluting activities would be performed, at least partially, by the other country. In the case of cooperation this result is reinforced with the possibility of receiving transfers. The governments that are chosen in the case of cooperation are less environmentally concerned that when there is no cooperation. Thus the situation, in terms of polluting activities and payoffs, is worse if countries sign an IEA. Buchholz et al. explain that this results holds for damage functions with shape of $D = \left(x_{in} + s x_{in}\right)^{1+\sigma} / \left(1+\sigma\right)$, with $\sigma < 0$ and irrespective of the size of the parameter s.[1] Moreover, when $s \to 1$, i.e. with a global pollutant, the median voter chooses a government that does not care at all for the environment (i.e. $\theta_i^g = 0$) whether or not the country is a member of the IEA. These results hold even when there are no transfers available – Buchholz et al. (2005), however, do not analyze the case without transfers.

8.2.1. Overview of the results of the BHP model

In this section, we offer a brief overview on the results of the BHP model. The analysis in the BHP model shows that, due to strategic voting, the elected government is 'less green', i.e. it cares less for the environment than the median voter. Moreover, if countries cooperate through an IEA, the result with this agreement is worse than when there is no cooperation –

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[1] This is one type of the payoff functions that we analyze in Section 8.4.

in terms of global emission reduction and payoff. The government that is chosen in the case of cooperation is less green than the one chosen in the absence of cooperation. Furthermore, for a global pollutant, the elected government does not care at all for the environment. Thus, the key result from the BHP model is that strategic voting hinders the success of an IEA.

These results depend on two features of the model: leakage effects and transfers. Firstly, in the BHP model emissions are substitutes between countries. In this setting, country i reduces its emissions as country j increases them. Thus, there is leakage in the model. This has a decisive impact on the incentives of voters when choosing a government. A voter, by choosing a 'less green' government, increases its own emissions. This causes an increase in the emission reduction efforts of the other country. Hence, by having a government that cares less for the environment voters shift the costs of the emission reduction activities, at least partially, to the other country. This is the main driving force for strategic voting when countries act as singletons. Secondly, transfers reinforce the incentives for voting for a 'less green' government. By choosing a government that cares less for the environment, countries have a better position when negotiating the transfers. A 'less green' government then may receive a larger share from the gains of cooperation – see (8.4). The prospect of receiving a larger amount of transfers gives the voters an incentive to strategically choose their government. Combining these two effects gives a strong incentive to vote for 'less green' governments because it has a positive effect on the payoff of the voters. The effect of leakage on strategic voting is reinforced by the possibility of having transfers when countries cooperate. Hence, the result of the BHP model that the incentives to have a 'less green' government are larger in the case of cooperation than when countries act separately. As we mentioned above, these results holds also for the case without transfers.

8.2.2. Stability of IEAs in the BHP model

The main result of the BHP model is that benefits from IEAs may be completely offset by strategic voting. This result looses its relevance, however, if we consider stability. It is straightforward to include a stability test in this framework. An agreement is stable if it is both internally and externally stable (d'Aspremont et al., 1983). Consider K as the case of country i and j signing an agreement and S the case for i and j acting as singletons – i.e. when they do not join the IEA. Then $\pi_i(S)$ is the payoff for country i when acting as a singleton, and $\pi_i(K)$ is the payoff when country i signs an agreement K with country j. Then, the agreement is internally stable if countries do not have an incentive to leave – i.e. if $\pi_i(K) - \pi_i(S) > 0$ for i = 1, 2. The agreement is externally stable if there is no other country

that wants to join the agreement.[2] Barrett (1994) shows that, for symmetric countries, a payoff function equivalent to the specification of the BHP model and no transfers, an agreement of two countries is never stable.[3] Hence, the BHP model, without transfers, is not stable. Furthermore, we can show that if an agreement is not stable without transfers in the BHP model, then it would be not be stable if transfers are available. Assume that K is not internally stable for j without transfers – i.e. $\pi_j(K) - \pi_j(S) < 0$. Trivially, for symmetric countries, this means that K is also not internally stable for i. Assume, firstly, that j is paying a transfer to i. Then, the payoff for country j will be $\pi_j(K) - T_j$ that is always lower than $\pi_j(K)$ for any $T_j > 0$. Hence, country j receives a lower payoff than in the case without transfers. This country is not strictly better off by joining the IEA, thus, the agreement is not internally stable. Secondly, assume that j is receiving a transfer from i. Then, by a similar reasoning, K is now not internally stable for i. Thus, although an agreement in the BHP model results in higher emission levels than without cooperation, this IEA is not stable. Hence, there is no need to worry about voters electing an even 'less green' government to sign an IEA because such agreement will never be implemented.

8.3. Modeling of IEAs and strategic voting for asymmetric countries

In this section, we set up a model on the formation of IEAs and strategic voting. We adopt the general structure of the BHP model but we do not consider transfers. Furthermore, we depart from Buchholz et al. (2005) in three respects. Firstly, we assume two countries i and j that are asymmetric. Secondly, we consider a pure public good – e.g. benefits from abatement of GHGs. Thirdly, we test for stability of the resulting IEA. As in Buchholz et al. (2005), we consider a three-stage game. At the first stage, voters elect the government that is going to represent them at the international negotiations. At the second stage, regions decide whether or not sign an IEA. At the third stage, regions choose their abatement strategies. The game is solved by backward induction. We now discuss these stages in more detail. At the first stage, voters (simultaneously in both countries) elect their most preferred candidate for the government. Following Buchholz et al. (2005) we assume the election process in a stylized way considering a majority-rule. The preferences of the median voter characterize those of the elected government. Moreover, we assume that the payoff of a voter is a function of

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[2] Given that in the BHP model there are only two players, when they sign an agreement they form what is called the grand coalition (i.e. a coalition that includes all the players in the game). As there are no more players that could join the coalition, external stability trivially holds and we focus the analysis only on internal stability.

[3] See Barrett (1994), Proposition 4.

abatement (i.e. emission reduction). Thus, the payoff function comprises two items: a function for benefits from abatement and a function for abatement cost.[4] The median voter in country i chooses the type of government θ_i^g that maximizes[5]

$$\pi_i^m\left(q_i\left(\theta_i^g,\theta_j^g\right)\right)=\theta_i^m B_i\left(q_i\left(\theta_i^g,\theta_j^g\right)+q_j\left(\theta_i^g,\theta_j^g\right)\right)-C_i\left(q_i\left(\theta_i^g,\theta_j^g\right)\right) \quad \forall i\neq j \qquad (8.6)$$

where $q_i\left(\theta_i^g,\theta_j^g\right)$ is the abatement chosen by the government of type θ_i^g taking the government of country j (θ_j^g) as given, $B_i\left(\cdot\right)$ are benefits from global abatement and $C_i\left(\cdot\right)$ are abatement costs from own abatement. We assume that benefits are increasing $\partial B_i\left(\cdot\right)/\partial q_i > 0$ at a decreasing or constant rate $\partial^2 B_i\left(\cdot\right)/\partial q_i^2 \leq 0$ and that abatement costs are increasing $\partial C_i\left(\cdot\right)/\partial q_i > 0$ at an increasing or constant rate $\partial^2 C_i\left(\cdot\right)/\partial q_i^2 \geq 0$. Furthermore, we assume a bounded preference space along the interval $\left[0,\overline{\theta}_i\right]$ with $\overline{\theta}_i$ as the finite upper bound of environmental preferences of the electorate of country i. We assume the lower bound at zero to represent those voters that have no preference at all for abatement, moreover, we rule out the possibility of having negative preferences. At the second stage, we assume that regions can choose between two membership strategies: to sign or not to sign an IEA. As we assume only two countries, this assumption means that either countries act as singletons or form a grand coalition.

Finally, at the third stage, we follow a standard assumption in coalition formation and IEAs concerning the choice of abatement. The government of country i, as a singleton, chooses the abatement level that maximizes its payoff function

$$\pi_i^g\left(q_i\right)=\theta_i^g B_i\left(q\right)-C_i\left(q_i\right) \qquad (8.7)$$

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[4] It is straightforward to show that any payoff that is a function of emissions (as in Buchholz et al., 2005) has a counterpart on the abatement space – for a detailed description about this equivalence see Diamantoudi and Sartzetakis (2006).

[5] In this section, we present the expressions only related to country i. For simplification, we do not present the corresponding expressions for country j because they have the same general structure than those of country i.

where θ_i^g expresses the type of the elected government, B_i are the benefits from global abatement $q = q_i + q_j$, and C_i are the abatement costs from regional abatement q_i. The corresponding first order condition is

$$\partial\,\theta_i^g B_i(q)\big/\partial q_i = \partial\,C_i(q_i)\big/\partial q_i\,. \tag{8.8}$$

Members choose their abatement levels following the assumption of coalitional payoff maximization (CPM). This means that if a coalition is established, members choose their abatement levels taking into account the net benefits of fellow members – i.e. they maximize the coalitional payoff π^K:

$$\pi^K = \theta_i^g B_i\big(q\big) - C_i(q_i) + \theta_j^g B_j\big(q\big) - C_j(q_j)\,. \tag{8.9}$$

The corresponding first order condition for country i is

$$\partial\big(\theta_i^g B_i(q) + \theta_j^g B_j(q)\big)\big/\partial q_i = \partial\,C_i(q_i)\big/\partial q_i \quad \forall i \neq j\,. \tag{8.10}$$

We consider three types of payoff functions for our analysis. These functions have been often used in the literature. The first type of function, used by Barrett (1994 and 1997a), considers a linear benefit function and a quadratic abatement cost function. The second type of payoff function, used by Altamirano-Cabrera and Finus (2006) and Finus et al. (2006), considers a linear benefit function and a polynomial abatement cost function. The third type of payoff function (Barrett 1994a) considers a linear-quadratic benefit function and a linear abatement cost function and it is the equivalent (in terms of abatement) to the payoff function used in the BHP model.

8.4. Main results and stability analysis

In this section, we present the results of our analysis. We examine three functional forms for the payoffs. For each functional form we compare the singletons with a coalition (agreement). In Table 8.1 we summarize our findings.[6] Firstly, we observe from the last column of Table 8.1 that when governments act as singletons the incentive of voters to act strategically depends on the presence of leakage effects. For the payoff functions of types 1 and 2, voters choose a government that has the same preferences as the median voter – i.e.

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[6] For simplicity, we present in Table 8.1 only the components of the payoff function for country i. As we already have indicated, the payoff function for country j has the same structure.

$\theta_i^g = \theta_i^m, \theta_j^g = \theta_j^m$. In contrast, for a payoff function of type 3, which allows for leakage, the government will have different preferences than the median voters – i.e. $\theta_i^g > \theta_i^m$ or $\theta_i^g < \theta_i^m, \theta_j^g = 0$. Secondly, when governments form a coalition (i.e. sign an IEA) there is always an incentive to vote strategically – irrespective of the type of payoff function. We find that in the equilibrium, for payoffs of type 1 and 2, voters in one country choose a government that does not have a preference for the benefits of abatement (i.e. $\theta_j^g = 0$) and voters in the other country choose a government that is 'greener' than the median voter (i.e. $\theta_i^g > \theta_i^m$). For a payoff of type 3, we find that voters in one country choose a government that is less green than the median voter (i.e. $\theta_i^g < \theta_i^m$) and voters in the other country choose a government that is 'extremely green' (i.e. $\theta_j^g = \overline{\theta}_j$).

Table 8.1 Strategic voting for different payoff specifications

Payoff type	Benefits	Abatement costs	Membership	Elected governments
Linear-quadratic [a] (Type 1)	$\mu_i q$	$\dfrac{\varsigma_i}{2} q_i^2$	Singletons	$\theta_i^g = \theta_i^m; \theta_j^g = \theta_j^m$
			Coalition	$\theta_i^g > \theta_i^m; \theta_j^g = 0$
Linear-polynomial [a] (Type 2)	$\mu_i q$	$\dfrac{\xi_i}{3} q_i^3 + \dfrac{\varsigma_i}{2} q_i^2$	Singletons	$\theta_i^g = \theta_i^m; \theta_j^g = \theta_j^m$
			Coalition	$\theta_i^g > \theta_i^m; \theta_j^g = 0$
Quadratic-linear [b] (Type 3)	$\mu_i q - \dfrac{\varepsilon_i}{2} q^2$	$\upsilon_i q_i$	Singletons	$\theta_i^g > \theta_i^m$ or $\theta_i^g < \theta_i^m; \theta_j^g = 0$
			Coalition	$\theta_i^g < \theta_i^m; \theta_j^g = \overline{\theta}_j$

Notes: a) There is no leakage in this type of payoff function; b) There is full leakage in this type of payoff function; $q = q_i + q_j$; and $\overline{\theta}_j$ is the upper bound for the preferences space of voters in country j.

