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von: Diplom Volkswirt Leo Urban Wangler

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Gutachter:

1. Prof. Dr. Andreas Freytag (Friedrich-Schiller-Universität Jena)
2. Prof. Dr. Werner Güth (Max-Planck-Institut für Ökonomik Jena)
3. Prof. Dr. Gert Tinggaard Svendsen (University of Aarhus)

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"Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons."

(Hardin, 1968, p. 1244)

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Contents

List of Figures

List of Tables

List of Abbreviations

%	percent
$CFCs$	chlorofluorocarbons
CH_4	methane
CO_2	carbon dioxide
$HFCs$	halocarbons
N_2O	nitrous oxide
SF_6	sulfur hexafluoride
€	Euro
ACEA	European Automobile Manufacturers' Association
AGGG	Advisory Group on Greenhouse Gases
APO	American Patent Office
App.	Appendix
AR(1)	first-order autoregressive process
BAU	business as usual
BIO	electricity technology using biomass as input
BIOGAS	electricity technology using biogas as input
BMU	Federal Ministry for the Environment
CCPs	command and control policies
CDM	clean development mechanism
cf.	compare (Latin: confer)
COAL	electricity technology using coal as input
DEPATIS	German Patent Information System
e.g.	for example (Latin: exempli gratia)
EEG	Renewable Energy Sources Act
EPO	European Patent Office
ES	Eurostat
et al.	and others (Latin: et alia)
ETR	economic theory of regulation
EU	European Union
EU-ETS	EU-Emission Trading System

FD	first differences model
FDIs	foreign direct investments
FITs	feed-in tariffs
GAS	electricity technology using fossil gas as input
GDP	gross domestic product
GEO	electricity technology using geothermie as input
GEPs	green electricity producers
GHG	greenhouse gas
GPO	German Patent Office
GSO	German Statistical Office
GTs	green technologies
HA	alternative hypothesis
HO	null hypothesis
ICSU	International Council of Scientific Unions
IEA	International Energy Agency
IEAs	international environmental agreements
INCAPMWh	installed capacity of electricity in megawatt-hours
IPC	international patent classification
IPCC	Intergovernmental Panel of Climate Change
JAMA	Japan Automobile Manufacturers Association
JI	joint implementation
JPO	Japanese Patent Office
KAMA	Korea Automobile Manufacturers Association
KP	Kyoto-Protocol
KWh	kilowatt hours
MPRs	minimum participation rules
NA	not available
NegBin	negative binomial
Nr.	number
NUCLEAR	electricity technology using uranium as input
OECD	Organization for Economic Co-Operation and Development
OLS	ordinary least squares
PCT	patent cooperation treaty
ppm	parts per million
R-sq	corrected coefficient of determination
R&D	research and development
RO	renewable obligation
ROCs	renewable obligation certificates
SEG	Electricity Feed Law

SOLAR	electricity technology using sun radiation as input
SUVs	sports utility vehicles
TPI	theory of public interest
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
US	United States of America
WATER	electricity technology using water as input
WIND	electricity technology using wind as input
WMO	World Meteorological Organization
°C	degree Celsius

List of Symbols

Chapter 2. *Political Economy of the Green Technology Sector*

Theoretical Model:

$*$	notation for equilibrium
^{c}	notation for equilibrium under complete competition
^{ETR}	notation for equilibrium with endogenized political process under ETR
^{TPI}	notation for equilibrium with endogenized political process under TPI
α	weight given to the TPI regime
π	profit
b	positive externality
c	marginal production costs
d	degression rate
i	particular producer of green electricity
j	technology specific industry
k	premium for innovative technologies
n	time period of support
p_j	price of a certain GT
pid	policy induced demand
q	firm specific output
r	opportunity costs of the investment
t	time period (year)
tg	specific time period
v	starting year of operation of a GT
x	quantity of electricity produced with a GT
E	experience parameter
$ENPV$	expected net present value
ES	expected surplus from investment
FIT	feed-in tariff
G	welfare of the incumbent government
GEP	green electricity producer
MR	marginal revenue

N	total number of firms within an industry
NE	demand
R	revenue
Q	total output produced in the industry
T	base year when the EEG was established
V	political support
W	welfare

Chapter 3. *Renewables and Innovations*

Econometric Model:

$**$	level of significance $\leq 1\%$
$*$	level of significance $\leq 5\%$
$+$	level of significance $\leq 10\%$
β	estimated coefficient
β_o	intercept
ν	error component specific to the negative binomial model
σ	standard deviation
σ^2	variance
φ	intensity parameter
c	group specific error component
$f()$	function
i	technologies/industries
n	total number of technologies
t	time period (year)
$t-1$	one year time lag
$t-2$	two year time lag
$t-3$	three year time lag
u	idiosyncratic error component
x	vector with independent variables
y	vector with dependent variables
z	control variables
Δ	first differences
A	vector with non-renewable energy technologies
$APAT$	vector with all patents filed in all IPC classes (in Germany)
B	vector with green technologies
$CPIE$	vector with the consumer price index for electricity (in PPP)
E	expected value

ELC	vector with the electricity consumption per capita
$INCAP$	vector with installed capacity of green technologies (in Germany)
P	probability to innovate
PAT	vector with patent applications in different GT industries
$RELPAT$	vector with the ratio between PAT and APAT
RuD	vector with public expenditures on research and development
S	size of the market
T	time span
X	vector of all explanatory variables

Chapter 4. *Strategic Trade Policy as Response to Climate Change*

Theoretical Framework:

$*$	notation for equilibrium
π	profit on the industry level
c^{pr}	marginal production costs
c_l	costs of lobbying
e	expectations
i	initial equilibrium
j	technology specific industry
$n1$	new equilibrium without exports
$n2$	new equilibrium with exports
p	price of a certain GT
pid	policy induced demand
q	output produced on the industry level
t	continuous time
ttr	technology transfer
y	value added to the national GDP by the GT sector with exports
A	size of the GT market
D_N	demand for a certain GT j without policy induced demand
D_S	demand for a certain GT j with policy induced demand
F	foreign country
H	home country
I	another third country
R	response function
Y	national GDP

Econometric Model:

$***$	level of significance $\leq 1\%$
$**$	level of significance $\leq 5\%$
$*$	level of significance $\leq 10\%$
α	group specific error component
β	estimated coefficient
β_o	intercept
ϵ	idiosyncratic error component
ν	error component specific to the negative binomial model
σ	standard deviation
σ^2	variance
φ	intensity parameter
i	technologies
lag	one year time lag
$lag2$	two year time lag
r	regions
t	time period (year)
$APATENT$	vector with all patent applications in the specific country
$CPIE$	vector with the consumer price index for electricity (PPP)
E	expected value
ELC	vector with the electricity consumption per capita
F	foreign country
H	home country
HF	expected revenues that H expects from F
$INCAP$	vector with installed capacity of green technologies (in Germany)
$PATENT$	vector with patent applications in F with priority in H
RuD	vector with public expenditures on research and development
X	vector of all explanatory variables

Chapter 5. *Is Regulation by Milestones Efficiency Enhancing*

Theoretical Part:

α	productivity of the public good
c	individual contributions
e	initial endowment
i	one single player
j	other players within the group
p	probability to lose total endowment
t	time period
B	baseline scenario

C^2	total contributions to the public good after two rounds
C^4	total contributions to the public good after four rounds
C^6	total contributions to the public good after six rounds
C_2	milestone in round two
C_4	milestone in round four
C_6	milestone in round six
E^*	symmetric and strict equilibria (maximum contributions to the public good)
E^0	symmetric and strict equilibria (zero contributions to the public good)
H	strict milestones
L	less strict milestones
P	probability scenario
S	status quo scenario
U	payoff

Econometric Model:

$***$	level of significance $\leq 1\%$
$**$	level of significance $\leq 5\%$
$*$	level of significance $\leq 10\%$
$cons$	intercept
Lag	one year time lag
N	total number of observations (without restart)
$N_{Indiv.}$	number of observation on the individual level
R_O^2	overall corrected coefficient of determination
s_{BH}	dummy for treatment BH
s_{BL}	dummy for treatment BL
s_{PH}	dummy for treatment PH
s_{PL}	dummy for treatment PL
s_{SH}	dummy for treatment SH
s_{SL}	dummy for treatment SL

Chapter 6. *Minimum Participation Rules with Heterogeneous Countries*

$\emptyset$	empty set
$\bar{q}$	MPR
e	unabated/baseline emissions
i, j	single player or coalition
k	another single player
q	level of pollution abatement
v	payoffs of one single country

$\mathcal{S}$	set of stable coalitions if no MPR is implemented
B	abatement benefits
C	abatement costs
E	payoff if no MPR is implemented
H	strict
L	less strict
N	set of countries
S	signatory countries (coalition)
$V_i(S)$	country i's payoff under coalition
$V_i(S_{-i})$	outside option payoff of player i
$V_{S_{+j}}(S_{+j})$	coalition payoff for an enlarged coalition

Chapter 7. *Environmental Policy and the European Automotive Industry*

emission	average CO_2 emissions per 100km
M	vehicle mass

Deutsche Zusammenfassung

Die vorliegende Arbeit beschäftigt sich modelltheoretisch, empirisch und experimentell mit dem Thema der Klimapolitik aus einer politökonomischen Perspektive. Der Ansatz der Neuen Politischen Ökonomie versucht, die ökonomischen Modelle um den politischen Prozess zu erweitern. Die Motivation für dieses Vorgehen steht in einem engen Zusammenhang mit der Erkenntnis, dass es unzureichend ist, die ökonomische Analyse auf Probleme des Marktversagens zu reduzieren. Neben Marktversagen können durch den politischen Prozess Probleme generiert werden (sog. Politikversagen).

Im Rahmen einer positiven Analyse kann die Neue Politische Ökonomie Erklärungsansätze liefern, die eng mit der Fragestellung verknüpft sind, warum bekannte Ineffizienzen den politischen Prozess überdauern. Dieses Problem lässt sich in vielen Fällen durch Partikularinteressen erklären. Aus einer normativen Perspektive lassen sich die resultierenden Erkenntnisse für Politikempfehlungen heranziehen. Vordergründig sind dabei jene Handlungsalternativen (zum Teil auch Handlungsbeschränkungen z.B. auf konstitutioneller Ebene) die es dem Staat ermöglichen seine Handlungen möglichst unabhängig von Partikularinteressen durchzuführen.

In der vorliegenden Arbeit werden verschiedene Fragestellungen analysiert. Da es sich bei dem Thema um ein sehr weites Forschungsfeld handelt, liegen die Arbeiten teilweise recht weit auseinander; gewähren aber in ihrer Gesamtheit einen umfangreichen Einblick in das zugrunde gelegte Thema. Durch die Fülle an Veröffentlichungen und die Breite des Spektrums war es nicht möglich, alle veröffentlichten Quellen zur Klimapolitik in die Arbeit zu integrieren. Für die vorliegende Arbeit sind die folgenden Fragestellungen von besonderem Interesse:

- Was ist unter der politischen Ökonomik der Klimapolitik zu verstehen?
- Inwiefern ermöglicht das implementierte System zur Förderung von erneuerbaren Energien (Erneuerbare-Energien-Gesetz (EEG)) eine effiziente Ausbreitung der Technologie?
- Besteht ein Zusammenhang zwischen Innovationen und der Diffusion von erneuerbaren Energien (GTs)?

- Warum haben Regierungen Anreize, in recht großem Umfang in erneuerbare Energien zu investieren, obwohl andere Länder ein Trittbrettfahrerverhalten offenbaren?
- Inwiefern ermöglicht die internationale Politikkoordination in Form von internationalen Umweltabkommen (IEAs) das Erreichen langfristiger Ziele?
- Welche Rolle spielen Institutionen wie sog. "'Mindestbeteiligungsregeln"' (MPRs) zur Steigerung der Effizienz von internationalen Umweltabkommen?
- Wie beeinflusst der Abstimmungsmechanismus die Anwendung bestimmter Politikinstrumente?
- Welche Lehren lassen sich aus den einzelnen Beträgen für die Klimapolitik ableiten?

Das einleitende erste Kapitel bildet die Grundlage für die Arbeiten der nachstehenden Kapitel. Die Problematik des anthropogenen Klimawandels wird aus der Sichtweise der Klimaforschung wiedergegeben. Die gegenwärtigen Forschungsergebnisse bilden die Grundlage für die ökonomischen Modelle. Diese versuchen Kosten- und Nutzenaspekte des Klimawandels zu evaluieren. Die Folgen des anthropogenen Klimawandels lassen sich als Teil des weltwirtschaftlichen Strukturwandels verstehen. Wie sich der Strukturwandel vollzieht, ist mitunter auch davon abhängig, welche wirtschaftspolitischen Instrumente angewandt werden, um den Folgen des Klimawandels zu begegnen. Im Anschluss an die Darstellung der verschiedenen Handlungsalternativen (Politikinstrumente zur Bekämpfung des Marktversagens) wird das Thema in einen politökonomischen Rahmen gebettet. Es folgt ein Überblick über die einzelnen Kapitel.

In Kapitel zwei steht der Sektor für erneuerbare Energien in Deutschland im Vordergrund der Betrachtung. In einem ersten Schritt werden institutionelle Reformen analysiert, die die Verbreitung von GTs bedingen. Auch die Kostenargumente sind Gegenstand der Analyse. In einem zweiten Schritt wird anhand eines theoretischen Modells der institutionelle Regelrahmen aus Effizienzgesichtspunkten analysiert. Anhand des Modells lässt sich aufzeigen, dass von der Ausgestaltung des Regelrahmens Kostenineffizienzen zu erwarten sind. Ineffizienzen werden durch die politische Gewichtung der technologiespezifischen Interessengruppen verursacht. Ein Ergebnis des Modells ist es, dass relativ hohe Grenzkosten eine suboptimal hohe Diffusion der GT implizieren, wohingegen relativ niedrige Grenzkosten mit einem zu niedrigen Angebot einhergehen.

Das dritte Kapitel befasst sich mit dem Strukturwandel im Energiesektor. Dabei stellt sich die Frage, inwiefern die politikinduzierte Nachfrage nach erneuerbaren Energien Innovationen hervorgebracht hat. Die ökonometrische Analyse kommt zu dem Ergebnis, dass eine Veränderung der Marktgröße sowie die Marktgröße selbst (beides sind Proxy für die Nachfrage) positiv mit Patentanmeldungen (als Proxy für Innovationen) korreliert sind. Zusätzlich wird zwischen dem Stromeinspeisegesetz und Erneuerbare-Energien-Gesetz auf einen Strukturbruch getestet.

Die Effekte internationaler Abkommen auf die nationale Politik und deren Entscheidungsträger bildet den Schwerpunkt in Kapitel vier. In diesem Zusammenhang spielen internationale wettbewerbspolitische Aspekte eine wichtige Rolle. Mit Hilfe eines Erklärungsansatzes der strategischen Handelspolitik wird die globale Perspektive des Kyoto-Protokolls mit den energie- und umweltpolitischen Maßnahmen auf nationaler Ebene (mit einem Fokus auf Deutschland) verknüpft. Der theoretische Rahmen kann den vermeintlichen Widerspruch auflösen, dass manche Länder relativ hohe Beiträge zum Klimaschutz leisten, obwohl andere Länder trittbrettfahren. Ausschlaggebende Größe sind dabei die zukünftigen Exporterwartungen. Dies wird mit Hilfe eines ökonometrischen Modells überprüft. Als Proxy für zukünftige Erwartungen dienen Patentanmeldungen im Ausland (mit Deutschland als Prioritätsland).