In the following, we explain these findings in more detail.

8.4.1. The linear-quadratic payoff function (Type 1)

We find that when both countries act as singletons (i.e. they do not sign an IEA) there is no incentive to vote strategically. At the voting game, citizens always vote truthfully for the candidate that represents their environmental preferences. Hence, the elected governments in both countries characterize the preferences of the median voter. The proof is straightforward.

First, from maximizing $\pi_i = \mu_i q - \dfrac{\zeta_i}{2} q_i^2$ with respect to q_i and then solving for q_i, we obtain that $q_i\left(\theta_i^g\right) = \theta_i^g \mu_i / \alpha_i$.[7] Second, maximizing the payoff of the median voter, expression (8.6), with respect to θ_i^g give us the following first order condition

$$\theta_i^m \mu_i \cdot \partial q / \partial q_i \cdot \partial q_i / \partial \theta_i - \zeta_i q_i \cdot \partial q_i / \partial \theta_i = 0. \tag{8.11}$$

Then, substituting $q_i\left(\theta_i^g\right)$ into (8.11), simplifying, and knowing that $\partial q / \partial q_i = 1$, we obtain $\theta_i^m \mu_i - \theta_i^g \mu_i = 0$, and hence $\theta_i^g = \theta_i^m$. There is no incentive for strategic voting. The rationale behind this result is clear. As we have explained, one of the driving forces for strategic voting in the BHP model is leakage. However, as payoff functions of type 1 have linear benefit functions, there is no leakage. Countries have dominant strategies and abatement decisions are independent of what the other country is doing. Voters cannot transfer the abatement burden to the other country. Thus, they cannot do better by choosing a government that has different preferences than its median voter.

The case is different for the coalition. Voters have incentives to act strategically if governments would sign an agreement. The voting game has a corner solution in which one country elects a government that is always greener than the median voter – i.e. $\theta_i^g > \theta_i^m$ – and the other country is electing a government that does not care at all for the benefits of abatement – i.e. $\theta_j^g = 0$. This is shown as follows: from (8.9) we know that signatory governments maximize their coalitional payoff π^K

$$\pi^K = \theta_i^g \mu_i (q) - \frac{\zeta_i}{2} q_i^2 + \theta_j^g \mu_j (q) - \frac{\zeta_i}{2} q_j^2. \tag{8.12}$$

From maximizing (8.12) with respect to q_i, and then solving for q_i, we obtain that $q_i\left(\theta_i^g, \theta_j^g\right) = \left(\theta_i^g \mu_i + \theta_j^g \mu_j\right)/\zeta_i$. Hence, the abatement of a coalition member in country i depends also on the type of government elected in country j. Then, maximizing the payoff of the median voter of country i with respect to θ_i^g gives us the following first order condition

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[7] For the results that we present in this subsection it is assumed that $\mu_i, \mu_j, \zeta_i, \zeta_j > 0$, $\mu_i \neq \mu_j, \zeta_i \neq \zeta_j$, and $\mu_i \gg \zeta_i, \mu_j \gg \zeta_j$, for all $i \neq j$.

$$\theta_i^m \mu_i \cdot \left(\partial q_i / \partial \theta_i + \partial q_j / \partial \theta_i \right) - \zeta_i q_i \cdot \partial q_i / \partial \theta_i = 0. \tag{8.13}$$

Simplifying (8.13) and solving for θ_i^g gives us country i's reaction function

$$\theta_i^g = \theta_i^m \left(1 + \frac{\zeta_i}{\zeta_j} \right) - \frac{\mu_j}{\mu_i} \theta_j^g. \tag{8.14}$$

Similarly, we obtain country j's reaction function

$$\theta_j^g = \theta_j^m \left(1 + \frac{\zeta_j}{\zeta_i} \right) - \frac{\mu_i}{\mu_j} \theta_i^g. \tag{8.15}$$

We show the reaction functions of country i, R_i, and country j, R_j, in Figure 8.1, assuming, without loss of generality, that $\theta_i^m \left(\mu_i / \mu_j \right) \left(1 + \zeta_i / \zeta_j \right) > \theta_j^m \left(1 + \zeta_j / \zeta_i \right)$. We observe that the equilibrium is a corner solution $\left(\theta_i^g, \theta_j^g \right) = \left(\theta_i^m \left(1 + \zeta_i / \zeta_j \right), 0 \right)$ as depicted in Figure 8.1. Then, as we assume that $\zeta_i, \zeta_j > 0$ (see footnote 7), $\theta_i^g > \theta_i^m$ holds and citizens in country i always elect a government that has greener preferences than the median voter. The rationale for this outcome is simple. The CPM assumption makes that the abatement in both countries depends on both government types. Furthermore, CPM ensures that both countries always have a positive level of abatement. Thus, voters in country j, by choosing a 'less green' government, free-ride on country i, given that they can lower j's abatement level and still enjoy the benefits from the abatement of i. However, voters in country i react to this by choosing a greener government than its median voter. If voters in i would decide to choose a government that reflects the median voter preferences they will have a lower payoff than the payoff when they act as singletons. By choosing a greener government, voters in country i offset the 'less green' government of country j and force country j to increase its abatement level – given that $q_j \left(\theta_i^g \right) = \left(\theta_i^g \mu_i \right) / \zeta_j$.
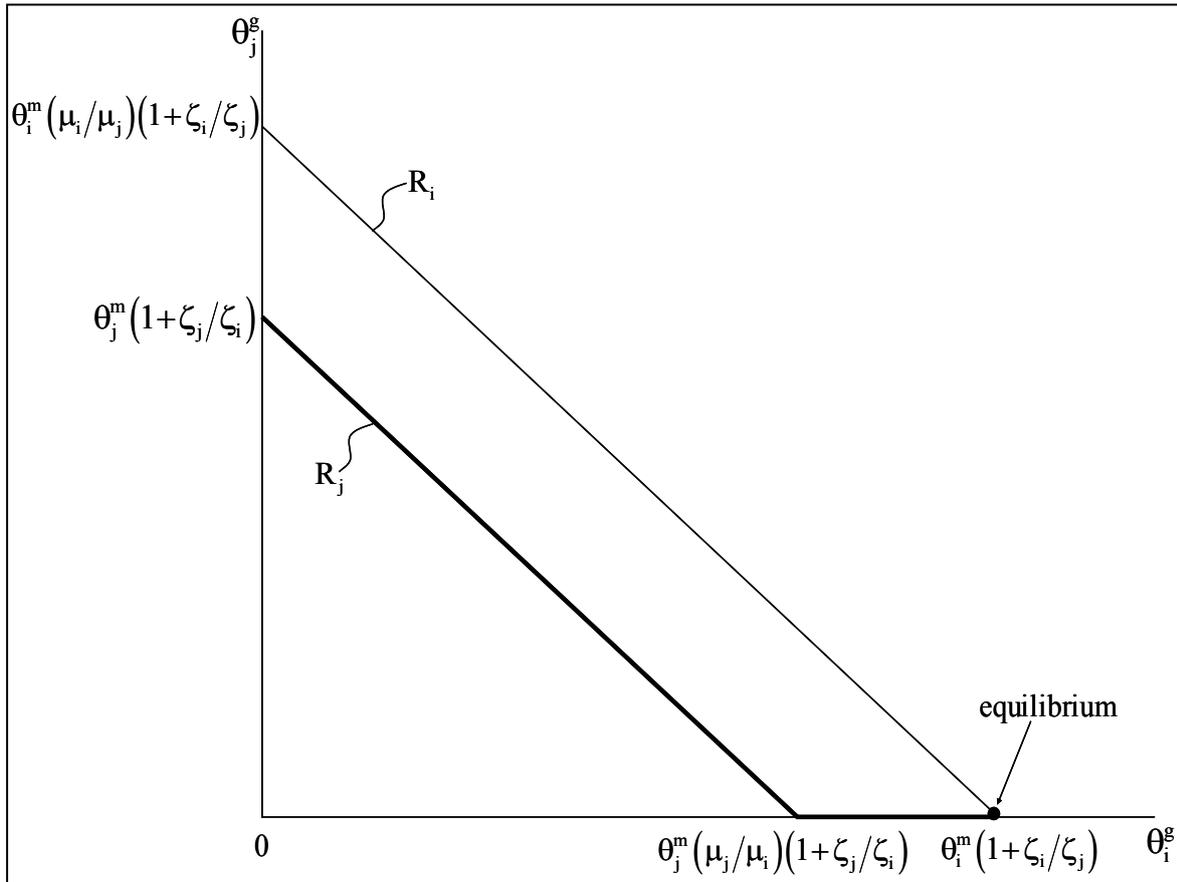
Figure 8.1 Reaction functions for choosing the type of government in country i and country j.

We find that the IEA results in a higher global abatement level compared with the singletons case, even though governments are elected strategically. The greening of i's government more than compensates for the 'less green' government in country j. The proof is straightforward.[8] Denote with q^S the global abatement in the singleton case

$$q^S = \frac{\mu_i}{\zeta_i} + \frac{\mu_j}{\zeta_j} \tag{8.16}$$

Then, denote with q^K the global abatement in the agreement

$$q^K = \frac{\left(1 + \zeta_i/\zeta_j\right)\mu_i}{\zeta_i} + \frac{\left(1 + \zeta_i/\zeta_j\right)\mu_i}{\zeta_j}. \tag{8.17}$$

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[8] We assume, without loss of generality, that $\theta_i^m = \theta_j^m = 1$.

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Then $q^K > q^S$ if the following holds

$$\frac{\left(1+\zeta_i/\zeta_j\right)\mu_i}{\zeta_i} + \frac{\left(1+\zeta_i/\zeta_j\right)\mu_i}{\zeta_j} > \frac{\mu_i}{\zeta_i} + \frac{\mu_j}{\zeta_j}. \tag{8.18}$$

Simplifying and rearranging terms of (8.18), we get that $\left(\mu_i/\mu_j\right)\left(1+\zeta_i/\zeta_j\right) > \left(1+\zeta_j/\zeta_i\right)$. That holds by assumption for the corner solution presented in Figure 8.1. Hence, global abatement under the coalition is larger than when countries act as singletons.

Although the agreement renders a higher level of global abatement than the singletons, we find that the agreement is not stable. The proof is simple and only entails to show that one of the countries does not have an incentive to join the coalition – i.e. to prove that the agreement is not internally stable. Consider the case of country j that is choosing a government that does not care about the benefits of abatement. As a singleton, a country chooses an abatement level that gives him a non-negative payoff. However, country j, as a coalition member, has always a negative payoff. Country j chooses $\theta_j^g = 0$, thus the payoff of its government $\pi_j^g\left(q_j\right) = \theta_j^g B_j\left(q\right) - C_j\left(q_j\right)$ becomes $\pi_j^g\left(q_j\right) = -C_j\left(q_j\right)$, that is always negative for any positive level of q_j. In the agreement, country j has always a positive level of abatement $q_j = \left(1+\zeta_i/\zeta_j\right)\mu_i/\zeta_j$. Hence, from the perspective of the government ($\theta_j^g = 0$) in country j payoffs are negative when signing the IEA and thus the agreement is not stable.