Das fünfte Kapitel versucht experimentell zu testen, inwiefern die Implementierung von Meilensteinen helfen kann, bestimmte (langfristige) Ziele zu erreichen. Dabei führt das Nichterreichen eines Meilensteins dazu, dass mit einer gewissen Wahrscheinlichkeit das vorhandene Vermögen zerstört wird. Inwiefern Meilensteine die Effizienz erhöhen, wird anhand hoher Anforderungen und niedriger Anforderungen untersucht. Das Experiment fußt auf einem 2X3 Faktor Design. In einem ersten Schritt werden die Ergebnisparameter des Öffentlichen-Güter-Spiels verändert und in einem zweiten Schritt die Wahrscheinlichkeit, durch welche der Verlust des vorhandenen Vermögens bedingt wird.

In Kapitel sechs werden Mindestbeteiligungsregeln (MPRs) theoretisch analysiert. Diese sind in die meisten IEAs integriert. Es stellt sich die Frage, inwiefern MPRs internationale Entscheidungsprozesse beeinflussen. Unter einer MPR wird ein Abkommen gesetzlich bindend, wenn ein bestimmter Grenzwert in Bezug auf Mitgliederzahl oder Beitrag erreicht wird. Die theoretische Grundlage liefert ein Kartellspiel (mit offener Mitgliedschaft) unter der Annahme heterogener Länder. Die Wahl der Mindestbeteiligungsregel ist ein endogener Entscheidungsparameter in dem zugrundegelegten Spiel.

Im siebten Kapitel stehen erneut Fragen zur Effektivität und Effizienz bestimmter klimapolitischer Maßnahmen im Vordergrund. Diese lassen sich anhand einer vorgeschlagenen Regulierungspolitik der Automobilindustrie von Seiten der Europäischen Union analysieren. Die Diskussion der wirtschaftspolitischen Maßnahmen kann demonstrieren, dass unterschiedliche Entscheidungsmechanismen für unterschiedliche Politikinstrumente Verzerrungen hervorrufen. Der ausgearbeitete Vorschlag führt zu Wettbewerbsverzerrungen und beschränkt die Konsumentensouveränität. Die Diskussion verweist auf zwei wichtige Gesichtspunkte: Erstens, im Bezug auf privaten Personenverkehr sind marktbasierte Instrumente, die auf der Nachfrageseite angewandt werden (Steuern oder Zertifikate), von Vorteil gegenüber marktbasierten Instrumenten, die Angebotsseitig implementiert werden. Zweitens, die Anwendung verschiedener Wahlregeln für unterschiedliche Politikinstrumente führt zu Verzerrungen bei politischen Entscheidungen.

Das achte Kapitel widmet sich den Schlussfolgerungen, den zentralen Resultaten der verschiedenen Kapitel und zusätzlichen Politikimplikationen.

Chapter 1

On the Political Economy of Climate Policy

1.1 Introduction

The problem of climate change is part of the current policy debate. Even though climate change is not perceived as being a new problem, and has its beginning in the 19th century, it is an issue that seems to be gaining more and more attention. One reason for this can be found in increasing empirical evidence from natural science indicating: (1) the problem of climate change is severe, and (2), it is of an anthropogenic nature.

However, perceptions of the climate change problem differ among citizens, organizations, sectors of society and countries. One reason might be that different groups within a society (e.g. different industries) are differently affected by the climate change problem and its related abatement costs. The same is true if one looks at countries instead of industries. It can further be observed that also among scientists the problems occurring from climate change are discussed controversially. These observations are related to the fact that the climate change problem is a complex one. Beliefs are still important in order to make a clear statement about its impact.

Beside the uncertainties about how to adequately react on climate change related problems, it can be observed that policies attempt increasingly to implement measures directed toward sustainablity.[1] Therefore, the current increase in the relevance of the climate change problem is also affected by the formation of *new* interest groups that mainly benefit from climate abatement policies.

It is the aim of this doctoral thesis to contribute to a better understanding of how structural change in the economic system changes (economic) opportunities and, hence,

[1]The United Nations (UN) Commission on Sustainable Development has, in its Brundtland report, defined sustainable development as follows: *Sustainable development is a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"* (Hauff, 1987, p. 46).

the related interests. In order to do so the economic models have to be extended by the political process. This is mainly done from a positive perspective. However, it is also the objective to make use of the results from the different studies to derive lessons for policy making.

This introductory chapter is aimed at establishing a basis for the understanding of the research contributions in subsequent chapters. The chapter is structured as follows. In section 1.2 current studies about the climate change problem are reviewed. This is done from a natural science perspective before the topic is approached from an economic perspective. In section 1.3 structural change is described in more detail, the main argument being that climate change causes structural change independent of policy making. In case that policy implements measures aimed to reduce the related burdens policy influences, the climate change related structural change. What follows is an overview of the available policy instruments that can be applied to internalize externalities. Related advantages and problems are also part of the discussion. In section 1.4 economic structural change is combined with the topic of political economy. The choice of policy instruments is discussed from the perspective of different groups within society that are able to influence political decisions. At the end of section 1.4 a short overview of the following chapters will be given.

1.2 Problems Related to Climate Change

1.2.1 Climate Problem and Awareness

From a natural science perspective, the problem of climate change is related to the fact that greenhouse gases (GHGs),[2] which are concentrated within the atmosphere, have an impact on the climate. Greenhouse gases, like carbon dioxide, absorb radiation coming from the earth and partly reflect it back. Estimates predict that without any atmosphere the temperature on earth would be minus 18°C on global average. The concentration of greenhouse gases in the atmosphere is held responsible that the average temperature is 15°C on average (Latif, 2010, p. 4).

From the time of the industrial revolution onwards, there has been a steady rise in the concentration of greenhouse gases in the atmosphere. This growth in GHGs is of an anthropogenic nature. It is stated that the stock of CO_2 has increased by 40 percent, the stock of CH_4 has increased by 120 percent and the stock of N_2O by 10 percent. Additionally, there was an increase in $HFCs$ which are now declining – due to successful policy measures implemented as a result of the Protocol of Montreal. The major concern

[2]Different gases are labeled as greenhouse gases. Water vapor, for instance, is also labeled as a greenhouse gas. In the actual debate on the climate change problem six major gases are of importance: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), halocarbons ($HFCs$) and chlorofluorocarbons ($CFCs$).

is with the increase in concentration of CO_2 in the atmosphere, as it is responsible for about two third of the increase in temperature (Latif, 2010, p. 4).

The phenomenon of the so-called greenhouse effect became known in the 19th century. In this respect, it is important to mention the French physicist Fourier, who compared the influence of the atmosphere on the climate to the heating of a closed space beneath a pane of glass (Fourier, 1827). A considerable number of experiments on the radiative properties of greenhouse gases, like water vapor and CO_2, were conducted by John Tyndall, a British physicist. He found out that "perfectly colorless and invisible gases and vapors" can absorb and emit radiant heat (Tyndall, 1861). Toward the end of the 19th century and at the beginning of the 20th century the first theories were postulated linking changes in the climate to changes in CO_2 concentration in the atmosphere (e.g. Arrhenius, 1903).

The first theories about the anthropogenic nature of climate change lost significance when Wood (1909) found that the relationship was not comparable to the heating within glasshouses. In glasshouses most of the heat is generated through a lack of convection and advection rather than emitting and re-emitting longwave radiation through the glass. It could be shown that the radiative component generating heat within glasshouses accounts only for about 20 percent of the heat. The anthropogenic nature of climate change was further diminished in importance when Milankovitch (1930) established a different model explaining the nature of climate change. Changes in temperature were explained by changes in the distance between the sun and the earth due to variations in the orbit.

However, despite these findings, further research was conducted (Callendar, 1938; Scherhag, 1939). New dynamics entered into the debate with models computing the impact of a steady increase in emissions for the long-run (Plass, 1956; Callendar, 1961). Plass (1956) concluded that a doubling in CO_2 concentration would increase the average temperature by 3.6°C. A major critique came from Kaplan (1960) and Möller (1963). Kaplan (1960) made the point that the water content of the atmosphere was not integrated into the model. Möller (1963) was able to show that the predicted radiation effect is very sensitive to changes in model assumptions, like the implementation of humidity and cloudiness.

Today, different models have been established to compute future changes in the climate. By comparing the different models it can clearly be observed that the predicted outcomes differ.[3] This variation can be used as a measure of the uncertainty related to climate change models (Räisänen, 2007). However, it has to be kept in mind that this method very likely underestimates the related uncertainty, the reason being that the

[3] For a model intercomparison see also: http://www.clivar.org/organization/aamp/publications/mips.htm

biases of the individual models partly cancel each other when the multimodal mean is calculated (Räisänen, 2007, p. 6).

Previous modeling mistakes, as well as the still existing uncertainty as to the model outcomes, have resulted in criticism that the predictions are too unreliable to serve as background for public policy. However, this assessment is far too easy, as the debates, as such, did lead to steady improvements in climate models. The adaption of the models over time also did not change the general message that an increase in CO_2 emissions will increase the global mean temperature. It seems more convincing to interpret modeling predictions in the direction that they estimate future developments of the climate based on the current knowledge (important determinants are available data and computing capacity). The models somehow help to understand the impact of current decisions for the well-being of future generations. This is one reason why it seems to be wise to take the model predictions seriously. From a political economy perspective, one should expect that even under certainty policy-makers are not able to react in an optimal manner to the climate change problem. In general, however, the related uncertainty very likely aggravates this problem instead of reducing it.

1.2.2 Climate Research and Climate Policy

Research in the field of climate change benefited notably through the research conducted by the World Meteorological Organization (WMO). It created a global database and tried systematically to foster the improvement of climate models. With the development of models able to forecast future developments of the climate, the public interest in the topic of climate change increased remarkably. Large international conferences received more and more public attention (for an overview compare Sardemann, 1997).

In 1961 there was a symposium organized by the United Nations Educational, Scientific and Cultural Organization (UNESCO) together with the WMO on Changes of Climate where the impact of changes in CO_2 on the climate were part of the discussion. An additional outcome was the establishment of a working group trying to improve the database and methodology for climate modeling. Two years later (1963), a conference about the "Implications of Rising Carbon Dioxide Content of the Atmosphere" took place. Participants of the conference agreed that an increase of CO_2 concentration of 100 percent can generate an increase in temperature of about 3.8°C.

The Stockholm conference on the Human Environment (1972) can be seen as a starting point for climate policy making (Linnér and Jacob, 2005). The international community agreed that an increase in temperature of 2.0°C would likely cause melting of the polar ice caps, rising sea levels and, as a result, a loss of land areas. There was, in addition, the fear that the world might also experience global cooling due to particle emissions. As a result, the international community agreed to "be mindful of activities in which there is an appreciable risk of effects on climate, [...] [to] carefully evaluate the likelihood and magnitude of climatic effects [...] [and to] consult fully other interested states when activities carrying a risk of such effects are being contemplated or implemented" (UN, 1972). The first world climate conference, labeled as a "conference of experts on climate and mankind", took place in Geneva in 1979. It was initiated by the WMO, the United Nations Environment Programme (UNEP), and the International Council of Scientific Unions (ICSU). It concluded that climate change is a serious problem that asks for political action in order to counter its consequences for social and economic development (Linnér and Jacob, 2005, p. 405).

In 1985, a workshop on climate change took place in Villach (Austria). Participants of this workshop made clear statements about the anthropogenic nature of climate change due to the increase in concentration of CO_2 and other greenhouse gases within the atmosphere (WMO, 1986). An Advisory Group on Greenhouse Gases (AGGG) was established, which can be seen as a prototype for the Intergovernmental Panel of Climate Change (IPCC) founded in 1988.

The IPCC was initiated by the WMO and UNEP. Its task is to inform about actual knowledge on anthropogenic climate change. In order to do so, the IPCC evaluates results from current research. The results are then published as assessment reports. They serve as background information for the climate conventions. The IPCC consists of three different working groups providing expertise in the following fields:

1. The science of climate change;

2. Impacts, adaption and mitigation;

3. Socioeconomic and cross-cutting issues.

The IPCC itself states that "because of its scientific and intergovernmental nature, [it] [...] embodies a unique opportunity to provide rigorous and balanced scientific information to decision makers. By endorsing the IPCC reports, governments acknowledge the authority of their scientific content. The work of the organization is therefore policy-relevant and yet policy-neutral, never policy-prescriptive" (IPCC, 2010). This seems to be important if one keeps in mind that the assessment reports are highly influential as they serve as the basis to formulate the climate conventions.

1.2.3 Climate Predictions

It could be observed that during the last century the world temperature increased on average by about 0.8°C (IPCC, 2008). As a consequence Arctic ice decreased in the last 30 years by about 30 percent and during the century the see level increased by about 20 centimeter. As previously explained, parts of these changes are not anthropogenic, but rather than internal. However, current studies claim that the internal increase in temperature is only responsible for about 25 percent of the change in temperature. At least 50 percent of the remaining change in temperature seems to be related to an increase in GHG emissions (Latif, 2010, p. 6).

The complexity of the climate carries with it the threat that changes happen rather slowly before they pass a certain threshold causing catastrophic consequences. This is often referred to as "irreversible climate change" (Solomon et al., 2009, p. 1704). The thresholds as such are difficult to estimate. However, even if one were able to stabilize current CO_2 emissions the stock of CO_2 within the atmosphere will still increase for approximately the next 100 years, as most of the greenhouse gases remain in the atmosphere (persistency of the climate) for several decades. This shows that even under a strict climate regime stabilizing the emissions of greenhouse gases does not cut the risk that there is likely to be an increase in catastrophic climate events. Two major lessons can be drawn from combining persistency with irreversibility:

1. The climate might still undergo change even if climate policy is successful;
2. Due to the complexity of the climate, surpassing certain thresholds might destabilize the whole climate system causing catastrophic consequences.

The IPCC assumes that without effective measures to limit GHG emissions the global mean temperature in 2100 will have increased by 4°C. Some predictions go even further and estimate an increase of 6°C for the business as usual (BAU) scenario (IPCC, 2008). It is expected that extreme weather events will increase and that there will be a rise in sea level by at least one meter. The Arctic ice will melt rapidly (it may already be free of ice by the middle of this century), similar to mountain glaciers. This will also affect the availability of drinking water in these areas, leading to dramatic results. As a further consequence, it might also be that sea currents change or disappear, causing drastic changes in temperature in the affected regions. Another fear is that an increase in mean temperature can cause the disappearance of permafrost, freeing additional CO_2 and aggravating the problem of climate change due to an increase in CO_2 concentration within the atmosphere (Latif, 2010, p. 7).

In order to keep the risks of climate change at a level that remains manageable, most scientists agree that the increase in temperature should not exceed a maximum of 2°C, compared to the pre-industrial time (which implies that the concentration of CO_2 in the atmosphere should not exceed a level of 450ppm). In order to achieve this goal, emissions of GHGs have to decline by 50 percent by 2050 and by about 80 percent by 2100 (Latif, 2010, p. 11). The empirical evidence, however, shows that emissions have increased since 1990 (from 1990 until 2008 by about 40 percent).

1.2.4 Economic Predictions

The previous results serve as a background for economic research in the field of climate change (a survey is given by Aldy et al., 2011). The emissions of CO_2 are supposed to generate negative externalities. According to Baumol and Oates (1988) two conditions have to be fulfilled to speak of an externality: First, "an externality is present whenever some individual's (say A's) utility or production relationships include real [...] variables, whose values are chosen by others [...] without particular attention to the effects on A's welfare". Second, "the decision maker, whose activity affects others' utility levels or enters their production functions, does not [..] pay in compensation for this activity an amount equal in value to the resulting [..] costs to others" (Baumol and Oates, 1988, p. 17). Indeed, this definition can be related to anthropogenic climate change. This is one reason why the economic interest in the problem of climate change has increased over time. Of particular interest are the welfare effects. The major results from the related literature are summarized in table 1.1.

Table 1.1 shows selected characteristics of economic studies on the impact of climate change. The first column is dedicated to the underlying assumption on the long-term increase of the global mean temperature. The forecasts on the development of the temperature in general build on the assumption that the concentration of greenhouse gases within the atmosphere doubles (compared to the pre-industrial time). The second column of table 1.1 shows the estimated impact on welfare in the future expressed in changes of gross domestic product (GDP). The third column summarizes the predicted change in GDP in those regions which are assumed to be most affected by climate change. The fourth column identifies those regions. In the fifth and sixth column the same information is given for those regions which are supposed to be least hit by climate change and which benefit in most of the cases.

Studies coping with the economic effects of climate change have to make assumptions about the future development of the climate. These assumptions imply predictions on future emissions, sea level rise, changes in rainfall and storminess to mention only a few of them. In a second step the changes have to be translated into economic consequences (Tol, 2010, p. 14). Two approaches can be distinguished in climate modeling, the enumerative approach and the statistical approach.

Studies by Fankhauser (1995), Nordhaus (1994b) and Tol (1995, 2002) can be related to the enumerative approach. This means that the estimates of the physical effects of climate change are obtained from natural science papers. They serve as a starting point to make predictions on health of the population or the general impact climate change has on a certain region. The physical impacts are then evaluated with prices and added up in a further step. In order to make the costs comparable with current values, extrapolated costs have to be discounted. The discount rate is one variable which is highly under

TABLE 1.1: Estimated welfare loss due to climate change (as equivalent income loss in percent, estimates of the uncertainty are given in bracket as standard deviations or 95 percent confidence intervals)

Study	Warming (°C)	Impact (%GDP)	Worst-off region (%GDP)	(Name)	Best-off region (%GDP)	(Name)
(Nordhaus, 1994b)	3.0	-1.3	–	–	–	–
(Nordhaus, 1994a)	3.0	-4.8 (-30.0 to 0.0)	–	–	–	–
(Fankhauser, 1995)	2.5	-1.4	-4.7	China	-0.7	Eastern Europe and the former Soviet Union
(Tol, 1995)	2.5	-1.9	-8.7	Africa	-0.3	Eastern Europe and the former Soviet Union
(Nordhaus and Yang, 1996)	2.5	-1.7	-2.1	Developing countries	0.9	Former Soviet Union
(Plambeck and Hope, 1996)	2.5	-2.5 (-0.5 to -11.4)	-8.6 (-0.6 to -39.5)	Asia (w/o China)	0.0 (-0.2 to 1.5)	Eastern Europe and the former Soviet Union
(Mendelsohn et al., 2000)	2.5	0.0[b] 0.1[b]	−3.6[b] −0.5[b]	Africa	4.0[b] 1.7[b]	Eastern Europe and the former Soviet Union
(Tol, 2002)	1.0	2.3 (1.0)	-4.1 (2.2)	Africa	3.7 (2.2)	Western Europe
(Nordhaus and Boyer, 2003)	2.5	-1.5	-3.9	Africa	0.7	Russia
(Maddison, 2003)[a,d,e]	2.5	-0.1	-14.6	South America	2.5	Western Europe
(Rehdanz and Maddison, 2005)[a,c]	1.0	-0.4	-23.5	Sub-Saharan Africa	12.9	South Asia
(Hope, 2006)[a,f]	2.5	0.9 (-0.2 to 2.7)	-2.6 (-0.4 to 10.0)	Asia (w/o China)	0.3 (-2.5 to 0.5)	Eastern Europe and the former Soviet Union
(Nordhaus, 2006)	2.5	-0.9 (0.1)	–	–	–	–

[a] The global results were aggregated.
[b] The top estimate is for the "experimental" model, the bottom estimate for the "cross-sectional" model.
[c] The study Mendelsohn et al. (2000) does only include market impacts.
[d] The national results were aggregated to regions for reasons of comparability.
[e] The study of Maddison (2003) only considers market impacts on households.
[f] The numbers used by Hope (2006) are averages of previous estimates by Frankhauser and Tol (1996); Stern (2007) adopts on the work of Hope (2006).

Own illustration following Tol (2010).

debate (Nordhaus, 2007; Weitzman, 2007). In general it can be said that translation of the climate effects into monetary terms relies on a cost benefit approach. Studies on the evaluation of mortality risks or the future development of agricultural prices serve here as a benchmark for the estimated costs (Tol, 2010). One problem seems to be that two very complex methods are combined together. If there are biases in the models from natural science then they add up with possible biases within the economic models.

The study of Mendelsohn et al. (2000) can be related to a statistical approach. This approach tries to estimate welfare effects (based on cross-sectional country specific data) by using observed variations in prices and expenditures. They are than extrapolated in order to make predictions on future cost developments. In this case also the choice of the interest rate has important effects on the results. One critical assumption of the statistical approach is that it assumes the observed variation to be constant over time. As the climate is very complex and crossing certain thresholds may change the behavior of the climate (Solomon et al., 2009), this assumption seems to be too restrictive. The statistical approach is also used by Maddison (2003) and Nordhaus (2006). Maddison (2003) uses the estimation approach to look at country specific patterns of aggregated household consumption while Nordhaus (2006) uses empirical estimates of the aggregated impacts of the climate on income levels across the world. Again, the underlying assumption that the observed spatial patterns remain constant over time might be too restrictive (Tol, 2010). A general critique that is related to all cost benefit approaches is the use of the GDP as a variable measuring welfare effects. An approach trying to overcome the related problem is to use happiness as a determinant for the cost benefit analysis (Maddison, 2003).

It can be seen that both described approaches have shortcomings and advantages. The major advantage of the enumerative approach seems to be that they use the models from natural science as their foundation. But this might be problematic as the models from natural science might already be biased. One of the most critical issues is related to extrapolation as it can cause substantial biases within the estimates (Brouwer and Spaninks, 1999). Further difficulties arise with the assumptions made about adaptation. Statistical studies have the advantage that they take real world differences instead of extrapolated differences as the basis for calculations. But there is also a problem related to causality as regional differences are mainly explained by climate differences. It can further be questioned whether statistical methods are able to cope with the complexity and non-linearity of the climate.[4] Another critical issue is that important aspects of the climate, like sea level rise, do not have much spatial variation (Tol, 2010, p. 17).

As shown in table 1.1 economic models also differ in their predictions about future developments. Nevertheless, the presented models show similarities in some points (Tol, 2010).

[4]This critique, however, also holds for different model approaches.

1. The welfare effects related to a doubling of atmospheric concentration of GHG emissions are relatively small (measured in changes of GDP). If it is estimated to be equivalent to the one year growth rate of the global economy then over a longer time period the effect of climate change on changes in GDP seems to be unimportant. This is one reason why policy recommendations based on these models very likely come to the result that rather slight than strict GHG reductions should be undertaken.

2. The studies done after 1995 find that climate change generates welfare losses as well as welfare gains and that a slight increase in temperature seem to be accompanied by welfare increases.[5]

3. Even though climate change seems to generate welfare gains in certain regions, the related welfare losses in other regions are predicted to be higher. Most of the studies relate the welfare losses to the low income countries.

4. The estimates of economic effects of climate change seem to get less pessimistic over time.[6]

5. Uncertainty related to economic models on climate change is vast and right-skewed. If one takes the example of a model which assumes average warming in temperature of 2.5°C, then the average welfare effect of climate change is about −0.7 percent of GDP (with a standard deviation of 1.2 percent).

1.2.5 Critical Assessment

These general results arise from the fact that most of the models are based on similar model assumptions and databases. Some model assumptions are very strict, which also limits the explanatory power of the models. The following example shall make this more clear. If one keeps in mind that global mean temperature under the BAU scenario may well exceed the 3°C benchmark of the models (e.g. to 5°C) then forecasts might result in much higher economic costs. The predicted welfare effects are only reliable if policy is able to stabilize greenhouse gases at a level which does not allow an increase in temperature on a level that exceeds the benchmark of the models. The empirical evidence so far seems to point more in the direction that it will be very difficult to approach emission targets that allow to stabilize the climate below these defined thresholds (Latif, 2010, p. 11).

[5]However, one of the most critical issues in the context of climate change is that there are no studies estimating an increase of more than 3°C. This assumption is very optimistic as the studies from natural science predict that such changes are possible (see subsection 1.2.3).

[6]One major reason for this is the implementation of adaptation capacity within the models which somehow moderates the estimation outcomes of the first models.

Another discussion results from the observation that most damage from climate change is predicted to happen in developing countries. This implies that developing countries are highly dependent on the climate policy implemented in industrialized countries. But the problem is also intertemporal, as the benefits from climate change abatement policies will mainly effect future generations (again, in particular, in poor countries) (Schelling, 2000). Based on this observation one can argue that adaptation policies might be better suited for developing countries than the reduction of CO_2 emissions. This raises the question about the right adaptation policies (Schelling, 2000; Lomborg, 2006). Another aspect is that one can expect that aid policy in the near future will more and more be diverted to the climate (Michaelowa and Michaelowa, 2007).

There are studies which try to evaluate the impact that strict emission reduction within developed countries has on developing countries (Tol and Dowlatabadi, 2001; Tol and Yohe, 2006). These studies come to the result that the reduced growth of developed countries (due to emission reductions) also effects developing countries negatively (e.g. due to a slowdown in exports). As the economic slowdown also reduces the provision of primary health care in developing countries it might be a better strategy to focus on development policy rather than CO_2 emission reductions. Tol (2005) comes to a similar result. He shows that economic development is a cheaper way of reducing climate change induced malaria, compared to reducing CO_2 emissions. However, this argument cannot be translated to coastal protection (Tol, 2007). Further, there is the argument that high-income countries may find it cheaper to pay compensation to poorer countries instead of investing in expensive abatement technologies. It is likely that the payment, as such, will be given in form of technical and financial assistance for adaptation (Paavola and Adger, 2006).

So far, the discussion has shown that the climate change problem is very complex and it is difficult to derive optimal policy recommendations from cost benefit analysis. Another result is that the climate change problem requires international solutions. Further, it turns out that there is no clear consensus on how to optimally distribute climate change policies among industrialized (with a focus on abatement policy) and developing countries (with a focus on adaptation policy). From an economic point of view it seems to be more attractive to focus on adaptation policies in developing countries rather than CO_2 mitigation policies in industrialized countries. However, as long as economic growth is still accompanied by increasing CO_2 emissions, economic development will conflict with climate protection policies (e.g. China) if climate abatement policies are not cheaply available. Hence, there are good reasons to link the climate change problem to the development of abatement technologies. Green technologies (GTs) can be more cheaply developed in developed countries. Independent from the location where climate policy finally takes place, it seems that the major initiative has to come from the industrialized countries, as adaptation policy is also costly. Whether industrialized countries are able to take the initiative depends on their capability to react adequately to the climate change problem and to handle the related structural change.

In the absence of policy measures, anthropogenic climate change already causes structural change because of the related shift of external constraints on individual choices. According to predictions from natural science, significant changes in external constraints will happen in the future. The externality problem, together with the normative criteria of sustainability, establishes the necessity for immediate policy intervention. The application of policy measures, generally, can be seen as an exogenously implemented "policy induced structural change" in the economy. In order to better understand the socio-economic interrelationships that relate to structural change (that results from an increase in temperature and/or the application of different policy instruments), the topic of structural change is discussed in more detail before focusing on policy instruments which are able to internalize externalities.

1.3 Structural Change and Climate Policy

1.3.1 What is Structural Change?

The previous section has shown how the climate change problem over time has entered the policy debate. This can be explained by the change in external constraints making socio-economic responses necessary. As the notion of structural change describes a dynamic process with interactions and interdependencies, this process has to be explained in more detail. The ensemble on which structural change refers to is often described as a system. The theoretical background for the following description of structural change is mainly oriented on Hernes (1976) (see Timmermans et al. (2008) for an overview). This general description of structural change is further extended with economic studies on structural change.[7]

Structural change can be interpreted as a change in equilibrium. Equilibrium can be seen as a stable structure. This stable structure implies a process that maintains the stability but also maintains the process able to maintain stability. Structural change is a process generating change in the (previous) stable structure (Hernes, 1976, p. 514). There is continuous interaction between the micro and macro levels. Structural change has to take this interrelationship into account (see also Rip and Kemp, 1998; Geels and Schot, 2007; Timmermans et al., 2008).

At the micro level individual decisions are of particular interest. The behavioral assumption is that individuals "seek the best or, at least, satisfactory ways to realize their goals; that this is done under bounded rationality, meaning that they act on uncertain

[7]Structural change from an economic point of view is mainly related to the field of evolutionary economics and/or institutional economics.

expectations and partial knowledge" (Hernes, 1976, p. 515).[8] An overview on the assumption of bounded rationality is given by (Kahneman, 2003).

On the macro level there is on the one hand the collective institutional set. Observables are for instance reward structure, language, legal rules and available products (to mention only a few). On the other hand there are aggregative or distributive outcomes of choices over alternatives. These variables can be measured in terms of marriage rates, prices, CO_2 emissions, and so on. Observable outcomes on the macro level are partly under human control, can be the result of informal rules, may happen by chance and are to a large extent unintended. This is why the properties of aggregated outcomes are populations and not individuals (Hernes, 1976, p. 516).

What matters in the theory of structural change is the interaction between the micro level and the macro level (e.g. Rip and Kemp, 1998; Geels and Schot, 2007; Timmermans et al., 2008). This can be done by trying to specify how macro variables can be translated into individual motivations. From the perspective of institutional economics it is from particular interest to study the institutions influencing individual behavior (e.g. Hodgson, 1998; North, 2005). One general example would be that the market structure (e.g. in form of competition) affects the market behavior of firms (e.g. price setting, marketing strategies). Market access for green technologies over feed-in tariffs has an impact on the individual demand for green technologies.