8.4.2. The linear-polynomial payoff function (Type 2)

This payoff function is the specification of the STACO model that is used in the other chapters of this thesis – for details see Chapter 3. We find that for the singletons case there are no incentives to vote strategically. Hence, $\theta_i^g = \theta_i^m$. The proof is similar to the one for the payoff function of type 1. First, from maximizing $\pi_i = \mu_i q - \frac{\xi}{3}q_i^2 - \frac{\zeta_i}{2}q_i^2$ with respect to q_i and solving for q_i, we obtain that $q_i\left(\theta_i^g\right) = \left[1/\left(2\upsilon_i\right)\right] \cdot \left[-\zeta_i + \left(-\zeta_i^2 + 4\xi_i\theta_i^g\mu_i\right)^{1/2}\right].$ [9] Second, maximizing the payoff of the median voter of country i with respect to θ_i^g give us the following first order condition

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[9] For the results that we present in this section it is assumed that $\mu_i, \mu_j, \zeta_i, \zeta_j, \xi_i, \xi_j > 0$, $\mu_i \neq \mu_j, \zeta_i \neq \zeta_j, \xi_i \neq \xi_j$, and that $\mu_i, \varepsilon_i \gg \zeta_i, \xi_i$ and $\mu_j, \varepsilon_j \gg \zeta_j, \xi_j$ for all $i \neq j$.

$$\theta_i^m \mu_i \cdot \partial q / \partial q_i \cdot \partial q_i / \partial \theta_i^g - \xi_i q_i^2 \cdot \partial q_i / \partial \theta_i^g - \zeta_i q_i \cdot \partial q_i / \partial \theta_i^g = 0. \tag{8.19}$$

Then, substituting $q_i\left(\theta_i^g\right)$ into (8.19), simplifying, and knowing that $\partial q / \partial q_i = 1$, we obtain $\theta_i^m \mu_i - \theta_i^g \mu_i = 0$, hence $\theta_i^g = \theta_i^m$ and voters do not elect strategically their government.

We find that, the first order conditions of the coalition cannot be solved analytically. Thus, we do not obtain general theoretical results. However, numerical simulations provide us with useful insights on the incentives of citizens to vote strategically. Using the STACO calibration explained in Chapter 3, we run the model for several coalitions of size two. We test how the payoff of the median voter changes as the voters choose governments with different preferences and how the other country reacts to that. Our simulations show that, similar to the findings for the payoff of type 1, voters converge to an equilibrium where one country chooses a government that does not care at all for the benefits of abatement – i.e. $\theta_j^g = 0$ – and the other always choose a government that is greener than its median voter – i.e. $\theta_i^g > \theta_i^m$. Furthermore, we find that global abatement and payoff are larger in the agreement than in the singletons case. However, the agreement is not stable. We find that the countries with low marginal costs have a lower payoff when joining the agreement than when they remain as singletons. Hence, the agreement is not internally stable under a linear-polynomial payoff function.

8.4.3. *The quadratic-linear payoff function (Type 3)*

The payoff of type 3 has been examined by Barrett (1994) within the context of an abatement game and used as an example in the BHP model within the context of an emissions game. We find that countries as singleton always have the incentive to vote strategically. This is mainly due to the fact that there are no dominant strategies in the abatement stage – i.e. the benefit function is not linear. Thus, leakage effects give an incentive to voters for choosing strategically a government that has different preferences than the median voter – i.e. $\theta_i^g \neq \theta_i^m$, $\theta_j^g \neq \theta_j^m$. At the second stage, country i as singleton maximizes $\pi_i = \theta_i^g\left(\mu_i q - \frac{\varepsilon_i}{2}q^2\right) - \upsilon_i q_i$ with respect to q_i obtaining the following first order condition[10]

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[10] For the results that we present in this section it is assumed that $\mu_i, \mu_j, \varepsilon_i, \varepsilon_j, \upsilon_i, \upsilon_j > 0$, $\mu_i \neq \mu_j, \varepsilon_i \neq \varepsilon_j, \upsilon_i \neq \upsilon_j$ and that $\mu_i, \varepsilon_i \gg \upsilon_i$ and $\mu_j, \varepsilon_j \gg \upsilon_j$ for all $i \neq j$.

$$\theta_i^g \left(\mu_i - \varepsilon_i q_i - \varepsilon_i q_j \right) - \upsilon_i = 0 \ . \tag{8.20}$$

Then, solving (8.20) for q_i we obtain country i's reaction abatement

$$q_i = \frac{\mu_i \theta_i^g - \upsilon_i}{\varepsilon_i \theta_i^g} - q_j \ . \tag{8.21}$$

Similarly, country j's abatement is

$$q_j = \frac{\mu_j \theta_j^g - \upsilon_j}{\varepsilon_j \theta_j^g} - q_i \ . \tag{8.22}$$

We show in Figure 8.2 the reaction functions for abatement of country i, R_i, and country j, R_j, assuming without loss of generality, that $\left(\mu_i \theta_i^g - \upsilon_i \right) \big/ \varepsilon_i \theta_i^g > \left(\mu_j \theta_j^g - \upsilon_j \right) \big/ \varepsilon_j \theta_j^g$. Because the slope of both reaction functions is -1, whenever a country reduces its abatement, the other increases it by the same amount – i.e. there is full leakage. We observe that the equilibrium is a corner solution $\left(q_i^g, q_j^g \right) = \left(\left(\mu_i \theta_i^g - \upsilon_i \right) \big/ \varepsilon_i \theta_i^g, 0 \right)$ as depicted in Figure 8.2. Hence, $q_i \left(\theta_i^g \right) = \left(\mu_i \theta_i^g - \upsilon_i \right) \big/ \varepsilon_i \theta_i^g$. Note that when both countries are symmetric with respect to their benefit parameters (i.e. $\mu_i = \mu_j$ and $\varepsilon_i = \varepsilon_j$) then the country with the lowest marginal abatement costs would do all the abatement. When both countries are symmetric with respect to their abatement cost parameter (i.e. $\upsilon_i = \upsilon_j$) then the country with the largest marginal benefits would do all the abatement. As we assume asymmetric countries in every respect the final result depends on both types of parameters. We find that voters in country j try to transfer the abatement burden to country i, however, voters in country i react by greening their government forcing country j also to abate more.
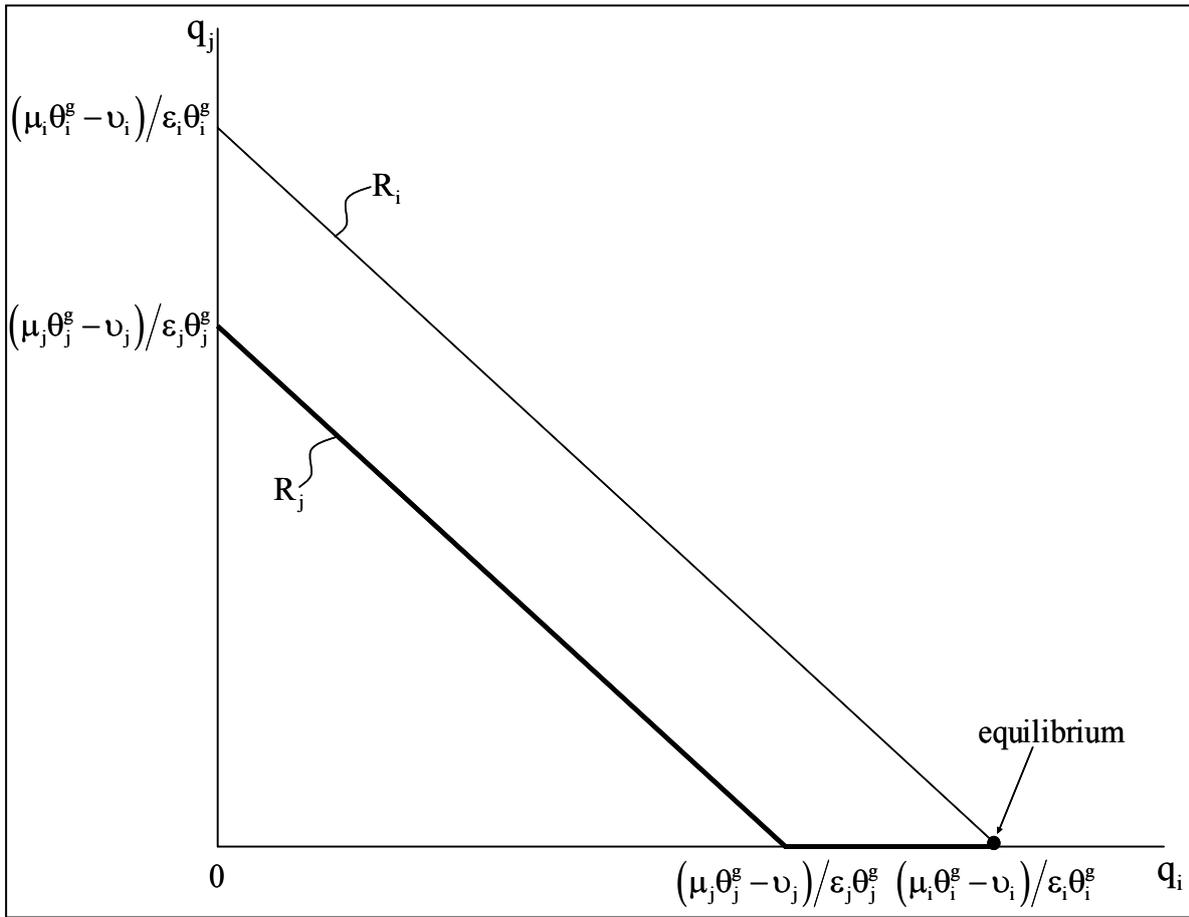
Figure 8.2 Reaction functions for abatement of country i and j (as singletons).

At the voting game, the median voter in country i maximizes its payoff with respect to θ_i^g obtaining the following first order condition

$$\theta_i^m \left(\partial q_i / \partial \theta_i - \varepsilon_i q_i \cdot \partial q_i / \partial \theta_i \right) - \upsilon_i \cdot \partial q_i / \partial \theta_i = 0 .$$ (8.23)

Simplifying (8.23) and solving it for θ_i^g gives us country i's choice of government

$$\theta_i^g = \theta_i^m + \frac{\upsilon_i \left(1 - \mu_i \right)}{\mu_i} .$$ (8.24)

From (8.24) we note that if $1 - \mu_i > 0$ then country i's voters choose a greener government than their median voter. If $1 - \mu_i < 0$ then country i's voters choose a 'less green' government than their median voter. Trivially, for country j, as it is not performing any abatement at all, voters choose a government that does not care at all for the benefits of abatement – i.e.

$\theta_j^g = 0$. Hence, because of leakage effects, country j can free-ride on the abatement efforts of country i.

Coalition members maximize their coalitional payoff that for a two-country case is

$$\pi^K = \theta_i^g \left(\mu_i q - \frac{\varepsilon_i}{2} q^2 \right) - \upsilon_i q_i + \theta_j^g \left(\mu_j q - \frac{\varepsilon_j}{2} q^2 \right) - \upsilon_j q_j. \qquad (8.25)$$

Maximizing (8.25) with respect to q_i we obtain the following first order condition

$$\theta_i^g \left(\mu_i - \varepsilon_i q_i - \varepsilon_i q_j \right) + \theta_j^g \left(\mu_j - \varepsilon_j q_i - \varepsilon_j q_j \right) - \upsilon_i = 0. \qquad (8.26)$$

Then solving (8.26) for q_i we obtain country i's abatement

$$q_i = \frac{\mu_i \theta_i^g + \mu_j \theta_j^g - \upsilon_i}{\varepsilon_i \theta_i^g + \varepsilon_j \theta_j^g} - q_j. \qquad (8.27)$$

Similarly, country j's abatement is

$$q_j = \frac{\mu_i \theta_i^g + \mu_j \theta_j^g - \upsilon_j}{\varepsilon_i \theta_i^g + \varepsilon_j \theta_j^g} - q_i. \qquad (8.28)$$

In Figure 8.3 we show the reaction functions for abatement of country i, R_i, and country j, R_j, assuming, without loss of generality, that $\upsilon_i > \upsilon_j$ – i.e. that country i has the lowest marginal cost. Solving (8.27) and (8.28) yields a corner solution where the country with the lowest marginal cost performs all the abatement in the coalition – in this case country i. Abatement levels are thus $\left(q_i^g, q_j^g \right) = \left(\left(\mu_i \theta_i^g + \mu_j \theta_j^g - \upsilon_i \right) \big/ \left(\varepsilon_i \theta_i^g + \varepsilon_i \theta_i^g \right), 0 \right)$ – see Figure 8.3.