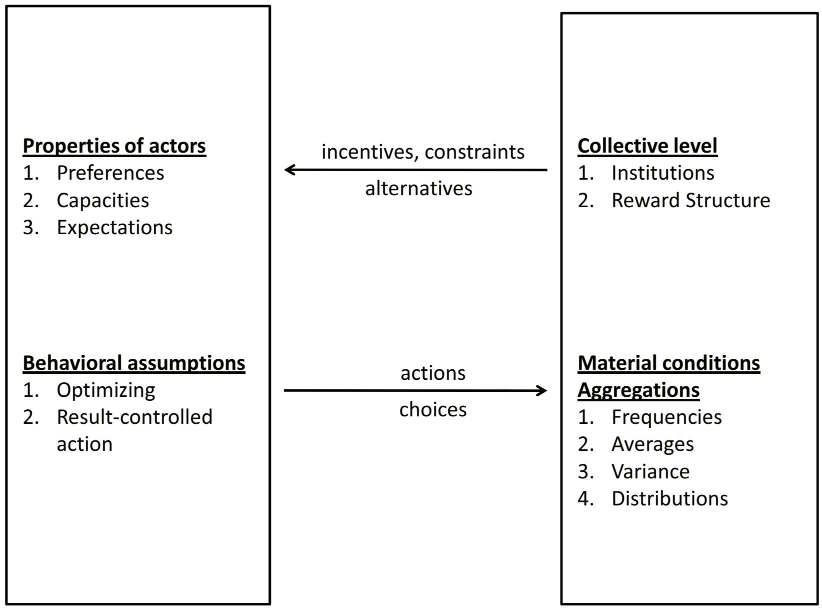
For particular cases the causality for the underlying relationship is not always clear as social parameters have an impact on choices of individuals but the mechanism also works the other way around, as individual choices of action change choice parameters thus opening or destroying alternatives.[9] One example would be that the consumption of natural resources has an impact on future consumption and hence the choices on consumption of natural resources of future generations. The dependence between micro and macro level can also be demonstrated by cyclical development of prices. High prices set the incentives for an increase in production which leads to lower prices in the following period which slows down the increased production (so-called pork cycle) (Hanau, 1927).

In order to understand structural change, it is important to be more explicit about what a structure can be. "A structure is a configuration of parts, and a structural

[8]This implies that feedback mechanisms have an influence on individual behavior. Hence, individuals modify their expectation for those cases where the outcome of action deviates from the intended result. If actors accidentally find a better solution they also try to adopt it. Preferences of individuals are influenced by different factors, such as abilities, rights and competences. Learning processes have an influence on individual consumption patterns (compare also Witt, 2001). Individual plans influence individual actions leading to results which are then again evaluated. This has an influence on decision making in previous steps or rounds. Future plans by individuals are determined by future expectations (Hernes, 1976). However, the described behavioral pattern is only stylized. Behavioral economics is one field of economic research which subsequently contributes to a better understanding of individual choice and individual behavior (cf. Levitt and List, 2007).

[9]The discussion whether demand has an impact on supply or whether supply has an impact on demand can also be related to this problem (e.g. van den Ende and Dolfsma, 2005; Chidamber and Kon, 2009).

FIGURE 1.1: Relationship between micro and macro level



Own illustration following Hernes (1976).

description is a characterization of the way the components in a set are interrelated" (Hernes, 1976, p. 518). A further distinction to be made is between output structure and process structure (compare also Timmermans et al., 2008). An output structure can be categorized by integers which measure the outcome (e.g. CO_2 emissions), the process structure is related to the process that leads to the outcome and can be explained by a set of equations (e.g. a growth model that connect economic growth to an increase in CO_2 emissions). Another aspect to be aware of is that processes have their own structure, as well. Hence, the overall CO_2 emissions can be reduced even though the growth rate remains the same. This is possible if a change in the process structure takes place. Structural change, therefore, can be defined as the "discrepancy between the extant structure and the processes which are responsible for creating the structure" (Ryder, 1964, p. 461). This allows for three different levels of structure to be distinguished:

1. output structure;
2. process structure;
3. parameter structure.

The complexity in studying structural change lies in the difficulty in looking at the dynamic interrelations between the processes.[10] This requires to account for changes in parameter values as well as for changes in the process structure. A further requirement is that there is a feedback mechanism from the output structure to the process structure, as well as from the output structure to the parameter structure. The particular interest of evolutionary economics is to understand the dynamic economic processes for the economy as a system (see Nelson, 1995; Fagerberg, 2003, for a survey of the literature).

Based on the three levels of structure mentioned above, four forms of structural change can be distinguished. The first form is called simple reproduction. In the related state of the art, production must be replicated in order to keep the process going (e.g. Marx, 1978). In this case output structure, functional form and parameter values remain unchanged (Hernes, 1976, p. 524). The second form is labeled as extended reproduction. There is growth in the output, but functional form and functional parameter values remain unchanged. The third and fourth forms distinguish between transformation and transition. Transition can be defined as a change in the output structure and parameter values (but not in the functional form), whereas transformation is a change in the functional form leading to a change of the output structure and its development over time (Hernes, 1976, pp. 526).

The previous description made clear that the climate change problem is inevitably related to structural change. However, it is still an open question to which form of structural change it has to be related. On the one hand, one can interpret climate change as a problem generating changes in parameter values (e.g. rainfall, or temperature) as done in the studies summarized at table 1.1. On the other hand there are studies stating that the behavior will change significantly, after a certain threshold is overcome, suggesting a change in the functional form (e.g. Stern, 2007; Solomon et al., 2009). Therefore, if climate change increases continuously without a change in the functional form the process is best described by the notion of transition. However, if the concentration of CO_2 within the atmosphere overcomes critical thresholds the climate can change completely causing a system transformation. Beside the fact that this generates serious harm to the environment, there is the problem that the new functional form very likely will be unknown, making it even more difficult to react to.

The description so far has only focused on the climate as a system. If the economy as a system does not react to those threats there will be an extended reproduction of CO_2 emissions increasing the stock of CO_2 within the atmosphere with the described consequences. The 2°C target seems to be an attempt by politicians to reduce the risk of substantial system transformation. If there is serious effort to fix the increase in

[10]Note that changes in the output structure are possible even if process structure and parameter structure remain constant (e.g. if the system moves towards a new equilibrium Hernes, 1976, p. 512).

temperature at a level of 2°C (to come from extent reproduction to a level with simple reproduction), this requires transition and transformation processes within the economy. There are propositions to foster such a development. In the literature this is mainly discussed under the notion of "transition management" (e.g. Rip and Kemp, 1998; Kemp et al., 2007; Kern and Smith, 2008; Nill and Kemp, 2009). Innovations are one important factor for structural change towards sustainability as they are able to influence the parameter structure as well as the functional form (e.g. Dosi, 1988; Klepper, 1997).[11]

The most important lesson that can be drawn from the previous discussion is that the externality problem resulting from the problem of anthropogenic climate change generates structural change in the economic system. Research related to the climate problem, generating new evidence about the impact of CO_2 concentration within the atmosphere, signals to politicians the need for policy reactions. This can be done by the application of different policy measures. The application of certain policy instruments changes the internal parameters of the system and/or the functional form in producing economic output. The following section gives an overview of the different policy measures that can be applied in the case of the climate change problem. The related change in external constraints is policy induced, generating a "policy induced structural change" within the economic system.

1.3.2 Environmental Policy

Different policy measures are available to cope with the climate change problem (compare also Aldy et al., 2011, pp. 918). In this section regulations in the form of command and control policies (CCPs) and voluntary agreements will be introduced before market-based approaches (taxes and certificates) will be discussed. Further instruments, such as joint implementation, negative rules and geo-engineering, are also part of the analysis.

Command and control policies

Command and control policies are often applied in the case of environmental problems (Dietz et al., 2003, p. 1909). The general approach is to regulate the production process to overcome the externality problem. The effectiveness of CCPs is closely related to the applicability of monitoring (Hechter, 1988) and sanctioning mechanisms (Di Mento, 1989, p. 112).

CCPs can be technology-based or performance-based. Technology-based standards require that firms use specified equipment, processes, or procedures. Performance-based standards define a certain quantity related to pollutant emissions or polluting activities.

[11] At this stage one can also introduce the distinction between radical and incremental innovations. Incremental innovations seem to be more related to the parameter structure and radical innovation more to the process structure.

They are more flexible compared to technology-based standards as regulated entities are free to find solutions for the required levels of pollution reduction. This is one reason why performance-based standards, in general, are seen to be more cost-effective. However, technology-based standards may perform better in saving information and administration costs (Stavins, 1997).

From a theoretical point of view, there are concerns related to CCPs as there is almost no chance of meeting the optimal level of regulation. In theory, at the individual firm level it would be possible to achieve static efficiency (marginal abatement costs are equal to marginal damages) if the regulatory entity is informed about the pollution control cost function. However, as this information very likely is not available, CCPs turn out to be inefficient. Another problem occurs due to the fact that production processes within the same industry differ (Stavins, 1997, pp. 300).

From a dynamic perspective, inefficiencies increase even more as the regulatory standard increases entry barriers for potential new market participants (Buchanan and Tullock, 1975). Another concern is related to innovations. Once the standard has been implemented by the individual firm there are low incentives to develop or adopt cleaner technologies. Under dynamic considerations technology standards are seen to be worse than performance standards because technology standards constrain the technological choices available and that reduces incentives to develop alternatives (e.g. Magat, 1979; Brunnermeier and Cohen, 2003; Requate, 2005).

CCPs can also be criticized for their focus on "end-of-pipe" solutions.[12] Another problem occurs as CCPs very likely turn out to be cost-ineffective (Hahn, 1989; Newell and Stavins, 2003). Many studies evaluating environmental policy instruments come to the result that CCPs in most of the cases are inferior compared to other possibilities (Bernstein, 1993; Stewart, 1992; Hahn and Stavins, 1991; Goulder and Parry, 2008).

Voluntary agreements

Voluntary agreements are policy instruments that are increasingly applied in environmental policy (cf. Sinclair, 1997). Under such agreements there is the threat of mandatory government intervention if certain benchmarks are not achieved voluntarily. Firm, specific incentives to agree on the "voluntary" political targets stem from the fear of being confronted with more costly regulation if the voluntary targets are not met (Stavins, 1997, p. 302). Theoretically, voluntary agreements are similar to performance-based standards, with the major difference being that sanctioning cannot be applied. The incentive to stick to the accord stems from the threat of future sanctioning (in case the standard is not met). What may follow are command and control policies.

[12]" 'End-of-pipe' refers to ameliorating pollution just before the point at which it enters the environment rather than seeking to prevent its generation in the first place" (Sinclair, 1997).

Environmental taxes

The classic market-based approach is the so-called Pigouvian tax (Pigou, 1920) (for simplicity also called environmental tax). The idea is to tax negative externalities and/or to subsidize positive externalities. Social and private marginal costs can be equalized by the price mechanism. One positive aspect related to environmental taxes is that theoretically revenues can be used to compensate for those taxes which distort incentives, such as income or corporation taxes. This double dividend is of particular importance as the possibility of a fiscal neutral implementation of environmental taxes might increase their acceptability (Pearce, 1991).

Compared to CCPs, environmental taxes have low compliance costs.[13] The applied tax will be common to all polluters. This allows for a search for different abatement strategies depending on individual marginal abatement costs. If polluters have high marginal abatement costs they very likely will pay the tax in contrast to polluters with low marginal abatement costs. Transaction costs for environmental taxes are supposed to be relatively low (Baumol and Oates, 1971, 1988). Under the assumption that the tax is set at a level internalizing the externality, static efficiency is achieved. From a dynamic perspective, there is further the incentive to adopt even cleaner technologies to escape the related costs (Tietenberg, 1990). In theory, environmental taxes can be easily adjusted to new information on the externality problem.

Even though environmental taxes theoretically have positive features, in practice they confront severe problems. A general difficulty is the quantification and evaluation of the externality. In many cases it is technically impossible to define and measure the damage resulting from the marginal input of the good causing the externality. Apart from this, there is the problem that the effectiveness to achieve the environmental target depends on the price elasticities of demand. For instance, if the price demand curve is very steep it is also possible that the necessary tax increase would generate hostile reactions within society. Another problem stems from the fact that the deadweight loss resulting from the carbon tax, to guarantee efficiency, would have to be evaluated against the gains resulting from environmental protection. Tax incidence is a further aspect that would have to be taken into account in order to evaluate the impact of taxes appropriately (Pearce, 1991, pp. 942).

It can be seen that environmental taxes, in theory, have advantages compared to command and control policies. However, difficulties relate to its application. Further criticism stems from the Coase theorem (see part "negotiations"). The information problems are substantial. In many cases, where environmental taxes can be effectively applied, they very likely turn out to be inefficient. Even though environmental taxes are market-based instruments they cannot be treated as a first best solution. From a

[13] The suggestion is that environmental taxes (as well as tradable certificates) can reduce compliance costs compared to CCPs, by 50 percent and more (Tietenberg, 1990).

more pragmatic perspective, there is, nevertheless, the possibility to make use of taxes to control externalities "reasonably efficient" (Baumol and Oates, 1988, p. 159). This approach is known as the charges and standards approach.

Charges and standards

In the case of the charges and standards approach, policy has to define a certain internalization target that can be approached over tax adjustments (Baumol and Oates, 1971, 1988). The definition of standards can help to overcome the information problems related to the Pigouvian tax. Problems occur due to the uncertainty about the tax rate and the time needed for the iteration process. What turns out to be difficult in practice is the measurement of the externality. Further, there is the problem that the implementation of charges and standards might evoke political protest. However, for some environmental problems the charges and standards approach can be seen as a policy instrument with some convenient properties due to its applicability.

Negotiations

The political instruments mentioned above overlook one important aspect: in many cases the externality occurs mainly because property rights are not appropriately defined. From this point of view, the role of the state in dealing with the externality problem changes remarkably.

In his seminal article "The Problem of Social Costs", Coase (1960) pointed out that under well defined property rights and zero transaction costs voluntary negotiations are able to generate a Pareto optimal outcome. One lesson that can be drawn for economic policy is to make use of the legal system to overcome the externality problem. If one agrees that it is the major role of the state to define and guarantee property rights, then many environmental problems under the Coase theorem turn out to be a result of state failure and not of market failure.

According to the definition of the externality problem there has to be one party who is injuring and one party who is injured by the activity. From this point of view policy making also changes, as the focus is not primarily on the injuring party. Both parties compete on the consumption of the common good. Efficiency in economic terms requires that marginal benefits of the injuring party are equal to marginal costs of the injured party. This result is independent from the allocation of the property rights (invariance thesis). Property rights can therefore be allocated to the injuring party, the injured party or distributed to both of them. On the macro level the resulting outcome will be the same. However, on the micro level the allocation of property rights affects individual incomes.

The second lesson that can be drawn from the Coase theorem is that transaction costs are one reason for market failure. This becomes more clear if one keeps in mind that externality problems exist even under defined property rights. Under the presence of transaction costs the invariance thesis cannot be applied (the resulting outcome is dependent on the allocation of the property rights). This brings up the question on the role of institutions able to reduce the problem of transaction costs.

Without transaction costs, the negotiation solution can be seen as a policy option for solving the externality problem efficiently. Also, from a dynamic perspective, efficiency is maintained as the parties involved can realize gains if new abatement technologies become part of the production process. There are continous incentives to innovate. However, transaction costs can be supposed to increase with the parties involved. In most of the cases the externality problem cannot be reduced to only two parties (as in Coase, 1960). In the case of climate change one can well argue that all citizens (and future generations) are involved in the externality problem. A further requirement is that all actors know about the costs and benefits of the externality problem. Asymmetries in power between the parties involved can be seen as a further problem. This again shows that in many cases the definition of property rights is a necessary but not sufficient condition in order to establish an efficient solution.

Tradable certificates

Parts of the problems can be solved if institutions are established that reduce transaction costs sufficiently. Theoretically this requirement can be achieved if the state implements an institutional setting (e.g. a market) that allows the exchange of property rights on externalities.[14] If the quantity is defined on a level able to internalize the externality, the equilibrium price resulting from exchange in permissions indicates the social costs imposed by the externality. Certificates will be allocated where efficiency is highest which implies that costs for emission reduction are minimized. Incentives for buying permits are given if abatement costs exceed permit prices, and incentives for selling permits are given when permit prices exceed abatement costs. Trade will continue until there is an equilibrium, meaning that marginal abatement costs are equal to marginal certificate prices. If equilibrium is achieved for all market participants, allocation of permits *ceteris paribus* has ex-post generated the cost minimizing result (Stavins, 1997, p. 305).

The question for the government is how to allocate the certificates ex-ante. Different opportunities exist:

- Firms can be given shares of the total permit volume for free ("grandfathering");
- The certificates can be auctioned;
- Both approaches can be combined.

[14]The market might also evolve spontaneously through the initiatives of private actors.

The major advantage in auctioning is that it solves some of the asymmetrical information problems that are related to the difficulties estimating the demand for certificates. The auction revenues can further be used to reduce other tax distortions. The major argument for grandfathering can be found in a lower resistance from an industry that now has to deal with the related increase in production costs. Grandfathering is further related to the problem that it implements additional barriers for new market entrants. This problem can partly be reduced with time limited certificates. Time limited certificates can also facilitate adjustments in response to new information. From a dynamic perspective, producers have incentives to integrate pollution costs into their optimization calculations. This has a positive impact on innovations (Stavins, 1997, pp. 306).

Joint implementation

One instrument which combines environmental protection with economic development is the so-called joint implementation (JI) approach.[15] The idea is to set incentives for emission reduction in other countries. If cooperation between countries takes place, there is one party funding emission reduction in the other country. Joint implementation can easily be combined with trade in certificates. Theoretically, there are many advantages and disadvantages related to joint implementation (Barrett, 1995; Loske and Oberthür, 1994). Prime advantages are the following:

1. It might be a first step towards an international tradable certificate system;
2. Joint implementation is a cost-effective instrument that can be applied by industrialized countries to finance emission reduction in developing countries;
3. Emissions can be reduced in countries where abatement costs are low.

Beside the positive aspects, problems are identified. One problem results from the fact that most developing countries do not have specific emission reduction targets. This makes it difficult to determine the impact that joint implementation has on the overall emission reductions of the country. Smaller projects may not come to fruition through joint implementation because of high transaction costs. Many problems in developing countries are a result of loosely defined and non-existing property rights, which again increases transaction costs. Due to monitoring difficulties, there are project specific incentives to report too high positive impacts for the environment (principal agent problem) (Stavins, 1997, pp. 311).

Negative rules

In the case of externalities, one could restrict property rights to internalize the externality. In contrast to command and control policies, rules have to be adjusted in the

[15] In the context of the Kyoto-Protocol, JI is also referred to as clean development mechanism (CDM).

form of restrictions. The restrictions can be implemented in the form of negative rules (Hayek, 1978). Static efficiency can be achieved. From a dynamic perspective, one major advantage can be found in the flexibility and freedom that is given after the negative rules are defined. Incentives to innovate are high. However, difficulties occur if it becomes necessary to adjust the rules to changing knowledge. For the formation of stable expectations, property rights should also be stable (Wegner, 1998, p. 221). This requirement very likely cannot be fulfilled in the case of environmental problems.

Geo-engineering

One relatively new policy instrument discussed in the literature is so-called geo-engineering (cf. Keith, 2000). This solution is primarily related to the climate change problem. The idea of geo-engineering stems from the natural experiment of the eruption of Mount Pinatubo in the Philippines in 1991 (Crutzen, 2006). The injection of sulfur dioxide into the stratosphere had significant impacts. Estimates have determined that the mean temperature decreased by 0.5°C.

As mentioned previously, there are two forces affecting the world climate. First, there is the concentration of greenhouse gases in the atmosphere, and second, the amount of radiation that strikes the earth (also depending on the solar cycle and Milanovitch cycles). In contrast to an investment into abatement technologies, geo-engineering would have an impact on the world climate through the second force mentioned above. Therefore, geo-engineering can be defined as "solar radiation management" (Barrett, 2008). If effective, geo-engineering can be seen as a substitute to emission reduction. However, even though this offers new opportunities on climate change policies, so far the concept lacks "broad support from scientists" (Cicerone, 2006). Supporters of the idea mainly refer to the study by Crutzen (2006), which seems to point in the direction that geo-engineering is feasible.

What is important in current debates on geo-engineering is that spacial patterns of the world climate are supposed to remain constant even under local application of geo-engineering (Govindasamy and Caldeira, 2000; Govindasamy et al., 2003). Knowledge of geo-engineering becomes extremely valuable, as single countries may be able to change the world climate system on their own. The theoretical prediction is that coordination problems will be less severe than in the case of climate change mitigation policies (Schelling, 1996). From a political point of view this raises questions about international policy because of the related conflict potential (Barrett, 2008; Victor, 2008). Economically the idea of geo-engineering seems to be highly attractive due to its cost argument. Compared to mitigation policies geo-engineering is expected to cost almost nothing (cf. Nordhaus, 1994b; Teller et al., 2003; Nordhaus and Boyer, 2003). Further, there is the argument that geo-engineering could help to gain additional time to find solutions for stabilizing the climate. Supporters of the idea are optimistic that geo-engineering can help to reduce the risk of climate destabilization (Wigley, 2006).

Albeit geo-engineering seems to be an interesting option for policy making, it raises important questions. One problem occurs with the path dependency resulting from geo-engineering. Once this policy option is established, it has to be maintained continuously, as CO_2 concentration within the atmosphere keeps increasing. According to Matthews and Caldeira (2007), an abrupt halt of this policy is problematic, as it can cause a severe climate change with temperature increases. The complexity of the climate seems to indicate that it is dangerous to believe that it can be managed like a production process. The above discussion has shown that many processes are understood only weakly. The application of geo-engineering might generate unintended harm. A general criticism is that geo-engineering comes very close to what can be considered as "pretence of knowledge" (Hayek, 1964, 1975). It might be that further research on the topic finds more convincing arguments for its applicability. So far, the knowledge is rather limited. There is also the possibility that increasing knowledge will discover additional unintended problems, thus reducing the attractiveness that seems to be attached to geo-engineering, especially from an economic point of view. However, independent of the direction the perception of geo-engineering evolves, the high economic gains suggest that further research on this topic will be applied (there is no prisonners' dilemma related to the funding of research on geo-engineering).

The discussion has shown that different options can be applied. All in all, market-based approaches have major advantages over command and control measures. Tradable certificates are a promising tool for emission reduction in the context of anthropogenic climate change. What has not been introduced, until now, is the distinction between national and international levels of decision making. This distinction is important, as many national policies effectively applied on the national level turn out to be ineffective from an international perspective. This raises the question about the degree of international coordination.

Policy coordination and the Kyoto-Protocol

Theoretically, global environmental mitigation policies constitute a global public good because of international spillovers (Ostrom, 1990). The increasing rivalry in consumption on GHG emissions relates anthropogenic climate change to the "tragedy of the commons" (Hardin, 1968).[16] Investment into climate change policies is confronted with high free-riding incentives.

To a certain degree common good problems can be internalized over international policy coordination. As this also reduces competition between countries, the need for

[16]There is rivalry in consumption but exclusion of additional users is not possible.

coordination has to be evaluated carefully (Klodt, 1999). Competition among jurisdictions can serve as an instrument to discover a "social desirable outcome" if the optimal solution is not known ex-ante (Tiebout, 1956). If there is a high degree of uncertainty, it is optimal to limit coordination to the definition of a benchmark for emission reduction. This allows for the establishment of ex-ante competition over optimal solutions to achieve the defined target. International policy coordination can be used to define quantity targets, e.g. for emission reduction. Regarding environmental problems, policy coordination is common and often applied (Barrett, 2003, pp. 165). Many studies analyze international environmental agreements (IEAs). This string of literature tries to explain the formation of IEAs, its related welfare effects and the impact of institutions mainly on the stability of IEAs (for an overview see Barrett, 2005; Brink, 2002; Finus, 2008).

From a political perspective, the Kyoto-Protocol (KP) can be interpreted as an IEA aimed at coordinating international climate policies. Signatories to the KP have to achieve certain CO_2 emission reduction targets measured in a percentage of the base year 1990. The time frame for GHG reduction is from 2008 to 2012 (Böhringer, 2003; Böhringer and Vogt, 2004). The average emission reduction of GHG (from a global perspective) is to be 5.2 percent until 2012 on 1990s baseline emissions (for a more detailed discussion on the KP see chapter 4, p. 86). The long-term success of the KP also depends on achieving a follow-up agreement (cf. Helm, 2008).

The presentation of the different policy instruments already raises questions related to the decision making process, nationally and internationally. Questions that could be raised (to mention only a few) are: Why are command and control policies applied in many cases, even though from a theoretical point of view they are not a first best solution? What are the national incentives to invest in climate abatement technologies when international policy coordination fails in many aspects? What generates the incentives for national governments to become members (or non-member) of an IEA? What kind of rules can be endogenously applied to reduce free-riding incentives to participate in IEAs? How does climate change-related structural change effect the formation of interest groups at the national level and hence the outcome of political decisions nationally and internationally? What is the impact of voting rules on the choice of particular environmental instruments? In order to deal with these and related questions, the climate change problem has to be looked at from a political economy perspective. The topic of political economy is introduced in the following section. After defining political economy, a short overview of research contributions in the field of the "political economy of climate policy" is given. Different interests within society on environmental policy and its instruments are summarized as a next step. Finally, there is a short overview of the chapters of this thesis that are related to the "political economy of climate policy".

1.4 Political Economy of Climate Policy: An Introduction

1.4.1 Definition and Basic Assumptions

Political economy and economics were synonyms until the early 20th century. This changed when economics evolved to be the term denoting a discipline, and political economy was used to describe different phenomena within the discipline (Groenewegen, 1987; Besley, 2007). Today, the notion of political economy is closely related to the extension of economic models about collective decision making. Nevertheless, there are still differing concepts of political economy. As a result, political economy can only be defined broadly, as a clear cut definition would exclude some research fields in this area. For the remainder of this thesis the following interpretation of political economy will be used:

"*[Political economy] refers to the study of the collective or political processes through which public economic decisions are made*" (Oates and Portney, 2003, p. 327).

From the previous description of policy instruments, it can be seen that from a pure economic perspective there are different propositions on how to design optimal (efficient) measures internalizing externalities. Theoretically, market-based instruments are superior to other approaches because of the predicted static and dynamic efficiency. However, if it comes to the implementation of policy measures, it can often be observed that (1) the first best solution is not applied (this goes in hand with inefficiencies), and/or there are (2) problems related to effectiveness. For applied economics, there is the complicacy that besides market failure there is the problem of state failure. From a positive perspective, political economy studies the underlying process leading to these unintended outcomes. From a normative perspective, the findings from political economy can also help to find solutions for the inefficiencies resulting from state failure (cf. Vanberg, 2005). In what follows the focus will be on the political economy of environmental policy, mainly from a positive perspective. Normative questions are further elaborated in the last chapter of this thesis.

In order to explain decision making outcomes on the macro level in many cases the median voter model serves as a background (cf. Mueller, 2003, pp. 231). In this framework collective decision making is an outcome of the voters' preferences in the context of direct democracy or indirect democracy (decision making is delegated to elected representatives). As the underlying assumption is the application of majority rule, the median voters' preferences determine decision making outcomes (Black, 1948;

Downs, 1957).[17] Even though the median voter model is central to many political economy models, in many cases it is a too simplifying assumption.

Another model describing decision making is the theory on regulation, or the so-called Stigler and Peltzman model (Stigler, 1971; Peltzman, 1976). This model assumes that regulated entities have certain possibilities to apply pressure on the regulatory authority. Possibilities to apply pressure are public campaigns of criticism, the threat of losing jobs, the threat of quitting the budget generating relationship (over outsourcing) and/or campaigns resulting in a loss of votes for the incumbent government. Pressure is applied in order to escape (or reduce) the burden of regulation. It might also be that regulation turns out to be beneficial for the regulated entities. The regulating agency offers services in exchange for the maintenance of the relationship with the regulated sector.[18] The model is closely related to the theory of bureaucracy (Niskanen, 1968, 1971). The Stigler and Peltzman model is useful for explaining problems that come with environmental regulation. An example is given by the regulation of the GT sector in Germany.

One further model serving as a background to understanding policy making on national and international levels builds on Olson's (1965) seminal contribution on "the logic of collective action". As with the theory of public goods, interest groups are confronted with free-rider problems. In many cases this limits the capability to organize common interests and to influence decision making to support these common interests.[19] One possibility to overcome this free-rider problem is to provide some direct services to the members of the interest group. In many cases group membership is also coercive (as a result of interest groups being successful in lobbying for mandatory group membership). In both cases, it comes down to organized interest groups being able to enforce (or maintain) their interests. These interests mostly deviate from common interests (e.g. the interests of the median voter). In many cases lobbying takes place in order to generate rents and/or to maintain rents and this increases inefficiencies. The price (in terms of social costs) is then paid by those who are not able to organize their interests (e.g. consumers).

1.4.2 Political Economy of Environmental Policy

One early contribution on the political economy of environmental regulation comes from Buchanan and Tullock (1975). They focus on the incentives at the firm level and argue that emission standards are preferred to emission taxes because they can increase profits. Profits are assumed to be positively affected because emission standards serve as

[17] Representatives are elected over majority vote.

[18] For a brief discussion of some model limitations compare Oates and Portney (2003).

[19] Under majority vote one can define common interests as the interests that are related to the median voter.

an entry barrier for new firms. The situation is different for charges (taxes), as they have to be paid by established firms and new firms. The model builds on the assumption of incomplete competition and on the assumption that regulated industries are able to exert their preferences over the instrument that is applied (in contrast to the consumers who are relatively worse off compared to the charges approach). This basic framework has been extended (e.g. Coelho, 1976; Dewees, 1983; Yohe, 1976).

What can be influenced by interest groups is the stringency (or effectiveness) of environmental regulation. Lobbying can be applied at different points of the decision making process with different impacts on stringency (Magat et al., 1986). The role of institutions (e.g. for decision making) has been analyzed by Campos (1989). He is able to show that different voting procedures, as well as other forms of legislative institutions, have an influence on the political outcome. An influential model has been developed by Becker (1983). The underlying assumption is that interest groups use political power to benefit from redistribution of rents. This implies that governments have to select among the pool of available policy choices those instruments which are more powerful in distributing rents from less organized interest groups to more organized interest groups. As an implicit result, it turns out that environmental regulation generates high inefficiencies.

What also matters to politicians is the delegation and separation of power. Some democratic entities have a major interest in maximizing control over other entities (e.g. certain industries). McCubbins and Page (1986) argue that CCPs are applied more often than market-based approaches because political entities try to maintain and/or increase their power. In contrast, market-based approaches allow firms more flexibility which also reduces political influence on private decisions. This theory is closely related to the theory of bureaucracy.