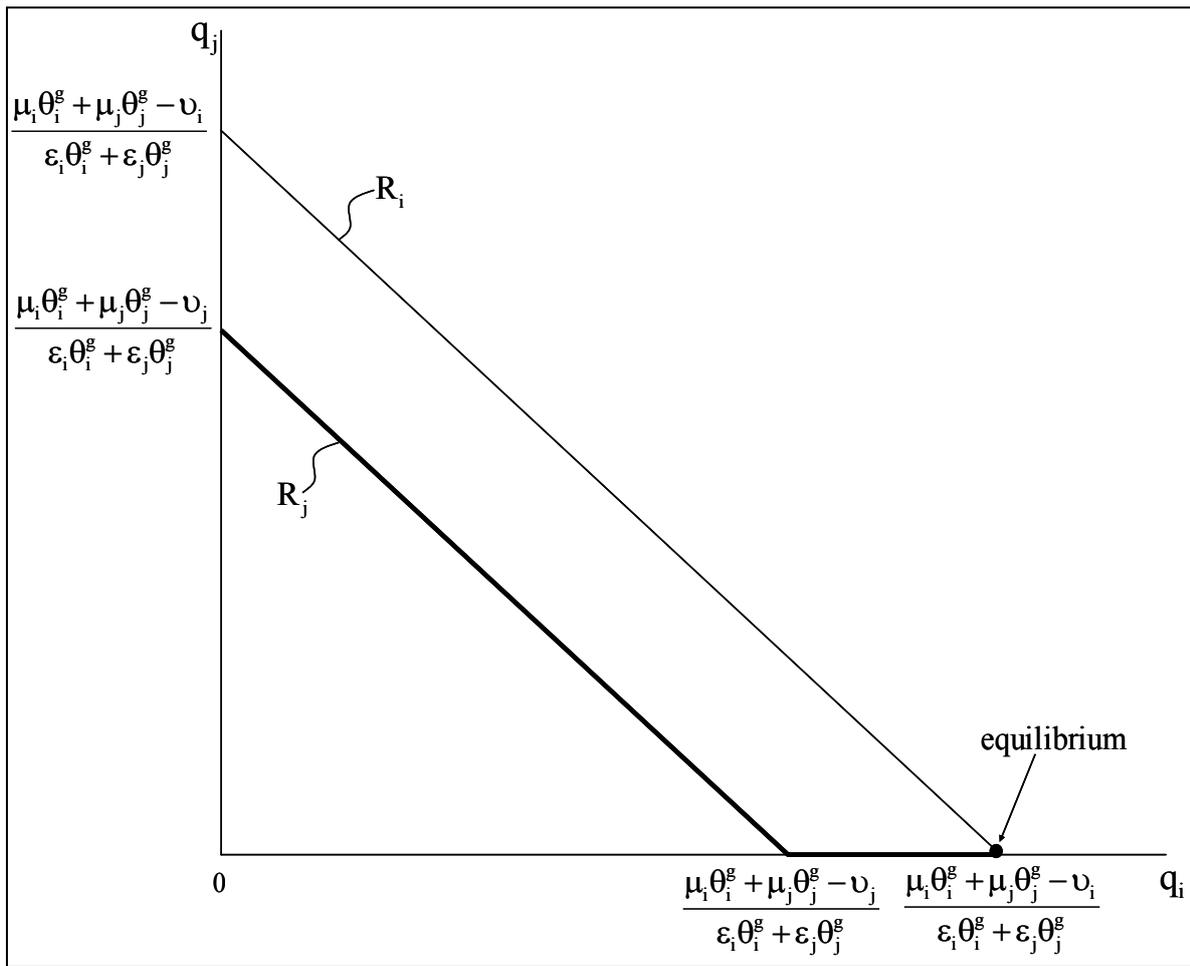**Figure 8.3 Reaction functions for abatement of country i and j (as coalition members).**

In the voting game, we find that country j choosing $\overline{\theta}_j$ – i.e. choosing the value at the upper bound of j's political space – and country i choosing $\theta_i^g < \theta_i^m$ is an equilibrium. Country i is doing all the abatement in the coalition (given that it is assumed to be the one with the lowest marginal cost). Country j is not abating at all; hence, it does not have any cost and only enjoys the benefits from global abatement. This gives to the voters in j an incentive to elect strategically their government. As country j only receives benefits, voters would choose the government that ensures the largest benefit possible. In fact, this constitutes a dominant strategy and voters in j elect an extremely green government – i.e. $\theta_j^g = \overline{\theta}_j$. The best response of voters in country i to this strategy is to elect a government that put less weight on the benefits from abatement – i.e. they vote for a 'less green' government than the median voter $\theta_i^g < \theta_i^m$. The extent of choosing a 'less green' government in i depends on the parameters of the payoff function and in an extreme case voters would choose a government that does not care at all about the benefits from abatement – i.e. $\theta_i^g = 0$.

At a first glance, it is not clear if the IEA, in this setting, improves (in terms of global abatement) upon the singletons case. Whether global abatement with a coalition q^K exceeds the global level of abatement of the singletons q^S depends on the parameters of the payoff function. We find that $q^K > q^S$ if and only if

$$\frac{1}{\epsilon_j}\left(\mu_i - \frac{\upsilon_i}{\overline{\theta}_j}\right) > \frac{1}{\epsilon_i}\left(\mu_i - \frac{\upsilon_i}{\theta_i^g}\right). \tag{8.29}$$

As we assume that $\overline{\theta}_j \gg \theta_i^g$ and noting that both sides of (8.29) include υ_i, then, the only differences are on the parameters of the benefit function. Thus, from (8.29) we note that if regions do not differ much in their marginal benefits, then $q^K > q^S$ and that only if $MB_i \gg MB_j$ then the agreement will not improve upon the singletons in terms of abatement.

Finally, the agreement is not stable, because there is no internal stability. Again for the proof it is sufficient to show that a country has a lower payoff as a coalition member than as a singleton. However, as in the case of the singleton it is not clear which of the two countries (high marginal cost or low marginal cost) will abate. We have to examine two cases. Firstly, assume that country i is not abating as a singleton. Then, voters in i elect a government that does not care at all about the benefits of abatement – i.e. $\theta_i^g = 0$. Then, the only abatement level that guarantees a non-negative payoff to the government in i is choosing $q_i = 0$. Thus, the payoff for country i as a singleton is zero. However, country i, as a coalition member, may have a negative payoff – i.e. $\pi_i^K < 0$. A sufficient condition for this to happen is that $\epsilon_j \geq \epsilon_i / 2$. Then $\pi_i^K < 0$ holds and, thus, the agreement is not internally stable. Otherwise, $\pi_i^K < 0$ happens only if $\theta_i^g < \upsilon_i / \mu_i$ holds. In the extreme case of $\theta_i^g = 0$ as a coalition member, country i has always a negative payoff and the resulting agreement is never stable. Secondly, assume that country i is abating as a singleton. We know that country i, as a singleton, always performs a level of abatement that results in a non-negative payoff, $\pi_i^S \geq 0$. However, as a coalition member country i has always a larger abatement level than as a singleton (due to the CPM assumption). In none of the cases country j abates, thus country i's payoff only reflects the net benefits of its own abatement. These net benefits are maximized at the abatement level of the country acting as a singleton, any abatement different from that will not be efficient and hence it will result in a lower payoff than π_i^s. As country i has

always a larger abatement as a coalition member than as a singleton (because of the CPM assumption), the agreement is not internally stable.

8.5. Summary and conclusions

Game theoretical studies on international environmental agreements (IEAs) point out that an agreement's success is hampered by free-rider incentives. However, a recent study by Buchholz et al. (2005) identifies another reason for an unsuccessful IEA, namely that voters support candidates whose environmental preferences differ from their own. Voters choose a 'less green' government because it gives them a better bargaining position at the international negotiations. This gives the negotiating countries the possibility of receiving larger transfers or shifting the abatement burden to another country. Furthermore, Buchholz et al. show that the situation in environmental and economic terms would be worse when countries sign an IEA than when they do not cooperate to tackle the environmental problem. These results are mainly driven by the fact that there is leakage in the model. Moreover, stability is not considered in their analysis. The results would be less striking if stability is considered. It can be shown than an IEA under the Buchholz, Haupt and Peters (BHP) model is not stable and thus is not going to be implemented. This chapter extends the analysis of the BHP model and studies the effect of strategic delegation in the success and stability of an IEA. To attain this objective our framework considers an IEA to tackle a global pollutant, two asymmetric countries, but we do not consider transfers. In this context, we examine three functional forms often used in the literature.

There are four key results from our analysis. Firstly, we find that when countries act as singletons (i.e. they do not cooperate), leakage effects are the main cause for strategic voting. The first two types of payoff functions that we test include a linear benefit function, hence there are dominant strategies in abatement and thus no leakage effects. We find that for these types of payoff functions voters always choose the government that has the same preferences as the median voter. In contrast, voters choose strategically on the third type of payoff function that we test. This function includes a non-linear benefit function and hence leakage effects. However, it is not clear whether or not the elected government is 'less green' than the median voter as Buchholz et al. (2005) state. We find that this depends on the parameters of the model. In particular, it depends on the parameters of the benefit function.

Secondly, we find that when countries sign an IEA, voters always have an incentive to elect their government strategically. This is irrespective of the presence of leakage effects. However, contrary to the BHP model, we do not find that, for a global pollutant, both countries experience a 'race to the bottom' and choose a government that does not care for the benefits of abatement. We find that, in the equilibrium, voters in one country choose a

government that is 'less green' than the median voter, whereas, in the other country, voters elect a government that is always greener than the median voter. These results are driven by the fact that members choose the abatement levels that maximize their joint payoff – i.e. we assume that they behave according to the CPM assumption. The CPM assumption makes abatement a function of the characteristics of the government of both countries – as expressed by a parameter that reflects the preference towards the benefits from abatement of the government. Thus, if a country wants to free-ride and put the abatement burden on the other country, the latter reacts greening its government because that ensures that the abatement in both countries remains positive.

Thirdly, we find that strategic voting does not result in IEAs that are worse in environmental terms (i.e. abatement levels) than the case without cooperation. Contrary to the BHP model, in our framework, an IEA always achieves a larger level of abatement than in the singletons case. However, we find that most of the time these agreements are not stable. We explain that for the types of payoff function that we test, only under very special parameter specifications the agreement results in a non-negative payoff for both countries.

Finally, we find that the results of the BHP model do not generalize to pure public goods. We find that that strategic voting undermines the success of IEAs in terms of abatement. However, this is not a result of having both countries electing 'less green' governments. We show that signing an agreement improves in terms of abatement, most of the time, upon the situation without cooperation. Nevertheless, we find that these agreements are not stable. Hence, they will never be implemented. Strategic voting, thus, does not undermine the success of IEAs because voters elect 'less green' governments, but because strategic voting makes IEAs unstable.

Chapter 9. Summary, conclusions and recommendations

9.1. Introduction

Global cooperation is crucial to tackle climate change. However, cooperation on such a scale has proven to be difficult given the public good nature of the problem. Abatement of greenhouse gases (GHGs) results in benefits at a global scale. This translates into strong free-rider incentives that threaten the success of an international agreement. There are two main approaches for international cooperation to reduce GHG emissions. Firstly, countries can cooperate on the diffusion and promotion of technology in order to reduce emissions. This approach favors cooperation through a non-binding agreement. The prominent example of this approach is the creation in 2006 of the Asia-Pacific Partnership on Clean Development and Climate (also known as AP6) by Australia, Japan, China, India, South Korea and the USA. Secondly, countries can cooperate to set emission targets. This approach set limits to emissions of GHGs through legally binding commitments codified in an international climate agreement (ICA). The most prominent example of this approach is the Kyoto Protocol.

However, even if these approaches are successful and they achieve a meaningful reduction of GHGs, the effects of past emissions on the atmosphere will still be noticeable for hundreds of years from now. Industrial activities in the last two centuries have resulted in a major environmental pressure, of which climate change is only one example. These activities (that include combustion of fossil fuels and changes in land use, among others) substantially increase the amount of GHGs in the atmosphere. A high concentration of these gases is very likely to cause an increase in the mean world temperature and an important change in the climatic and ecological systems of the world. The negative effects of climate change are noticeable both on the natural systems (e.g. rise in sea levels, reduction of ice covers, and retreat of glaciers) and on the socio-economic systems (e.g. increase in heat stress, vector-borne diseases and loss of lives due to an increase in extreme weather events such as floods and storms). Nevertheless, there are also positive effects of climate change, such as an increase in crop yields as a result of higher temperatures and more precipitation, fewer cold related deaths, less energy demand for heating and an increase in amenity and recreational values related to higher temperatures and milder winters (Nordhaus and Boyer, 2000; Tol, 2002a, and 2002b). However, on a global scale, it is likely that the positive effects have a lower impact than the negative effects (IPCC, 2001). In particular, the rise in the global sea level is expected to continue. This would have an important impact on densely populated

settlements in coastal zones. Furthermore, there is a considerable consensus in the international policy arena that negative effects are going to be evident in the near future.