Other studies look at the preferences of the voters and their influence on decision making. Interesting in this context is the effect of income levels on environmental regulation. Tucker (1982) focused on welfare effects within the U.S. and came to the conclusion that rich people benefit most from high environmental standards. This is somehow in line with the findings of Ackerman and Hassler (1981). They found that coalitions among environmentalists and industries are possible. This can be the case if environmental regulation carries the threat of imposing harm on the industry in the form of job losses. There is further empirical evidence that voters care more about short-term economic development (income level and/or unemployment) than about the ecological situation (Paldam, 1991; Schneider, 1994). As a consequence, political parties can win more votes with short-term policies (Frey, 1992; Horbach, 1992).

The impact of eduction on environmental preferences has been analyzed by Kahn and Matsusaka (1997). They used data from the U.S. and found that education affected environmental preferences positively. The authors interpret these results to suggest that less skilled workers are more directly affected by environmental regulation (e.g. over wages or possible job losses). Schneider and Volkert (1999) come to similar results and show that education has a positive influence on the election results of strongly environmental-oriented parties.

This short introduction into the political economy of environmental policy makes clear that political outcomes depend highly on the influence of the groups of actors that are engaged in environmental policy making. Next, the interests of the different actors within the economy are introduced. The line of arguments mainly follows Kirchgässner and Schneider (2003) (compare also Kollmann and Schneider, 2010). This description of different interests serves as a background to facilitate an understanding of the following chapters.

Kirchgässner and Schneider (2003) follow Frey (1992) and distinguish among four different main actors: (i) voters, (ii) politicians, (iii) public bureaucrats, and (iv) those who are related to the industry (including capital owners, managers and employees). Part of the discussion are the incentives to establish market-based approaches in comparison to command and control policies (Frey, 1992, pp. 134).

Voters

It can be said that voters are increasingly concerned about environmental issues. Nevertheless, environmental interests 'compete' with other interests that are mainly 'purely' economic in nature. For instance, in the case of climate change, investment in CO_2 reducing abatement technologies is a global public good. One important question for voters is related to distributional effects of the costs. In most cases the costs are delegated to the consumers.[20] This makes many environmental policies unpopular with voters. Only in cases of high price elasticity are the costs delegated to industry related interests.

If a region where the industry is located is negatively (positively) affected by environmental policy, resistance (support) is supposed to be high.[21] Whether overall regulation is at a level that is too low or too high is not clear. Climate change policy can again be used as an example. If the industry that is negatively affected by climate change policies dominates within a region (e.g. a country or county) climate change policy can be at a level that is too low (Kirchgässner and Schneider, 2003, p. 374). If structural change towards more climate friendly technologies takes place (e.g. the GT sector), partial industry related interests might also support strict climate change policies. Whether

[20]Of major importance is the price elasticity of demand. For low price elasticities of demand and/or very elastic supply consumers have to pay the major costs related to environmental protection.

[21]Horbach (1992) found for Germany that the Green Party receives less votes in regions with high unemployment and/or a high concentration of industries which could be negatively affected by environmental regulation.

environmental regulation is at a level that is too high or too low depends on the industry specific pattern.

A decrease in the resistance of voters to environmental friendly policy measures can emerge from the double dividend. The revenues from environmental taxes can be used to reduce other (distorting) tax burdens. While this alternative seems to be promising, empirical evidence shows that the expected losers in such a tax reform would lobby strongly against it (Kollmann and Schneider, 2010). Support for strict environmental policy can emerge if there is underemployment in a certain region and environmental standards can be combined with the production of consumer goods (better environmental quality and higher real incomes). Under these specific circumstances efficient environmental standards can gain political support.

However, there is still the problem of the majority of voters being short-term rather than long-term oriented (Paldam, 1991; Schneider, 1994). One major problem is that climate change policies are mainly beneficial for future generations but the abatement costs reduce current consumption levels. As a consequence, this can result in an undersupply of climate change policies (Frey, 1992; Horbach, 1992).

From the perspective of voters it is difficult to find reasons why CCPs are more often applied than market-based instruments. Voters preferences point more in the direction of them being in favor of CCPs. One reason might be that they prefer not to be confronted with the costs that are more apparent in the case of market-based instruments (Kirchgässner and Schneider, 2003, pp. 373-375).

The evaluation of recent empirical studies generally confirms the arguments mentioned above (Kollmann and Schneider, 2010, pp. 14). The following three conclusions can be drawn: (1) contributions to the public good "environment" is confronted with free-rider problems; (2) there is a time gap between the investment and resulting benefits, and this explains why environmental issues are rather unpopular; (3) voters give other problems, such as unemployment, a higher priority than environmental issues (Kollmann and Schneider, 2010, p. 17).

Politicians

It is assumed that politicians will pursue a certain policy if it serves the interests of the median voter provided there is no considerable resistance from influential interest groups or the bureaucracy. Thus, if voters accept (or even demand) suboptimal levels of environmental protection, and if politicians maximize the chance to be re-elected, there are few incentives to push for strict environmental policies.

The assumption that the main aim of governments is to get re-elected is too strict for particular cases. There are cases where re-election prospects act as a constraint but are not the overriding factor determining a government's actions. This can theoretically be explained by combining the partisan hypothesis (Hibbs, 1977, 1992) with politico-economic models (Frey and Schneider, 1978b,a, 1979). Where there is a coalition government, including a 'green' party and a dominant party that has strong relations to interest groups supporting environmental policies like emission reduction, a stronger climate change policy can emerge relative to the median voters' preferences. Re-election prospects are the limiting factor. There is still the question of whether this policy is efficiently applied or not. If there is no real pressure from voters, then bureaucratic instruments seem to be attractive because they allow control of industries directly. Market-based approaches are also attractive, as they can generate revenues. On the one hand these revenues can be invested to increase re-election chances. On the other hand, market-based approaches generating revenues for the government might also strengthen the opposition (Kirchgässner and Schneider, 2003, p. 376).

In comparing tradable certificates to environmental taxes, it can be seen that environmental taxes have advantages over tradable permits as the latter instrument is often perceived as a "licence[] to pollute the environment" (Kirchgässner and Schneider, 2003, p. 376). Thus, promoting or endorsing tradable permits would seem to be politically unsound for politicians who are known to be concerned with in efforts to save the world climate (cf. Ott and Sachs, 2000). Additionally, if tradable permits are grandfathered to the industry the government does not receive revenues, suggesting that environmental taxes are preferred to tradable permits.

In general, one can expect that governments' preferences for climate protection policies are too low. Further, there is the argument that politicians have no direct preference for market-based instruments over command and control policies. Market-based instruments have the major advantage in generating revenue. However, in many cases this incentive is not strong enough to overcome the "bias" toward command and control. Politicians make use of the different policy options to react to other agents' interests. Hence, the design of a specific policy is mainly influenced by the affected interest groups (Kollmann and Schneider, 2010, p. 20).

Bureaucracy

The bureaucracy is strongly opposed to market-based instruments. Bureaucrats prefer command and control as this policy option "strengthens their personal position in the environmental policy game" (Kirchgässner and Schneider, 2003, p. 380). Empirical evidence is provided by Holzinger (1987) and it turns out that bureaucracies favor environmental regulation that is labor and resource intensive. Typically, this is the case with command and control policies (cf. Kollmann and Schneider, 2010, pp. 23). This finding is in line with the theory of bureaucracy (Niskanen, 1968, 1971). Bureaucracies have an interest in maintaining high administrative control. Further, they like to have the greatest possible leeway and a budget they can distribute without the control of politicians. Discretionary budgets are also important in meeting the demands of the particular lobbying groups for which the bureaucracy is responsible.

Market-based instruments, with a major focus on environmental taxes, are less attractive to the bureaucracy, compared to command and control. Command and control policies are relatively labor and cost intensive. Substituting CCPs with market-based instruments would require a high degree of flexibility from bureaucrats, and market-based approaches could increase the efficiency of bureaucratic processes. This can conflict with the interests of the bureaucracy, as it becomes more difficult to justify large staff numbers and large budgets. Taken together, the different arguments suggest that bureaucracies have a high preference for CCPs. Nevertheless, regulating bureaucracies also have an interest in high environmental quality (Kirchgässner and Schneider, 2003, pp. 380-381).

Industry

It is often said by officials of regulated industries that they support market-based policy instruments. What turns out to be difficult is their implementation. In many cases, when the discussion is about implementation of environmental taxes, industries favor voluntary agreements. If the discussion is about the implementation of an emission trading scheme grandfathering is of major interest. From the point of view of an industry, CCPs are preferred over tradable certificates, with grandfathering. Environmental taxes gain only low support. The major reason industries oppose market-based instruments can be found in the high efficiency. What also matters for industries are distributional effects.

Political pressure can be brought to bear through lobbying. According to Coen (2007), lobbyists can be seen as an "organization or individual that seeks to influence policy, but does not seek to be elected". If an industry prefers CCPs over market-based instruments, it tries to make use of lobbying to influence policy into this direction.

Firms have strong arguments based on international competition, employment issues or the threat to displace the industry. If command and control policies are applied, firms can make use of these arguments in negotiations. In the case of environmental taxes, it is more difficult to negotiate on the price as the tax rate will be the same for each firm. On average, one can expect CCPs to be less effective, compared to market-based instruments, making CCPs more attractive to industry.

Distributional consequences are related to the possibility of increasing market power by application of command and control policies (Buchanan and Tullock, 1975). This can have a positive effect on wages and/or profits within an industry. The same argument holds if tradable certificates are grandfathered to an industry.

This shows why industries generally oppose market-based instruments. In the case that industries have to accept the implementation of a market-based instruments, they prefer grandfathered tradable certificates over environmental taxes. The European Emission Trading System (EU-ETS) is an example. Industries were able to influence policy in the direction of grandfather certificates despite the fact that auctioning is theoretically superior and would increase governments revenues (cf. Goeree et al., 2010; Convery, 2009; Goers et al., 2010). It can further be expected that traditional industries have good opportunities to maintain their interests over those of most environmental interest groups. Five major arguments support this view. (1) Industry-related interest groups have sufficient financial resources for efficient lobbying (cf. Kollmann and Schneider, 2010). (2) Producers are close to the environmental problems making them experts regarding questions of environmental regulation in the form of CCPs. This generates asymmetrical information problems. Environmental interest groups, in contrast, have difficulties gaining the necessary information. Gullberg (2008) has been able to show for Europe that traditional industries are better connected and have more power to influence policy than is the case for green interest groups. (3) The asymmetrical information problem helps industries to influence public opinion. They have an advantage over interest groups supporting environmental causes. (4) Industry interest groups have 'market power' because they can always argue on the basis of employment within the industry, as well as the possibility of transferring production abroad. (5) Representatives of these industries also have personal representatives in legislative institutions. This helps them to maintain their interests (Kirchgässner and Schneider, 2003, pp. 379).

At this stage, it is important to mention that the arguments presented are also valid for those industries that are positively linked to the climate change problem (e.g. the GT sector). This reasoning is not elaborated enough in Kirchgässner and Schneider (2003) or Kollmann and Schneider (2010). From this perspective the primary arguments get more complicated as there is competition between old (polluting industries) and new (environmental friendly) industries to influence political decisions (e.g. Jacobsson and Lauber, 2008). Structural change towards climate friendly technologies implies that the GT sector carries more political weight (cf. Svendsen, 2003; Brandt and Svendsen, 2006). The argument that green interest groups are weak in influencing political outcomes, compared to traditional industries, is only convincing for those countries where the GT sector operates on low scale.

In comparing bureaucratic interests with industry-related interests, it turns out that industries favor soft and inefficient policy instruments, whereas bureaucracies prefer the effective use of command and control policies. Whether a policy can be strictly applied or not is dependent on the preferences of the voters. From an intertemporal perspective, it seems that voters support strict environmental policies if an environmental problem is already apparent. If the consequences are somewhere in the future they prefer low regulatory standards.[22] From an international perspective, climate change policy is expected to be at a level that is too low (Kirchgässner and Schneider, 2003, pp. 381).

Some of the studies presented in the next chapters have a related perspective to the line of arguments presented above. However, there is one important difference. At the industry level the major focus is on industries benefiting from the problem of climate change. These industries are also well organized and successful in influencing policy making in favor of their own interests. From a national perspective (e.g. in the case of Germany), the industrial specialization pattern is, therefore, important in evaluating the "optimality" of climate change policy. There is, further, the argument that structural change in the energy system might evolve over time from countries with high environmental standards to the current free-riding countries. IEAs are important in this context. This more dynamic perspective has not been a major focus of the current literature on the political economy of climate policy, so far.

The following thesis builds on the theory of political economy and climate change policy. Command and control policies compared to market-based instruments is one focus of the research. Structural change in the energy sector is another focus. It is further the aim to test institutional factors that are endogenously implemented by policy-makers in order to improve political outcomes. This thesis makes a modest attempt to address the different questions related to the political economy of climate policy.

1.4.3 Aim and Approach of this Thesis

The thesis at hand contributes to the literature about the political economy of climate policy. This is done from a national and international perspective. Chapters 2 and 3 analyze structural change in the energy sector, mainly from a national perspective. Chapter 2 looks at the policy instruments implemented in order to foster diffusion of green technologies with a focus on effectiveness and efficiency. The discussion on the efficiency of command and control is of particular interest. In chapter 3 there is an assessment of structural change with a focus on innovative activity. In this context, innovations serve as an indicator for structural change. Chapter 4 deals with national as well as international differences with respect to diffusion of GTs. It seems that some countries have difficulties in fostering diffusion of GTs. The focus is on the national interests of the German government supporting strict environmental standards internationally. The structure of national interest groups has an impact on decision making in the context of international policy coordination. In chapter 5, the focus is on policy coordination (e.g. in the form of IEAs) from a long-term perspective. The major

[22] Kirchgässner and Schneider (2003) make the example that there is a considerable improvement in water quality of rivers and lakes but almost no effective policy reaction to the problem of climate change.

question is whether medium-term targets are helpful, unimportant or detrimental in approaching long-term targets. Chapter 6 examines the impact minimum participation rules have on the stability of IEAs. This institution requires that a minimum number of countries participate in an agreement in order to make the agreement binding. Chapter 7 discusses the particular case of European environmental policy for regulating the GHG emissions of private transport. The focus is, again, on the choice of policy instruments in combination with different voting procedures. Chapter 8 brings the main results together and draws some final conclusions.

As all of the chapters look at the climate change problem from different perspectives, they can be read independently (abbreviations are newly introduced at the beginning of each chapter). To facilitate selective reading, an overview of the individual chapters is given.

1.4.4 Structure

Chapter 2 discusses aspects related to the GT sector in Germany. As a first step, institutional reforms enabling diffusion of green technologies are analyzed. Cost arguments are also taken into account. As a second step, a theoretical model developed by Tanguay et al. (2004) is modified in order to evaluate the efficiency of the institutional setting in a political economy framework. The model is able to show that command and control policies are accompanied by cost inefficiencies, depending on the political weight of technology related interest groups. There is, further, the result that relatively high marginal production costs may generate suboptimal high diffusion of a certain GT j. For relatively low marginal production costs policy induced demand may also be too low.

Chapter 3 is about structural change in the energy system. By focusing on different green technology industries in Germany, it is of particular interest how policy induced demand stimulates innovation. Taking the change in market size as a proxy for increasing demand, and patent counts as a proxy for innovation, there is evidence that the presence of institutions enabling diffusion of GTs is correlated with innovative activity. In addition, a structural break is controlled for by comparing the two institutional settings incorporated into the legal system in Germany, namely the Electricity Feed Law and the Renewable Energy Sources Act.

Chapter 4 discusses the political economy of climate protection by combining national and international interests. The objective is to come to a better understanding of why climate change has become one of the main topics in the domestic agenda of some countries (e.g. Germany), despite the fact that there are obvious free-riding problems resulting in increasing difficulties for international policy coordination. Using a strategic trade policy framework, the paper discusses, theoretically, the incentives for domestic policy-makers to advocate an ambitious climate policy and assesses these incentives empirically with econometric methods.[23]

Chapter 5 is about viewing individual contributions as investments in emission reduction. We rely on the familiar linear public goods game to set global reduction targets which, if missed, imply that all payoffs are lost with a certain probability. Regulation by milestones imposes not only a final reduction target but also intermediate targets. In our leading example, the regulating agency is Mother Nature, but our analysis can, of course, also be applied to other regulating agencies. We are mainly testing for milestone effects by varying the size of milestones in addition to changing the marginal productivity of individual contributions and the probability of a loss.[24]

Chapter 6 looks at minimum participation rules. They are implemented in almost all international environmental agreements. Under such a rule, an agreement becomes legally binding if and only if a certain threshold in terms of membership or contribution is reached. The model is a cartel game with open membership and heterogeneous countries in order to study the endogenous choice of a minimum participation rule and its role in the success of international environmental agreements.[25]

Chapter 7 deals with a global public bad and evaluates environmental policy options in order to internalize externalities. With a focus on the Commission's proposal on reducing CO_2 emissions from passenger cars, regulation will distort competition and constrain consumer sovereignty. Political economy considerations are taken into account to identify additional problems. The study comes to the conclusion that a demand side approach is to be highly recommended. Two important lessons can be derived from the discussion. First, market-based instruments applied on the demand side (taxes or certificates) seem to be optimal to tackle the problem of CO_2 emissions generated by private transportation. Second, different voting rules applied to different environmental instruments may distort political decisions towards the direction of non-market-based instruments.[26]

Chapter 8 is dedicated to final conclusions, the central results of the different chapters and development trends of climate change policy with respect to policy implications.

[23] Leo Wangler came up with the initial idea and was responsible for the theoretical and the empirical part of this chapter. All other parts were in equal responsibility of the two authors.

[24] Leo Wangler and Hannes Koppel have developed together the basic idea and were responsible for the instructions, controll questions, data collection by running the experiment and the empirical part of this chapter. Werner Güth was mainly responsible for the mathematical formulation of the model. All other parts were in equal responsibility of the four authors.

[25] Leo Wangler has written the main part of the introduction, the literature overview and the political economy analysis. Hans-Peter Weikard and Leo Wangler have developed together the idea for the model. Hans-Peter Weikard was mainly responsible for the mathematical formulation of the model. All other parts were in equal responsibility of the three authors.

[26] Leo Wangler came up with the initial idea for this chapter and was responsible for the theoretical and political economy considerations. Bianka Dettmer has mainly contributed to the supply and demand patterns in the automotive industry. All other parts were in equal responsibility of the two authors.

Chapter 2

Political Economy of the Green Technology Sector*

2.1 Introduction

Diffusion of green technologies (GTs) is highly dependent on the institutional setting. The targets policy-makers are trying to achieve by increasing the share of electricity produced with GTs are well defined under the "Renewable Energy Sources Act" (EEG). As stated in Article (1), the EEG is an act aimed to

"facilitate a sustainable development of energy supply, particularly for the sake of protecting our climate and the environment, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to conserve fossil fuels and to promote the further development of technologies for the generation of electricity from renewable energy sources".

(EEG, 2009)

Diffusion of GTs is fostered by the definition of political targets. Up to 2010 it was the target to increase the share of renewable energy production in the internal electricity market to a level of 12.5 percent (EU, 2001) on average in all European countries. The European proposal for 2020 is to achieve a share of 20 percent (COM, 2008). Germany aims to achieve a share of 30 percent of electricity production with GTs by 2020 (EEG, 2008). The future role given to electricity produced with GTs underlines the importance of studying the legal system responsible for structural change in the energy system.

*This chapter is mainly based on Wangler (2010a). I am indebted to Andreas Freytag, Sebastian v. Engelhardt, Hannes Koppel, Oliver Kirchkamp, Georges Tanguay and Tina Wolf for helpful comments on an earlier version of this work.

The current system responsible for diffusion of GTs is best described as a command and control policy instrument (CCP instrument).[1] The aim of this chapter is to make a contribution to the assessment of the EEG and the related diffusion of GTs with a focus on efficiency. As the EEG indirectly connects supply of green electricity with demand for GTs, it was an effective tool to promote the settlement of certain GT industries. Because there is a lot of uncertainty related to the success of GTs and their future development, it is difficult to make a statement about the overall success of the EEG as a tool for industrial policy. However, we will be able to show, theoretically, that even though there might be positive effects related to the diffusion of GTs, the level of diffusion very likely turns out to be non-optimal (even though we abstract from incomplete information and transaction costs).[2] This does not necessarily mean that too much energy is produced with a certain GT j. The result of our model suggests that GTs with relatively high marginal production costs (production costs relative to the positive externality) very likely diffuse at too high levels whereas technologies with relatively low marginal production costs very likely diffuse at a level that is too low. This result is counterintuitive and new to the literature. It is in line with the empirical observation that politicians try to adjust feed-in tariffs to decreasing marginal production costs.

The outline is structured as follows: In a first step in section 2.2 we connect environmental policy to the literature of Law and Economics. We proceed in section 2.2 by giving a short overview of different studies with the focus on the political economy of environmental policy. Then, research contributions about structural change in the energy sector are reviewed. Section 2.3 describes the underlying institutions of the EEG and its antecedent, the "Electricity Feed Law" (SEG) in more detail. Section 2.4 takes a closer look at the diffusion of GTs and the related costs. What follows in section 2.5 is a theoretical model based on Tanguay et al. (2004) and the Economic Theory of Regulation developed by Stigler (1971). The model assesses the EEG from a political economy perspective. In section 2.7, the different results of the previous chapters are put together to draw a conclusion.

[1] One definition for CCPs is given as follows: "Under a command-and-control approach, government regulators specify the control technology or the maximum levels of pollution [. . .]. Other approaches, such as market-based incentives or contractual arrangements, allow sources much more flexibility to take into account variances in costs, production processes, and individual circumstances relevant to environmental protection goals." (Stewart, 1993, p. 2057, fn. 79). For further discussion of CCPs compare Ackerman and Stewart (1987).

[2] In the context of this chapter the term "inefficiency" or "non-optimality" means that diffusion is either too low or too high.

2.2 Environmental Policy and Renewable Energies

2.2.1 Environmental Law and Economics

From an economic policy point of view, it is an important question to find appropriate policy-instruments to cope with environmental problems (Pearce, 1991). Many theoretical arguments go in the direction that market-based instruments, such as taxes and tradable certificates, are superior to other approaches which do not make use of the price mechanism to deal with environmental problems (Baumol and Oates, 1988). A combination of standards and prices may also allow desirable outcomes to be achieved (Baumol and Oates, 1971). The major advantage of market-based approaches is related to flexibility and cost-effectiveness.

That environmental taxation can be used to enhance economic efficiency is based on the work of Pigou (1920). Under the existence of externalities, there is a divergence among social and private costs. Optimality would require that marginal taxes on a particular negative externality are set equal to marginal social damages. Social damages can be interpreted to be the difference between private and social costs. An ecological tax confronts polluters with the "true" social costs of the production activity, with the possible result that emissions will be reduced.

Coase (1960) challenged the common view that government activism is a first best solution to cope with the externality problem. In his seminal article "The Problem of Social Costs", Coase pointed out that under well defined property rights and negligible transaction costs voluntary negotiations are able to generate a Pareto optimal outcome. The novelty of this new paradigm lies, on the one hand, in the emphasis on making use of the legal system to overcome the externality problem and, on the other hand, the problem of transaction costs being seen as the main reason why private negotiations may not generate the social optimum. It is, therefore, of particular interest to study the legal system with a major focus on the role of transaction costs. Theoretically, an institutional setting that is in line with low transaction costs and private exchange of property rights is markets set up to allow trade in externalities. Market prices for the certificates indicate the external costs related to the externality and producers have incentives to integrate the externality into their optimization calculations (Norregaard and Reppeling-Hill, 2000).

Even though ecological taxes also have to be treated as market-based instruments, there are severe difficulties in using them efficiently, in practice. One of the problems is that a taxing authority needs complete knowledge of all relevant external costs in order to generate an optimal outcome. Taxation can only be efficient if there is complete knowledge about the externalities and the activities by which they are caused, and the related utilities, damages and marginal costs also have to be taken into consideration

(Paulus and Limburg, 1995, p. 27). In order to make taxes applicable, authorities also need to know the relative share the pollution generating source has on the total externality. The need for complete information about the related external costs makes it difficult to apply ecological taxes efficiently. The difficulty of their practical application is one of the major reasons why economists often treat ecological taxes more as a theoretical benchmark than as an efficient policy device (Paulus and Limburg, 1995, p. 28). The knowledge required in the case of tradable certificates is the total quantity of the externality that is socially acceptable. A system with tradable certificates does not require any knowledge about marginal damage or costs. This is one reason why tradable certificates seem to be a good instrument for coping with environmental problems like air pollution (Crocker, 1966). Tradable certificates also turned out to be superior to taxes by taking cost arguments into account (Dales, 1968; Montgomery, 1972). If the focus is on specific transaction costs the same conclusion can be drawn (Crals and Vereeck, 2005). Straightforward theoretical arguments for the rare use of tradable certificates are missing. Why CCPs, in general, are more often applied than market-based instruments can be explained by the political economy of environmental policy (Yandle, 1999).

2.2.2 Political Economy of Environmental Policy

Early work worth mentioning in this context has been done by Buchanan and Tullock (1975). The authors compare command and control policies with market-based instruments in competitive markets. The question is why market-based instruments in most cases are not the first choice of policy-makers. The main reason why governments more often support direct control policies is due to the lobbying activities of the regulated industries. The incentive to lobby against environmental taxes is linked to the efficiency of a penalty tax (Buchanan and Tullock, 1975, p. 140). Redistribution of property rights might be significant and firms will lobby in favor of abatement subsidies. If firms compare the penalty tax with results expected from regulation, regulation might be beneficial to a particular industry as it implements barriers to market entrance. This result also demonstrates the power of certain interest groups, as command and control policies do not increase the political budget and are therefore relatively unattractive to policy-makers.

Kirchgässner and Schneider (2003) have studied the acceptance of CCP measures by looking at the different actors who shape and influence the political outcome. The interests of four groups of actors are described in detail: voters, politicians, public bureaucrats and the owners or decision makers of those industries to be regulated. It turns out that, beside the industries which are regulated, bureaucrats have a high interest in CCP measures. This finding is mainly based on the fact that CCP "strengthens [the] [..] personal position [of bureaucrats] in the environmental policy game" (Kirchgässner and Schneider, 2003, p. 380). The constitutional setting of the political process seems to be important for the success of market-based instruments (e.g. taxes or certificates). Decentralized systems tend to be closer to individual preferences and seem to be more successful in implementing environmental reforms that favor the public interest. Elements of direct democracy are instruments that are equally important. Compensating citizens with general tax reductions might also help in implementing ecological taxes or tradable permits. That environmental taxes do not always increase the budget of policy-makers is the result of a study by Fredriksson (2001). Taxes may have the surprising effect of decreasing the revenue of the government. This is mainly due to the fact that industries are likely to lobby for abatement subsidies.

How citizens have been successful in a political contest against a monopolistic energy supplier in Germany is described by Graichen et al. (2001). The authors use a case study to demonstrate that self-organization of citizens with respect to energy production can be successful. A theoretical model shows the determinants necessary to get the results reported in the study. Thalmann (2004) uses an empirical approach to find the determinants behind the failure to implement ecological tax reform measures in Switzerland. One result shows that awareness of the expected social benefits of ecological tax reforms is important. The failure of the referendum is mainly explained by a misunderstanding the expected benefits. The influence of different political systems on environmental regulation has been analyzed by Fredriksson and Wollscheid (2007). Contrary to suggestions in the literature, they did not find support for the hypothesis that democratic systems have a significant positive effect on environmental stringency. Their findings are based on an empirical cross country analysis involving 163 countries. Fredriksson et al. (2007) use an empirical approach to determine whether corruption hinders or facilitates environmental lobbying. The panel they use includes 170 countries. They found that an increase in environmental lobbying had a significant impact on the probability of ratification of the Kyoto Protocol. The positive impact they found was additionally positively correlated with the degree of corruption within countries. Tanguay et al. (2004) use an extended theoretical approach to Stigler's theory about public interest in the context of environmental regulation.[3] The empirical study supports the view that with respect to environmental regulation interest groups have an influence on the political outcomes and distort optimal results.

2.2.3 Change in the Energy System

The history of renewable energies is quite old. As stated by Sørensen (1991), during a long period of human history, renewable energy was the only energy option available.

[3]The approach proposed by Stigler was criticized by Posner (1974) because of the need for formalization of the model. A first formalization was made by Peltzman (1976). Therefore, in the literature the Stigler model is often called *Stigler-Peltzman-Model*.

The emergence of conventional energy production came about mainly due to the cost argument. Nowadays, the increase in prices for fossil energy sources, as well as environmental damages, are the main reason why policy-makers are again focusing on GTs (Sørensen, 1991, p. 10). In the context of environmental damages, global warming plays an important role. The argument for sustainability is used as an additional argument to justify diffusion of GTs (EEG, 2004). However, once the interest rate related to extraction of non-renewable energy is affected by investment into so-called "backstop technologies" (Nordhaus, 1973),[4] the speed of extraction can be assumed to increase rather than to decrease. This counterintuitive result mainly builds on well known theoretical arguments coming from environmental and resource economics (compare among others Hotelling, 1931; Dasgupta and Heal, 1974). Theoretically, diffusion of backstop technologies could evolve endogenously once a change in relative prices for conventional energy makes investment into GTs profitable (Nordhaus, 1973). It can be seen that there is a lack of straightforward theoretical arguments that justify a managed transition towards an energy system that mainly builds on GTs (compare also Sinn, 2008).

Dröge and Schröder (2005) evaluate whether subsidizing the green sector or taxing the polluting sectors are more efficient instruments to turn an industry green. They use simulation analysis and come to the result that a tax would be the optimal political instrument. If the sector polluting the environment is economically important, a subsidy of the green sector (e.g.t̃he GT sector) is also acceptable. The pioneering work of Nordhaus (1973) has been developed further by Chakravorty et al. (1997). The authors distinguish between the extractions of different resources. The simulation results show that if a shift towards a primary use of solar energy was to become profitable, the increase in world temperatures turns out to be less than predicted by the United Nations Intergovernmental Panel on Climate Change. Even though they have focused on the technology of solar energy in their study, other "backstop technologies" may also play a role.