It is recognized that climate change is a global challenge. Countries are sovereign and most of the time act following self-interest. An agreement to tackle climate change, then, should shape the incentives of countries in such a way that cooperation is fostered. Hence, the success (i.e. the level of reduction of GHG emissions) of an ICA depends to large extent on its design. ICAs' design faces two problems: enforceability and political feasibility. First, an agreement has to be self-enforcing. There is no supranational authority that can enforce and sanction an ICA. Second, an agreement has to be politically feasible. The design of an ICA must recognize that the position of the governments at the international negotiations tables are influenced by the national political actors such as ministries, political pressure groups (lobbies) and the general electorate. An ICA, hence, should reduce the chances of being rejected by the domestic political actors.

The objective of this thesis (see Chapter 1) is to analyze the impact of design characteristics and national political actors on the potential stability and success of ICAs. In this thesis, the cost-benefit, game theoretical and political economy strands of the literature are combined to attain this objective. For this purpose, I use the STAbility of COalitions (STACO) model, which combines a game theoretical module with an empirical module. STACO analyzes ICAs in a 'cartel formation' setting (i.e. only one agreement can be signed at a time). The game theoretical module considers coalition formation as a two-stage game. At the first stage, regions decide on their membership in an ICA; at the second stage, regions choose their abatement strategies considering the payoff function calibrated according to the empirical module. The empirical module considers that governments base their membership decision on a net benefit function. This function comprises benefits of abatement in the form of reduced damages from climate change and costs of abatement. The empirical module provides benefit and costs estimates for twelve world regions and captures long-run effects of GHG accumulation (I focus on emissions of CO_2) over a period of 100 years. STACO performs a stability check for all possible coalitions. The stability concept that I use is *internal* and *external* stability. An agreement is called internally stable if no country is better off by staying outside the coalition, whereas external stability means that no country is better off by joining a coalition. An ICA is called stable if it is both internally and externally stable.

The design of actual environmental agreements may differ from what is assumed in the literature on coalition formation and ICAs – see Chapter 2. A crucial assumption in this literature is that members choose their abatement strategies by maximizing the coalitional payoff. In the following, I refer to this as the coalitional payoff maximization (CPM) assumption. In practice, however, inefficient targets are often implemented, mostly due to

political reasons. Furthermore, the national representatives make their decisions about membership and abatement levels considering other factors rather than the maximization of net benefits. Then, political economy issues become relevant for the analysis. In this thesis, I pursue three approaches to include political economy aspects into the analysis of ICAs. Firstly, I introduce features from the actual negotiations into the design of an agreement. For instance, members of an ICA could vote for the accession of new members. Thus, the ICA becomes an exclusive membership agreement. I analyze this in Chapter 4. Furthermore, in Chapter 5, I consider the effect of permit trading schemes that are based on criteria that are regarded as equitable. Secondly, I abandon the CPM assumption to recognize the fact that a more even and modest distribution of abatement targets (as with a uniform abatement quota) would have a positive impact on the stability and success of ICAs. I study this in Chapter 6. Thirdly, I abandon the assumption of welfare maximizing governments at the national level. I assume that governments not only care about the outcome of the environmental policy but also about the particular political characteristics that they encounter domestically. Thus, the decision that a government takes at the negotiation of an ICA may be influenced by national political actors, I examine this in Chapter 7 for the case of the lobby groups and in Chapter 8 for the case of national voters.

The structure of the remainder of this chapter is as follows. Section 9.2 offers a summary of the main results of the thesis in the context of the research questions presented in Chapter 1. Section 9.3 discusses the general conclusions of the thesis. Section 9.4 presents a general discussion. Finally, in Section 9.5, I offer possible extensions of my research.

9.2. Research questions and summary of main findings

9.2.1. Research question 1 - Exclusive membership

How do membership rules affect the stability and success of an international climate agreement? What is the role of decision rules such as unanimity and simple majority voting in the context of an exclusive membership climate agreement?

Many of the studies on the stability of ICAs assume that these are open membership treaties. All countries are free to join or leave the agreement. This assumption is in line with almost all international agreements that deal with global issues. The public good nature of the benefits of abatement of GHGs, may suggest that a treaty would be more successful as more countries join. However, this does not take into consideration that ICAs have to be self-enforcing. A stable agreement might actually tackle climate change more effectively if only few countries are allowed to join. Hence, in Chapter 4, I study the effect of considering ICAs as exclusive

membership agreements. I assume that coalition members decide on the accession of new members. The decision is assumed to follow two rules that are widespread in actual political negotiations: unanimity and simple majority voting. I compare the results from the stable agreements that may arise under open and exclusive membership.

In Chapter 4, I find that in an exclusive membership agreement, global cooperation is difficult to attain. The grand coalition is not stable regardless of the membership rule and the voting rule used for accession. I find that partial cooperation is stable but only under exclusive membership. However, stable coalitions are rather small and do not improve significantly upon the situation without an agreement. There are three stable coalitions, one under majority voting and two under unanimity voting. In these coalitions, exclusive membership blocks the entry of members that may cause that the resulting enlarged coalition is internally instable.

From the stable coalitions, the most successful in terms of gains of cooperation (i.e. the difference in global payoff between full and no cooperation) is a coalition between the energy exporting countries (EEX) and China. This coalition achieves 11.7% of the possible gains of cooperation (i.e. the difference in payoff between the situation with no cooperation and the grand coalition) and it is stable under unanimity voting. The results suggest that it is worthwhile to consider the possibility of having an ICA based on exclusive membership rules. Furthermore, these results give a rationale for the frequent application of unanimity voting in international policy-making and suggest that when countries have a veto power this would not be a major obstacle to achieve larger participation in a stable ICA.

9.2.2. Research question 2 - Permit trading

How do different initial allocations of emission permits affect the stability and effectiveness of an ICA? What type of transfer scheme should be included in an IEA in order to increase participation and effectiveness in terms of abatement?

Emission permits are considered crucial instruments for addressing many environmental problems, both at the national and at the international level. Currently, its relevance is highlighted under the Kyoto Protocol and the actual functioning of emissions trading within the European Union. However, there is no clear consensus about the most successful way of allocating emissions permits. Often, it is argued that a distribution of permits following equity considerations may be desirable. In Chapter 5, I test seven different permit trading schemes. Each one reflects a different initial allocation of emission permits. I classify the schemes in two categories: pragmatic and equitable. The pragmatic schemes are close to the current status quo and allocate permits according to a uniform emission reduction from a

reference emission level. I consider two reference levels: emissions in the business-as-usual (BAU) case and emissions in the Nash equilibrium case (i.e. emissions when no agreement is signed). The equitable schemes are motivated by different notions of fairness cited in literature. I test five equitable schemes: egalitarian (per capita allocation of permits), historical responsibility (permits are allocated inversely to emissions in the BAU case), ability to pay (permits are allocated inversely to the GDP per capita), ability to pollute (permits are allocated inversely to the BAU-emissions per capita) and energy efficiency (permits are allocated inversely to the emissions per unit of GDP).

I find that, without permit trading, the gains of partial and full cooperation are unevenly distributed among coalition members. This is caused by the heterogeneity among regions. Depending on the permit scheme this inequality might be reduced – to some extent. I find that the pragmatic schemes help to reduce the uneven distribution of gains of cooperation. In contrast, equitable schemes only aggravate it. I find stable coalitions only under the pragmatic schemes. There are four stable coalitions, two under the allocation of permits according to the BAU emissions and two when permits are allocated according to the emissions in the Nash equilibrium. The coalition between the European Union (EU-15) and China is the most successful in terms of abatement and it is stable under the allocation of permits proportionally to BAU-emissions. This coalition achieves almost 25 % of the gains of full cooperation. These results, thus, do not support the conjecture that equity may enhance the success and participation of an ICA. A pragmatic scheme, though apparently less fair, may be more successful in attracting more countries to cooperate. Though these results cannot claim generality, they provide a relevant insight for designing a proper permit scheme and their probable effect on the success of an ICA. Furthermore, the design of a permit scheme needs to consider that in order to be successful it has to identify key players on the environmental problem and prioritize their participation (as in the case of EU-15 and China).

Finally, parallel to the analysis of this thesis, the STACO project offers further investigations of the role of transfers on stability of ICAs. Weikard (2005) studies a transfer scheme such that the coalitional payoff is distributed proportional to the outside option payoff for each coalition member. The outside option payoff is the payoff that would be obtained if a coalition member becomes a singleton but the remaining regions stay in the coalition. Weikard (2005) shows that this 'optimal sharing rule' makes it possible to determine the largest possible stable coalition. An application of the optimal sharing rule to the STACO model shows that 45% of the possible gains from cooperation are reaped by a stable coalition of five members.[1]

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[1] The model run for these results is not reported in this thesis. Further analysis of these results is still in progress.

9.2.3.Research question 3 - Uniform emissions quotas

Does a uniform distribution (in relative terms) of abatement targets lead to more successful ICAs? Is it possible to improve the effectiveness of ICAs through considering less ambitious (though non-efficient) abatement targets?

Most of the studies on ICAs assume that abatement decisions of members and non-members are efficiently chosen. However, this contrasts with the evidence on international environmental agreements. Many of these agreements specify a uniform quota for all participants. This is clearly inefficient given that countries have different marginal abatement costs. In spite of this inefficiency, the use of uniform quotas is wide-spread in international environmental policy. Most of the literature about ICAs (see Chapter 2) assumes that abatement of signatories is chosen following the CPM assumption. This assumption, however, results often in uneven and very ambitious abatement targets that reinforce the free-rider incentives of the members. In Chapter 6, I depart from this assumption. I study the effect that a uniform abatement quota has on the participation and effectiveness of ICAs. I analyze four agreement designs, representing different forms of choosing the level of abatement of coalition members. First, as a benchmark, I use the 'Reference Design' that follows the CPM assumption. This assumption implies a cost-effective allocation of abatement within the coalition and a coalitional optimal aggregate abatement level. The remaining three designs are not cost-effective. The second agreement design or 'Joint Quota' assumes that countries maximize their coalitional payoff but with a restriction. The restriction is that all coalition members have to reduce emissions by the same uniform rate (quota) from their level of emissions in the Nash equilibrium (i.e. when no agreement is signed). The last two agreement designs assume a bargaining process where each coalition member maximizes its own payoff considering that each member has to make a quota proposal for the coalition. Then, the third design or 'median quota proposal' assumes that members agree on the median proposal, corresponding to choosing the quota via majority voting. The fourth agreement design or 'lowest quota proposal' assumes that members agree on the lowest proposal, corresponding to choosing the quota via unanimity voting. Additionally, I consider the possibility of trading quotas among coalition members, which restores cost-effectiveness.

The results of Chapter 6 show that although the 'Reference design' would lead to large global gains of cooperation, it implies an uneven distribution of them. This is a major obstacle to global and even partial cooperation. I find that there are no stable coalitions in this setting. In contrast, the quota agreement designs help to improve participation in stable agreements. I find that each of the three quota designs result in one stable coalition at least. Quotas foster participation because they represent a less uneven distribution of abatement burdens. From the three quota designs the most successful (in terms of global net benefits) is the 'Lowest

quota proposal' design. In this setting, I find that the coalition of EU-15, China, India and rest of the World (ROW) is stable. This coalition reaps 19% of the gains from cooperation. The situation changes when I consider that quotas may be traded among coalition members. I find that the design that results in the most successful coalition is the 'Median quota proposal'. In this case, a coalition among USA, EU-15, China and India is stable. This coalition reaps 40% of the gains from cooperation. These results suggest that a critical revision of the CPM assumption is needed. Under this assumption the possibilities of cooperation are underestimated. Moreover, this assumption does not reflect the actual process and outcomes of international environmental negotiations. Countries often agree on uniform solutions (such as under the Montreal and Helsinki Protocols). The inefficiency of quotas, as I find, might be compensated through an increase in participation and the success of an ICA.

9.2.4. Research question 4 - Lobby groups

Do national pressure groups (lobbies) foster or hinder cooperation on an ICA?

A political economy analysis of an ICA needs to recognize that governments' concerns go beyond the maximization of the net benefits from climate policy. The analysis should include also how national political actors affect the actions of governments at international negotiations. For instance, governments may recognize the pressure exerted by lobbies. Political economy studies the influence of lobby groups on political outcomes. It is assumed that an incumbent politician makes a policy decision in order to maximize the weighted sum of social welfare and total lobby contributions. Politicians, thus, maximizes their political support function.

In Chapter 7, following the political support function approach, I study the effect of lobby groups on the size and stability of ICAs. Thus, I depart from the standard assumption on coalition formation analysis about the behavior of governments. I consider that governments are not simply welfare maximizers but that they consider the political pressure of their domestic agents – in this case the lobbies. Thus, a government bases its decision about participation and level of abatement considering both the net benefits from abatement and the lobby contributions. I assume that there are only two lobbies: industry and environmentalist. Lobby contributions depend on each lobby's payoff function and the abatement strategy chosen by the government. I consider two types of environmentalist lobbies, supergreen and green. A supergreen lobby is interested in the global effects of the abatement policies. A green lobby is only interested in the regional effects of abatement policies. As for the industry lobby, I assume that the industry is always harmed by their government abatement decisions given the associated abatement costs.

I find that, in the absence of an agreement, supergreen lobby contributions may help to foster an increase in abatement efforts. When supergreen and industry lobby contributions are considered, the singleton coalition structure improves, in terms of abatement levels, upon the case without lobby contributions. Even though there are three regions taking industry contributions, this does not offset the improvement in terms of global abatement and net benefits. The picture changes when I consider green and industry contributions. Then all regions are taking contributions from the industry. This has a clear detrimental effect on the level of global abatement and net benefits. I find that participation in a stable agreement improves when I consider the pressure from the lobby groups into the analysis. However, in my model setting, full cooperation is not stable and, although partial cooperation is stable, it does not help much to tackle climate change. I find that the success of stable coalitions, in terms of global abatement and payoff, depends on whether there is a supergreen or a green lobby. There is a stable coalition between Japan and EU-15 with supergreen and industry lobby contributions. This stable coalition achieves little in terms of gains of cooperation – it shows an improvement of only 2 %. However, when there are green and industry contributions the stable coalition falls short of achieving the abatement of the Nash equilibrium in the base case – i.e. in the case without contributions. Finally, I find that contrary to intuition, industry contributions are compatible with participation in an ICA. For instance, EU-15 receives industry contributions in the stable coalition. This happens because, as a coalition member, EU-15 increases its abatement from the singletons situation, however, this increase is modest and still allows it to receive industry contributions.

9.2.5. Research question 5 - Strategic delegation

Does the strategic behavior of voters result in less successful ICAs?

A political economy analysis of an ICA needs to recognize that voters delegate their decision power to their representatives at international negotiation tables. The representatives (generally the governments) then negotiate the terms, conditions and obligations that their countries will follow when joining an international agreement. This issue is approached with strategic delegation models. This approach analyzes situations of principals (e.g. voters, owners of firms) delegating their decision power to a representative, or agent (e.g. governments, managers), in order to bargain over an outcome of a policy or market position with a third party. The general result from the strategic delegation framework is that the appointed agents have different preferences than those of the principals. By choosing an agent with different preferences than their own, a principal can obtain a strategic advantage at the bargaining stage. In the context of international policy-making, this result means that voters might elect a politician that has different preferences than their own because it gives them an advantage at the international policy negotiations.

Game theoretical studies on IEAs point out that these agreements are not especially successful because of free-rider incentives. Following the strategic delegation approach, it has been argued that there may be another reason for unsuccessful IEAs, namely that voters support candidates whose environmental preferences differ from their own. Thus, when government's representatives meet at the international negotiations, they bargain for an agreement that does not tackle effectively the environmental problem. Voters choose a 'less green' government because it gives them a better bargaining position – i.e. lower abatement targets and associated costs and the possibility of receiving a larger compensation if transfers would be available.

In Chapter 8, I study the effect of strategic delegation on the effectiveness and stability of an ICA. I assume that there are different types of politicians, corresponding to the different attitudes towards the environmental problem of the voters. Furthermore, I assume that voters can elect the type of politician that will represent them at the international negotiations. This may or may not give incentives to vote strategically. I study a model of two asymmetric countries, for a pure public good and analyze stability. I find that when countries act as singletons leakage effects (i.e. the fact that the increase in abatement of one country is offset by a decrease in abatement of the other country) are the main cause of strategic voting. Moreover, I find that when countries sign an IEA, voters always have an incentive to elect strategically their government but that the resulting agreement improves in environmental terms (i.e. abatement levels) upon the case without cooperation. Finally I find that strategic voting undermines the success of an IEA but not because voters elect a 'less green' government but because strategic voting makes IEAs unstable.

9.3. General conclusions

Tackling climate change needs global cooperation. The literature on ICAs often states that cooperation is difficult to attain due to strong free-rider incentives. Hence, ICAs often are neither stable nor successful in achieving a significant reduction of the emission of GHGs. The success of an ICA depends to a large extent on its design. Along this thesis, I explain that there are instruments that help to improve, to some extent, the success and stability of an agreement, e.g. transfers or uniform abatement targets. Furthermore, it is crucial to consider the effect that national political actors may have on shaping the negotiations and the terms of an ICA agreed by the signatories. In Figure 9.1, I present the most successful stable coalitions (in terms of global payoff) that I find in each chapter. In this figure, I include the level of global payoff for the singleton case (i.e. when there is no cooperation) and for the grand coalition (i.e. when all cooperate signing the agreement) as references.
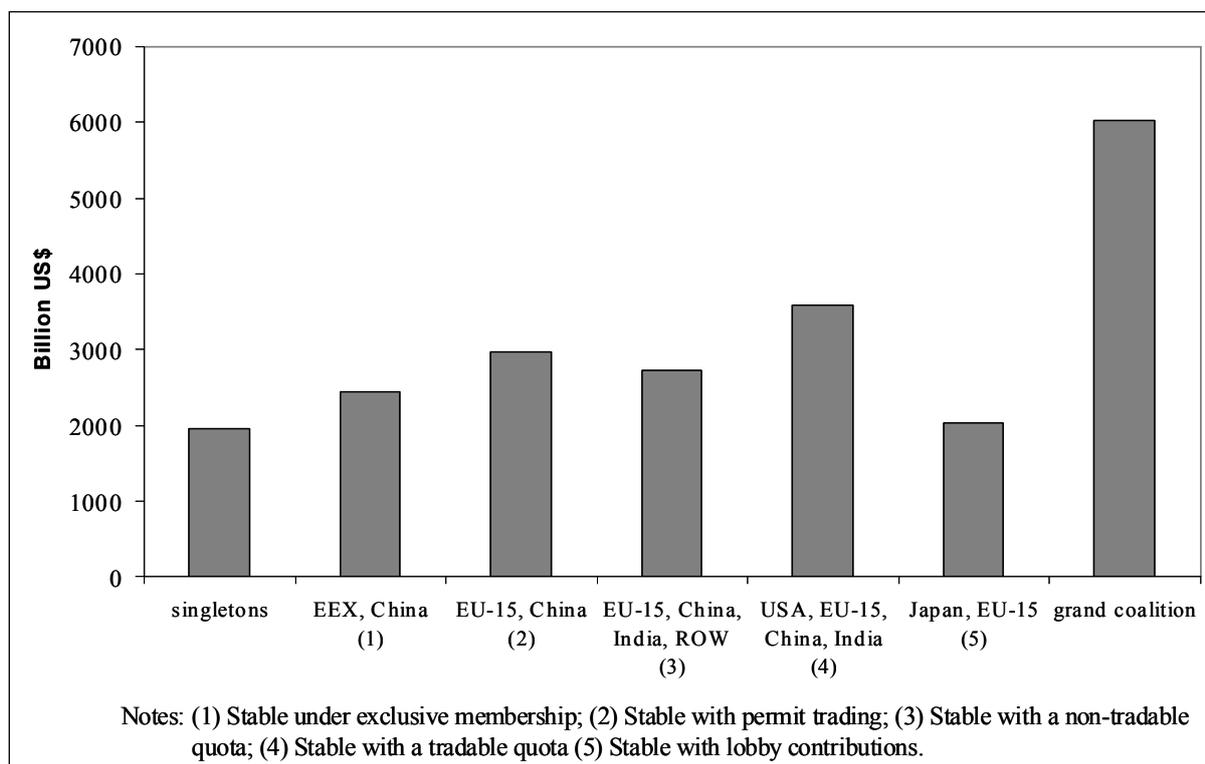
Figure 9.1 Reference and stable coalitions.

From Figure 9.1, it is evident that the gains of cooperation are large. The difference between the singleton and the grand coalition is noticeable. From the different agreement designs that I analyze, it is clear that a tradable quota is the most successful (fifth column on the figure). The stable coalition of USA, EU-15, India and ROW closes the gap between no cooperation and full cooperation by 40 %. The 'least successful' of these coalitions emerges when I consider lobby contributions into the analysis. This coalition barely improves upon the singletons case. The other agreement designs are moderate in their improvement upon no cooperation. Hence, it is clear that the design characteristics of an ICA have a crucial impact on its success.

Before I present the general conclusions of this thesis, it is worth to mention a word of caution. The conclusions that I offer in this section need to be read considering the caveats of the framework that I use (see Chapter 1). In brief, they have to be put in perspective given that I consider a 'one-shot game' (i.e. regions make their decisions once and for all) and a 'cartel formation' framework (i.e. that only one agreement can be signed at a time). Issues such as dynamically optimal abatement paths and multiple coalitions are not treated here. Nevertheless, the results from my analysis provide a useful insight on the impact of the design and the political actors on stability and success of ICAs. Some of the caveats are

already addressed in the broader context of the project where this thesis belongs – see Section 9.5.

From the results of this thesis, I identify four general conclusions. Firstly, an ICA, in order to be successful, needs to secure at least the participation of some of the key players for the climate change problematic such as USA, EU-15, China or India. It is necessary to recognize that the success of an ICA cannot be measured only in terms of the number of its signatories. Instead, the success could be measured in terms of how the agreement actually tackles climate change, e.g. measured in terms of actual reduction of GHGs. Policy-makers need to focus on the depth (i.e. the extent to which the problem is solved) rather than on the width (i.e. the number of signatories) of an ICA. This can be observed in Figure 9.1, even if two stable coalitions are of the same size (four members under non-tradable and tradable quotas), the coalition that achieves a better result, in terms of global payoff, is the one that includes USA – a clear key player in the climate change problem.

Secondly, the design of an agreement needs to exploit the asymmetries among countries. For instance, an agreement would be more successful in tackling climate change if it gives enough incentives to participate to countries with low marginal costs. In the setting of the model that I use, the stable coalitions that achieve large emission reduction, and hence large global payoffs, are those that involve regions with high marginal benefits (e.g. USA, EU-15) with regions with low marginal abatement costs (e.g. China, India) – see the fourth and the fifth columns in Figure 9.1. In contrast, a coalition that includes regions with similar cost-benefit structures achieves very little – see the column for the coalition of Japan and EU-15 in Figure 9.1. An agreement needs to be designed such that it can exploit the comparative advantages of each country. This means that both developed and developing countries have to be actively involved in abatement activities. These activities may be performed where the cheapest options of abatement are available, that in many cases are in the developing world. Furthermore, this is particularly relevant because the developing countries will be the largest emitters in the near future.

Thirdly, equity criteria may not be adequate to attain meaningful participation in an ICA. In the literature and actual negotiations, equitable principles are praised to be useful criteria to increase participation in an international agreement. A country would find it difficult to join an agreement if it considers that is unfair. However, I find that equity criteria may not help to increase the success of an ICA if countries only act on their self-interest. These criteria only seem to replace one type of asymmetry by another. If emissions permits, for instance, are allocated according to equity criteria there may be a considerable transfer of resources from the developed countries to the developing ones. The resulting agreement would be not stable. Then the design of an agreement needs to consider that having 'pragmatic' policies (i.e.

policies closer to the status quo) may result in a more successful agreement than considering equity criteria – e.g. a per capita allocation of emissions permits.

Fourthly, the analysis of ICAs and IEAs needs to acknowledge that the political process has a crucial influence on the success of these agreements. It is important that models on stability of ICAs recognize that national governments act following other criteria rather than maximizing social welfare. Issues such as the influence of lobby groups or the interests of voters shape the political agenda of governments negotiating an international agreement. Lobby groups, for instance, may stabilize an agreement but this may not be very successful in tackling the environmental problem – see the result for the coalition between Japan and EU-15 in Figure 9.1. In the actual political negotiations, governments may even support organized groups to become lobbies. Subsequently, these groups act as a tool to pressure further the government to have more stringent policy measures. Voters are also a crucial element to consider. As I point out in Chapter 8, the strategic behavior of the electorate may undermine the effectiveness of an IEA because it makes agreements unstable.

9.4. General discussion

From the exposition of Sections 9.2 and 9.3, it is clear that an ICA needs to be designed to attain a meaningful participation (i.e. that members actually reduce GHGs emissions). Thus, an agreement would better tackle climate change if it is deep (i.e. that attains a significant reduction of GHGs) rather than wide (i.e. that is signed by a large number of countries). Moreover, the design needs to include issues such as transfers (through permit or quota trading) and the possibility of restricting membership to the agreement. However, it would not be adequate to jump to the conclusion that the more instruments are included in an agreement the better outcomes may be attained. The combination of two instruments may indeed help, but it is likely than it would be less than the sum of what each instrument can do in isolation. Hence, the results from the instruments that I use throughout this thesis may be sub-additive.

Furthermore, the conclusions of Section 9.3, urge for a better understanding of political process in the negotiation of ICAs. The political economy aspects of these agreements are crucial to understand the underlying incentives of countries to participate. I highlight the relevance of national political actors in the outcomes of the negotiations. Lobby groups and voters certainly have an influence, direct and indirect, on the terms and success of an ICA. Moreover, the analysis of the decision-making process in ICAs and IEAs needs to consider that their success is related to the extent to which the government can be influenced. At the international level, lobby groups have a clear influence on the outcome of the negotiation, whereas voters have only an influence at national or local level. Policy-makers may perceive

this and act accordingly not only to maximize the overall welfare of the nation but also to maximize their private benefit (reflected not only in monetary terms but in the many forms of political support).

Finally, the analysis that I present in this thesis needs to be considered with caution for two reasons. Firstly, my analysis does not, and it was never meant to, replicate the framework of the Kyoto Protocol. The process and mechanisms included in the Protocol may be the subject of another thesis. Furthermore, the complexity on the process of negotiations, not only on the political side but also concerning the instruments used, is outside the scope of my thesis and might be considered as a future line of research (see Section 9.5). The setting that I use has a different focus from what actually happens at the Kyoto negotiations. For instance, the actual abatement targets for Annex I countries are not necessarily based on the CPM assumption. The apparent simplicity of the framework that I use allows me to focus on the general aspects of design and political economy. Secondly, the political economy side is more complex than what I reflect in my analysis. For instance, there are two current agreements that address the climate change problematic (see Chapter 1), The Kyoto Protocol and the AP6 Partnership. Hence, a framework based on a 'cartel formation' may seem not to be adequate and clearly multiple agreements (coalitions) may spawn in the coming years. If agreements target to be more deep than wide, it is possible that a set of regional agreements to tackle climate change constitutes a better approach than considering a unique global agreement. Then, regional advantages can be exploited and better results might be attained. This issue is also discussed as a future item for research in Section 9.5.

9.5. Issues for future research

I recognize that the analysis of this thesis must remain incomplete. As I mention in the Introduction of the thesis (Chapter 1), my research is part of a broader project. Many issues that are not treated in this thesis have been addressed by my colleagues of the STACO project. In the following, I mention possible lines of future research. From these, I highlight those that are currently analyzed in the project. I classify the further lines of research in three categories: (i) empirical data, (ii) structure of the empirical module, and (iii) structure of the game. Firstly, concerning the empirical data, a more detailed analysis is needed in order to determine, for instance, the regional parameters for the benefit function. Benefits of avoiding climate change are subject to a high degree of uncertainty and their regional distribution is not straightforward to determine. STACO parameters are deterministic and hence do not recognize that there are inherent uncertainties surrounding climate change. However, as a first step towards analyzing uncertainty on parameters within the STACO project, Dellink et al. (2005) link uncertainty about benefits and costs of climate change to the stability analysis of coalitions in a stochastic, empirical setting for the STACO model.

Secondly, the structure of the empirical module needs to be improved. One of the caveats of the STACO model (in the version that I use in this thesis) is that it considers constant abatement levels over the time horizon. A deeper analysis of how countries construct their abatement strategies over time is needed. Nagashima et al. (2005) present a dynamic version of the STACO model (STACO version 2.1). This version calculates optimal abatement paths over the time horizon of the model and it has been used to analyze the effect of permit trading. This is a first step towards a more sophisticated empirical module. A further option would be to link the STACO framework with more detailed climate models such as the EPPA model (Babiker et al. 2001). This possibility, however, has not been explored yet.

Thirdly, the structure of the game may be expanded to include many other agreement designs and political economy issues. In this respect, the STACO project already incorporates various approaches. Finus, Sáiz and Hendrix (2004) extend the analysis of STACO to include the possibility of having simultaneously a variety of agreements – i.e. it allows for multiple coalitions. Furthermore, the game may consider the fact that decisions may be revised after certain period – i.e. to analyze a repeated game. Weikard, Dellink and van Ierland (2006) use STACO version 2.1. to analyze the effects of renegotiations on the stability and success of an ICA. The game may also include other political economy issues, for instance, to include more aspects of an actual ICA such as the Kyoto Protocol. The analysis of the political economy of this Protocol, in the context of stability of ICAs, has not been explored yet and may be a promising line of research. In Chapter 5, I find that permit trading could enhance stability. However, the assumption in that chapter is to restrict permit trading to coalition members. An interesting extension would be to allow for trading also with outsiders. This framework would reflect some characteristics of the Kyoto Protocol, such as the CDM scheme.

Finally, the game may include a more detailed analysis of the influence of national political actors. In Chapter 7, I find that lobby groups have an important effect on the decision of countries to whether or not sign an ICA. Nevertheless, I consider that lobby groups do not interact with each other and that only one offers contributions to the government. The analysis may be extended to include features of lobby competition. In this framework, lobbies will consider that there are other lobbies in the political spectrum. Hence, they will bid for being the faction that actually influences the government. Furthermore, it would be interesting to analyze the fact that, in order to be implemented, an ICA has to be ratified by the national legislative powers – at least in democratic countries. This may become an obstacle if the Parliament finds that the terms of the agreement negotiated by the executive are not favorable to the country. The analysis on the political economy of ICAs may be extended to investigate the effects of different types of domestic ratification institutions and mechanisms on the participation and success of an ICA.

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SAMENVATTING

De politieke economie van de internationale klimaatverdragen

Mondiale samenwerking is cruciaal voor de aanpak van klimaatverandering. Dergelijke samenwerking is echter moeilijk gebleken vanwege het publieke goed karakter van dit probleem. Reductie van broeikasgassen leidt tot mondiale baten. Dit vertaalt zich in een sterke stimulans voor zwartrijdergedrag ("free-rider") die het succes van een internationaal verdrag bedreigen. Zelfs als het huidig beleid succesvol is en een aanmerkelijke reductie van broeikasgassen wordt bereikt, dan zullen de effecten van emissies naar de atmosfeer uit het verleden nog honderden jaren merkbaar blijven. Hoewel deze effecten zowel positief als negatief kunnen zijn, is het waarschijnlijk dat op mondiale schaal de positieve effecten (zoals een verhoging van voedselproductie als een gevolg van hogere temperaturen en meer neerslag, minder doden door onderkoeling, lager energieverbruik voor verwarming en een toename van bestaans- en recreatiewaarden) kleinere gevolgen hebben dan de negatieve effecten (zoals zeespiegelstijging, terugtrekking van gletschers, toename van hittestress, bacteriële ziektes en doden door een toename van weerextremen zoals overstromingen en stormen).

Het wordt onderkend dat klimaatverandering een mondiale uitdaging vormt. Landen zijn soeverein en volgen meestal hun eigen belang. Een verdrag om klimaatverandering aan te pakken moet daarom de belangen van landen zo vormen dat samenwerking wordt gestimuleerd. Het succes (d.w.z. het niveau van emissiereductie van broeikasgassen) van een internationaal klimaatverdrag (IKV) hangt sterk af van het ontwerp. Ontwerp van IKV's behelst twee problemen: afdwingbaarheid en politieke haalbaarheid. Ten eerste dient een verdrag "self-enforcing" te zijn aangezien er geen supranationale autoriteit is die een IKV kan afdwingen en sanctioneren. Ten tweede moet een IKV politiek haalbaar zijn en erkennen dat de positie van overheden aan de internationale onderhandelingstafels wordt beïnvloed door nationale politieke actoren, zoals ministeries, lobbygroepen en kiezers.

De doelstelling van dit proefschrift is om de gevolgen van ontwerpkarakteristieken en nationale politieke actoren op de politieke stabiliteit en succes van IKV's te onderzoeken. In dit proefschrift worden de literatuur over kosten-batenanalyse, speltheorie en politieke economie gecombineerd om dit doel te bereiken. Hiertoe gebruik ik het STAbiliteit van COalities (STACO) model, dat een speltheoretische module combineert met een empirische module. STACO analyseert IKV's in de context van 'kartelvorming' (d.w.z. dat slechts één verdrag tegelijk kan worden getekend). De speltheoretische module behandelt de coalitievorming. De empirische module gaat ervan uit dat overheden hun lidmaatschap van een verdrag bepalen op basis van een netto baten formule. Deze formule omvat de baten van emissiereductie in de vorm van verminderde schade (met een focus op de emissie van CO2).

Gevolgen van ontwerpkarakteristieken

Hoofdstuk 4 richt zich op de gevolgen van het ontwerpen van IKV's als verdragen met exclusief lidmaatschap. Ik veronderstel dat coalitieleden beslissen over de toetreding van nieuwe leden via twee regels: unanimiteit en meerderheid. Ik concludeer dat in een verdrag met exclusief lidmaatschap mondiale samenwerking moeilijk te bereiken is. De mondiale coalitie is niet stabiel, ongeacht de exclusiviteit van het lidmaatschap en de beslisregel voor toetreding. Partiële samenwerking is stabiel, maar alleen bij exclusief lidmaatschap. De stabiele coalities zijn echter vrij klein en doen het niet veel beter dan de situatie zonder verdrag.

Van de stabiele coalities is een coalitie van energie exporterende landen (EEX) en China het meest succesvol in termen van winst van samenwerking (het verschil tussen mondiale netto baten tussen volledige en geen samenwerking). Deze coalitie bereikt 11.7% van de potentiële winst van samenwerking en is stabiel bij beslissingen onder unanimiteit. De resultaten suggereren dat het nuttig is om te overwegen een IKV te ontwerpen met exclusief lidmaatschap. Verder geven deze resultaten een onderbouwing voor de frequente toepassing van beslissen bij unanimiteit in internationaal beleid en suggereren ze dat wanneer landen een vetorecht hebben dit geen belangrijk obstakel zou zijn om grotere participatie in een stabiele IKV te bereiken.

Emissierechten worden beschouwd als cruciale instrumenten voor vele milieuproblemen. Er is echte geen duidelijke consensus over de meest succesvolle manier om de rechten te verdelen. Het wordt vaak beargumenteerd dat een verdeling op basis van rechtvaardigheid wenselijk kan zijn. In Hoofdstuk 5 test ik 7 verschillende systemen van emissierechten. Elk reflecteert een andere initiële allocatie van rechten. Ik classificeer de rechten in twee categorieën: pragmatisch en rechtvaardig. De pragmatische systemen staan dicht bij de status quo en kennen rechten toe volgens een uniforme emissiereductie ten opzichte van een

referentieniveau van emissies. De rechtvaardige systemen worden gemotiveerd vanuit verschillende ideeën over rechtvaardigheid in de literatuur.

Mijn onderzoek wijst uit dat zonder emissierechten, de winst van gedeeltelijke en mondiale samenwerking ongelijk verdeeld is over de coalitieleden. Dit wordt veroorzaakt door de heterogeniteit tussen regio's. Afhankelijk van het onderzochte systeem kan deze ongelijkheid worden verminderd, althans enigszins. De pragmatische systemen helpen om de onevenwichtige verdeling van de winst van samenwerking te reduceren. De rechtvaardige systemen, daarentegen, verergeren het alleen maar. Ik vind alleen stabiele coalities bij de pragmatische systemen. De coalitie tussen de Europese Unie (EU-15) en China is het meest succesvol in termen van emissiereductie en is stabiel bij verdeling van emissierechten op basis van een referentieniveau van emissies. Deze coalitie bereikt bijna 25% van de potentiële winst van samenwerking. Deze resultaten ondersteunen dus niet de suggestie dat rechtvaardigheid het succes en participatie in een IKV kunnen stimuleren. Een pragmatisch systeem, hoewel ogenschijnlijk minder eerlijk, kan succesvoller zijn in het aantrekken van landen tot samenwerking.

De meeste studies van IKV's nemen aan dat de emissiereducties van coalitieleden en eenlingen efficiënt zijn. Dit is echter in tegenstelling tot de praktijk van internationale milieuverdragen. Veel van deze verdragen specificeren uniforme reductiequota voor alle leden. In Hoofdstuk 6 bestudeer ik het effect dat een uniforme reductiedoelstelling heeft op de participatie in en effectiviteit van IKV's. Ik analyseer vier systemen, die verschillende vormen voor het kiezen van het niveau van emissiereductie van coalitieleden representeren. Ten eerste, het "Reference Design" dat een kosteneffectieve verdeling van reductiedoelstellingen binnen de coalitie en een voor de coalitie optimale gezamenlijke hoeveelheid reductie impliceert. Ten tweede, het "Joint Quota" systeem dat veronderstelt dat coalitieleden de netto baten van de coalitie maximaliseren, maar onder voorwaarde. De voorwaarde is dat alle coalitieleden hun emissies moeten reduceren met een quota van hun emissieniveau wanneer geen verdrag wordt getekend. De laatste twee systemen veronderstellen een onderhandelingsproces waar elk coalitielid zijn eigen netto baten maximaliseert gegeven dat elk lid een voorstel voor een quota voor de coalitie moet maken. Ten derde veronderstelt het "Median Quota Proposal" derhalve dat leden akkoord gaan met het mediane (middelste) voorstel. Ten vierde, het "Lowest Quota Proposal" veronderstelt dat leden akkoord gaan met het laagste voorstel. Verder ga ik de invloed na van verhandelbaarheid van de quota tussen coalitieleden.

De resultaten van Hoofdstuk 6 laten zien dat het ontwerp van het quotasysteem kan helpen om de participatie in stabiele verdragen te verbeteren. De uitkomsten geven aan dat elk van de drie quotasystemen resulteren in ten minste één stabiele coalitie. Quota's stimuleren

participatie omdat ze een minder scheve verdeling van reductiedoelstellingen behelzen. Van de drie quotasystemen is het "Lowest Quota Proposal" het meest succesvol (in termen van netto baten). In deze specificatie vind ik dat de coalitie van EU-15, China, India en de rest van de wereld (ROW) stabiel is. Deze coalitie oogst 19% van de potentiële winst van samenwerking. Verder vind ik dat wanneer quota verhandelbaar zijn tussen coalitieleden, het "Median Quota Proposal" tot de meest succesvolle coalitie leidt. In dit geval is een coalitie van de Verenigde Staten (USA), EU-5, China en India stabiel. Deze coalitie oogst 40% van de potentiële winst van samenwerking. Deze resultaten suggereren dat de inefficiëntie van quota's gecompenseerd kunnen worden door een toename van de participatie in en het succes van een IKV.

Gevolgen voor nationale politieke actoren

In Hoofdstuk 7 bestudeer ik de gevolgen van lobbygroepen op de omvang en stabiliteit van IKV's. Ik wijk dus af van de standaard veronderstelling in de literatuur over coalitievorming ten aanzien van het gedrag van overheden. Ik veronderstel dat overheden niet simpelweg de welvaart maximaliseren, maar dat ze de politieke druk van nationale lobbies erbij betrekken. Een overheid baseert zijn beslissing over participatie en niveau van emissiereductie dus zowel op de netto baten van reductie als op de bijdragen van lobbies. Ik veronderstel dat er twee lobbygroepen zijn: industrie en milieubeweging. Ik beschouw twee typen van milieubewegingen, "supergroen" en "groen". Een supergroene lobby is geïnteresseerd in de mondiale effecten van het klimaatbeleid; een groene lobby is alleen geïnteresseerd in de regionale effecten van het beleid. Voor de industrielobby veronderstel ik dat emissiereducties hen altijd schaden, gegeven de bijbehorende reductiekosten.

Mijn onderzoek laat zien dat in afwezigheid van een verdrag, supergroene lobbybijdragen kunnen helpen om emissiereducties te stimuleren, maar alleen wanneer supergroene en industrielobby's worden meegenomen in de analyse. Verder laat ik zin dat volledige samenwerking niet stabiel is en, hoewel partiële samenwerking stabiel is, het weinig bijdraagt aan het terugdringen van klimaatverandering. In dit model hangt het succes van stabiele coalities, in termen van mondiale emissiereducties en netto baten, af van de aanwezigheid van een supergroene of groene lobby. Er is een stabiele coalitie van Japan en EU-15 met supergroene en industrielobby's. Deze stabiele coalitie bereikt weinig in termen van winst van samenwerking: slechts 2% van het potentieel. Wanneer er daarentegen bijdragen van groene en industrielobby's zijn, dan is het reductieniveau van de stabiele coalitie lager dan zonder de lobbybijdragen. Tenslotte laat ik zien dat, in tegenstelling tot de intuïtie, industriebijdragen samen kunnen gaan met participatie in een IKV. Bijvoorbeeld, in de stabiele coalitie ontvangt de EU-15 een bijdrage van de industrie.

Soms wordt beargumenteerd dat er een andere reden kan zijn voor het falen van internationale milieuverdragen, te weten dat kiezers kandidaten steunen wier milieuvoorkeuren verschillen van hun eigen. Kiezers stemmen voor een "minder groene" overheid (d.w.z. delegeren hun beslissingsmacht strategisch) omdat het ze een betere uitgangspositie geeft in de onderhandelingen: lagere reductiedoelstellingen en lagere bijbehorende reductiekosten en de mogelijkheid om een hogere compensatie te ontvangen als overdrachten beschikbaar zouden zijn. In Hoofdstuk 8 bestudeer ik de effecten van dit strategisch gedrag op de effectiviteit en stabiliteit van een IKV. Ik veronderstel dat er verschillende typen politici zijn, die overeenkomen met verschillende houdingen van kiezers ten aanzien van het milieuprobleem. Verder veronderstel ik dat kiezers het type politicus kunnen kiezen dat hen zal vertegenwoordigen in de internationale onderhandelingen. Ik introduceer een model met twee asymmetrische landen, voor een publiek goed en analyseer stabiliteit. Het model laat zien dat wanneer landen als eenlingen handelen, weglekeffecten (d.w.z. het feit dat een toename van emissiereducties in een land wordt tegengegaan door een afname van emissiereductie in het andere land) de belangrijkste bron zijn van strategisch stemgedrag. Verder laat ik zien dat wanneer landen een IKV ondertekenen, kiezers altijd belang hebben bij het strategisch kiezen van hun overheid, maar dat het resulterende verdrag beter is voor het milieu (in termen van niveau van emissiereductie) dan de situatie zonder samenwerking. Ten slotte laat ik zien dat strategisch stemgedrag het succes van een IKV ondermijnt, niet omdat de kiezers een "minder groene" overheid kiezen, maar omdat strategisch stemgedrag de IKV's instabiel maakt.

Uit de analyses die ik in dit proefschrift presenteer blijkt duidelijk dat een IKV ontworpen moet worden voor een substantiële participatie (d.w.z. dat leden de emissies van broeikasgassen wezenlijk reduceren). Een verdrag zou dus klimaatverandering beter aanpakken als het diep is (d.w.z. dat het een significante reductie van emissies bereikt) in plaats van breed (d.w.z. dat het door een groot aantal landen wordt ondertekend). Het ontwerp van een verdrag (ten aanzien van onder andere lidmaatschapsregels en instrumenten zoals verhandelbare rechten en quota's) is in dit perspectief een cruciaal punt. Verder is het belangrijk om een beter inzicht te hebben in de onderliggende politieke processen van onderhandelingen over IKV's. De politieke economie aspecten van deze verdragen zijn essentieel om de onderliggende belangen te begrijpen van landen om samen te werken. Ik benadruk de relevantie van nationale politieke actoren voor de uitkomst van de onderhandelingen. Lobby groepen en kiezers hebben zeker een invloed, direct en indirect, op de condities en succes van een IKV. Verder moet de analyse van het beleidsproces in IKV's rekening houden met het feit dat hun succes gerelateerd is aan de mate waarin de overheid kan worden beïnvloed. Op het internationale niveau hebben lobbygroepen een duidelijke invloed op de uitkomst van de onderhandelingen, terwijl kiezers alleen invloed hebben op het nationale of lokale niveau. Beleidsmakers nemen dit in ogenschouw en handelen dus niet

alleen om de totale welvaart van het land te maximaliseren, maar ook hun private baten (niet alleen gereflecteerd in monetaire termen, maar ook in de vele vormen van politieke steun).

ABOUT THE AUTHOR

Juan Carlos Altamirano Cabrera was born on October 17th, 1974 in Mexico City, Mexico. He obtained in 1999 his B.Sc. in Economics, with honors, at the Universidad Autonoma Metropolitana, Mexico City. He was awarded the Medal to the Academic Achievement for having the highest marks of his class. In 2000 he obtained a scholarship from the Mexican Council for Science and Technology (CONACYT) to study his M.Sc. degree in the United Kingdom. In September 2001 he obtained the M.Sc. degree in Environmental and Natural Resource Economics from the University College London. Between 2001 and 2002 he was a research fellow at the International Institute for Environment and Development (IIED) in London at the Mining, Minerals and Sustainable Development Project. In August 2002 he was appointed as a Ph.D. researcher at the Environmental Economics and Natural Resources Group of Wageningen University. In 2007 he successfully completed the doctoral training program of the Netherlands Network of Economics (NAKE) and of the Socio-Economic and Natural Sciences of the Environment (SENSE) research school. During his Ph.D. appointment he also taught at the Universidad San Carlos at Guatemala City and was consultant for the World Bank.

TRAINING AND SUPERVISION PLAN

Description	Credits[1]
SENSE Ph.D. courses	
Environmental Research in Context	2
Research Context Activity: Organizing the SENSE Ph.D. Colloquium 2003	6
Intertemporal Allocation of Natural Resources and Intergenerational Justice	3
Other Ph.D. Courses	
Microeconomics (NAKE, Tilburg University)	6
Selected Topics on Game Theory (NAKE, Utrecht University)	3
Endogenous Growth Theory (NAKE, Utrecht University)	3
Techniques for Writing and Presenting Scientific Papers	1.2
Other educational activities	
Time Schedule of Ph.D. Project	1
Oral presentations	4
24th Annual Meeting of the European Public Choice Society, 15-18 March, 2004, Berlin, Germany	
13th Annual Conference of the European Association of Environmental and Resource Economists, 25-28 June 2004, Budapest, Hungary	
14th Annual Conference of the European Association of Environmental and Resource Economists, 23-26 June 2005, Bremen, Germany	
26th Annual Meeting of the European Public Choice Society, 20-23 April, 2006, Turku, Finland	
3rd World Congress of Environmental and Resource Economists, 3-7 July 2006, Kyoto, Japan	
Published articles	
Altamirano-Cabrera, J.-C. and M. Finus (2006), Permit Trading and Stability of International Climate Agreements, *Journal of Applied Economics*, IX: 19-47.	2
Total (min. 30 credits)	**31.2**

Notes: 1) A credit represents 28 hours; NAKE stands for Netherlands Network of Economics