A review of the demand for green power is presented by Bird et al. (2002). The study gives an overview of the demand for contracts for electricity produced with GTs in countries like Australia, Canada, Japan, the US and several countries in Europe. In some countries the market share of contracts for green electricity is about 10 percent. At the global level, the average market share for such contracts was relatively low and did not exceed 1 percent. Factors that can be considered as driving forces for an increasing market share of green electricity contracts are customer education, aggressive marketing, price and transparency (e.g. product labeling) (Bird et al., 2002, p. 530).

More common than studies about the demand for green electricity are studies focusing on the supply of green technologies. Studies using a supply-side approach in

[4]Technologies able to produce energy without the use of non-renewable energy sources.

most cases give an overview of the policy-induced structural change related to GTs and the driving forces behind it. Jacobsson and Lauber (2008) describe in detail the development of the GT sector and the factors which have been important in its evolution. Their main argument is that the evolution of the GT sector in Germany was a "battle over institutions" between conventional energy producers and the renewable energy supporters.

The apparent success of feed-in tariffs (FITs) is summarized by Wüstenhagen and Bilharz (2006).[5] In section 2.3 and 2.5 we will describe in more detail the interesting fact that feed-in tariffs are able to connect supply/demand for a certain GT j with the supply/demand of green electricity. Langniß et al. (2008) study the institutional setting in Germany and develop policy conclusions by detecting parameters influencing the likelihood of political support for GTs. Agnolucci (2003) analyzes factors that can be considered as the main drivers for institutional change within the energy sector. With respect to the results, financial sustainability is a decisive factor. Furthermore, it has been found that different political factors, such as size and variety of coalitions, play a major role. Initiatives on the implementation of green technologies coming from the European Union (EU) play a similar important role (Agnolucci, 2003, pp. 148).

So far, the main findings can be summarized as follows. First, if we were to build an institutional arrangement for internalization of negative externalities related to conventional energy production, tradable certificates turn out to be a kind of first best solution. This result can be simply derived by application of the Coase theorem. The review of recent public choice literature has shown that beside the "'desirability" of environmental policy, the political process has some shortcomings leading to different results from those initially intended. Third, several studies assess the determinants of structural change towards a more environmental oriented policy and support for the GT sector. Structural change in the energy system is something that can be observed from different perspectives. The following section introduces the institutional framework enabling energy production by GTs in Germany.

2.3 Institutional Framework

The diffusion of GTs and production of green electricity in Germany, as well as in other countries, depends on the institutional setting implemented by the government. Even though development of GTs had already begun in the 1970s, expansion of the technology was restricted. This was mainly due to the political energy strategy. The main focus was on conventional technologies and monopolistic markets (Toke and Lauber, 2007, p. 683).

[5] A feed-in tariff is a "minimum price standard that obliges distribution network operators to connect [green electricity power plants], to purchase [green electricity] and to pay a fixed remuneration (cents per kWh) to the plant operator" (Langniß et al., 2008, p. 3).

In this section, two important institutional changes enabling innovation and diffusion of renewable energies and the production of green electricity are analyzed. The first important institutional change was the *Electricity Feed Law*, and the second the *Renewable Energy Sources Act*.

2.3.1 Electricity Feed Law

The SEG entered into law in January 1991 (Toke and Lauber, 2007, p. 683).[6] It was a simple feed-in mechanism with a guaranteed price for electricity that was fed into the electricity network based on a certain percentage of the average "market price" for conventional energy. The feed-in tariff was between 75 percent (for WATER and BIO) and 90 percent (for SOLAR and WIND) of the market price. As the market for electricity was monopolistic, the SEG can be considered as a first small step allowing for decentralized energy production and some kind of subtle competition.[7] Due to the still outstanding liberalization of the market, electricity prices were relatively high and stable (Mitchell et al., 2006, p. 298). Therefore, the SEG already allowed especially the wind energy sector to enter into the market and to produce a certain percentage of total electricity supply. The share of renewable energies increased at a relatively constant rate from year to year (this will further be evaluated in section 2.4). With respect to decentralization of the energy market as well as an increase in competition, the SEG can be considered a success. With respect to the monetary transfer, it seems clear that the diffusion of GTs was very limited. Cost intensive technologies, especially, such as photovoltaics, were not able to diffuse with high growth rates. In the progression from the SEG to the EEG, the liberalization of the electricity market in 1998 plays a notable role. Based on the liberalization (at least in the short run), the prices for electricity decreased and so did the monetary support transferred to GTs.[8] It can be argued that this was one of the reasons why the implementation of the EEG –introduced in the next section– became necessary (Mitchell et al., 2006, p. 298).

2.3.2 Renewable Energy Sources Act

The argument that the motivation behind the EEG was the liberalization of the energy market cannot be considered a satisfactory explanation. Political factors also play an important role. When, for the first time, the Green Party became part of the federal

[6] This was done by the coalition government of the Christian Democrats and the Liberal Party.

[7] Competition has a lot of *desirable* elements. For a more fundamental discussion about competition and economic policy see Eucken (1955, 1965).

[8] In the following the word *subsidy* is avoided to describe the monetary transfer to the GT sector. Instead of *subsidy* the term *policy induced demand* is used as a subsidy directly reduces the political budget. As in the case of GTs, the monetary transfer does not have direct impact on the federal budget, the welfare effects can only be simulated by using a general equilibrium approach. Therefore, the notation support (shifting rents to the GT sector) seems to fit better in the case of this model.

government in 1998, a fundamental reform with regard to energy production was decided.[9] There was political interest in supporting the expansion of the GT sector.[10]

FITs were used as a tool for industrial policy in certain GT industries. The EEG has many elements often described as CCPs,[11] and was installed on April 1, 2000. There are notable studies which compare the EEG with the British Renewable Obligation (RO). The RO is more market oriented. It was the political aim in Great Britain to allow for "maximum competition" in order to make the system as efficient as possible (Toke and Lauber, 2007, p. 681). It is quite surprising, in this context, that many studies find that the EEG allowed for diffusion of GTs at lower costs than the British RO system (Mitchell et al., 2006; Toke and Lauber, 2007; Butler and Neuhoff, 2007). Certainty about expected payoffs under the EEG may play an important role.[12] The experience with the British RO system somehow weakens the theoretical prediction that market-based instruments, in general, are superior to CCPs. What seems to be important in the case of supply of green electricity is to take the supply of GTs adequately into account. As mentioned before, the EEG connects green electricity production with diffusion of a certain GTs j. However, a supposition would be that a market-based approach for supply of GTs combined with tradable certificates for green electricity could generate a comparable result with a higher degree of efficiency.

The EEG is constructed in a way that requires electricity network operators to:

- connect GTs to the network;
- accept the entire electrical output produced by GTs;
- remunerate the producers of "green" electricity at a pre-determined rate for each KWh electricity produced.[13] The remuneration is foreseen to decrease slightly over time and is *guaranteed for 20 years.*

With respect to growth in the GT sector, it has to be mentioned that the EEG does not put any upper capacity limits on the diffusion of the technology. The following formula

[9] The decision was to substitute nuclear energy with other sources of energy supply.

[10] This is mainly due to the fact that the Green Party has its roots in the opposition to conventional energy supply (Wüstenhagen and Bilharz, 2006, p. 1682).

[11] This means that under the EEG certain technologies are selected ex-ante. In order to allow diffusion of different technologies, feed-in tariffs have to be set at different levels and therefore imply discrimination between different technologies.

[12] One of the main advantages of the British RO system is related to the fact that it is non-technology specific, meaning that it is not attempting to pick winners (Mitchell et al., 2006, p. 299). Energy suppliers are forced to buy a certain percentage of renewable obligation certificates (ROCs, 1 ROC=1MWh). ROCs are tradable and can be bought directly from the GT supplier or other suppliers. One of the main criticisms of the RO system is the uncertainty about future prices for ROCs and electricity. Therefore, a high risk premium increases the price for energy produced by GTs (Toke and Lauber, 2007, p. 682).

[13] The remuneration is also given to those plants which do not feed into the general network of electricity.

summarizes how $FITs$ are used by the German government as a tool for industrial policy:

$$FIT_{tvj} = FIT_{Tj}(1 - d_j)^{v-T} + k_j. \tag{2.1}$$

Specific remuneration per kilowatt-hour is denoted by $FIT\ j$, t represents the actual year of remuneration and T is the base year when the EEG was established. The starting year of operation is characterized by v, technology specific industry (SOLAR, WIND, ...) is indicated with j, d is the degression rate and the parameter k indicates additional premiums for innovative technologies (Langniß et al., 2008, p. 4). With respect to k_j, the future potential of certain technologies is taken into consideration. The different feed-in tariffs established are summarized in table 2.1.[14] [15]

TABLE 2.1: Remuneration (FIT) for different GTs

Technology j	Remuneration (2000-2003) (cents/KWh)	Annual Reduction (d)
Wind (WIND)	9.1	1.4%
Solar (SOLAR)		
Capacity$<$ 100KW	51.62	5.0%
Plants on building capacity $<$ 5 MW	48, 1	5.0%
Biomass (BIO)		
Capacity$<$ 500KW	10.0	1.0%
Capacity$>$ 500KW$<$ 5MW	9.0	1.0%
Capacity$>$ 5MW$<$ 20MW	8.5	1.0%
Hydro (WATER)		
Capacity$<$ 500KW	7.67	0%
Capacity$>$ 500KW$<$ 5MW	6.5	0%
Landfill and sewage gas (BIOGAS)		
Capacity$<$ 500KW	7.67	1.5%
Capacity$>$ 500KW$<$ 5MW	6.5	1.5%
Geothermal plants (GEO)		
Capacity$<$ 20MW	8.5	0%
Capacity$>$ 20MW	7.0	0%

Table 2.1 shows that the EEG sets remuneration rates differently for different GTs j. The range in 2003 was from 6.5 cents/KWh for electricity produced by using WATER and BIOGAS up to 51.62 cents/KWh for electricity produced using SOLAR. The comparison of the different technologies with respect to the feed-in tariffs is not as simple as it seems

[14]For a detailed overview of different feed-in tariffs related to the SEG and EEG compare App. A.1, p. 195, table A.2

[15]Note that the EEG has been renewed in 2004 and 2009. The numbers with respect to the feed-in tariffs for GT_j as well as the depreciation rate d have changed. Overall, it can be said that the feed-in tariffs have decreased whereas d has increased slightly by about 1 percent on average.

to be at first glance. As each technology also has different features, it can be argued that different feed-in tariffs are justified.[16]

2.3.3 Arguments for Different Feed-in Tariffs

Because GTs were not so much elaborated on due to reduced commercial use in the past, learning curves seem to be important, especially regarding the development of technologies like SOLAR or WIND (Isoard and Soria, 2001; Wene, 2008, pp. 21). Technologies like SOLAR might be promising regarding future energy generation, so that higher feed-in tariffs might be justified (compare figure 2.1).[17] The general argument goes as follows: Governments can generate positive welfare effects if they set artificial markets for new energy technologies. The learning process can lead to the result that technologies which would otherwise be too costly become cost efficient. As the manufacturing firms that produce a certain technology compete in the market, production costs will decrease and technical performance will increase. Uncertainty and market dynamics allow that the whole process will be accompanied with positive spillovers (e.g. innovations). Thus, a successful deployment program can provide what markets might not provide by themselves, namely the diffusion of certain GTs at high levels combined with certain political targets such as the reduction of greenhouse gas emissions (GHG emissions) (Wene, 2008, p. 16).

Figure 2.1 illustrates how learning has an effect on production processes with a focus on input and output (e.g. at the company level). The E in figure 2.1 represents an experience parameter. Therefore, as diffusion leads to a higher level of experience, output can increase for a given level of input, or less input is necessary in order to produce the same level of output. All in all, the technology gets cheaper and more cost efficient (Isoard and Soria, 2001; McDonald and Schrattenholzer, 2001).

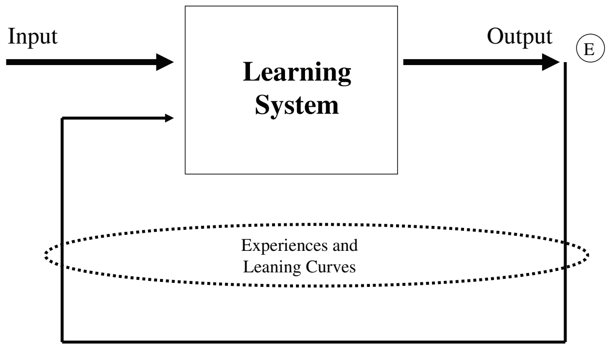
Dynamic effects are a strong argument to explain discrimination between different technologies. Nevertheless, two arguments have to be looked at separately from each other – reduction of GHG emissions (IEA/OECD, 2000, 2003) and industrial policy in order to foster development of "backstop technologies". If the main reason to support a certain GT j is to reduce GHG emissions, the argument is that the investment *should* go to the cheapest technology available in order to achieve a certain target of emission reduction.[18] This would be an argument against discrimination between different technologies. Apart from this, one can also argue that certain technologies have a high future potential so that it might be desirable to allow diffusion of these technologies because

[16]As the sun shines only in daytime, SOLAR cannot produce electricity during the night. WIND can produce electricity during the night, but the amount of energy produced is not very constant.

[17]Especially in the case of SOLAR learning curves are very important (Zwaan and Rabl, 2003; Tributsch, 2004; Zwaan and Rabl, 2004).

[18]Investors would be able to take cost reductions due to learning curve effects or economies of scale into account, and the investment would go into the cheapest technology able to achieve the political target.

FIGURE 2.1: Input output model based on learning curves



Own illustration following Wene (2008); IEA/OECD (2000).

they might become important for energy production on large scales in the near future.[19] Even though the second argument can be criticized because of the pretension of knowledge (Hayek, 1945), it seems to be the main reason why policy-makers discriminate between different feed-in tariffs. If one accepts the second argument, there is still the question of the optimal level of diffusion.

2.4 Diffusion and Costs of Green Technologies

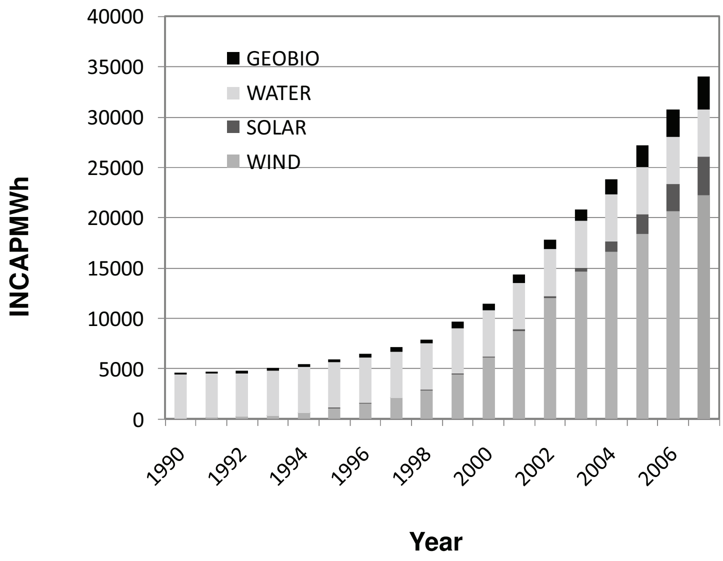
This section gives a short overview of the diffusion of green technologies and the related costs.

2.4.1 Diffusion of Green Technologies

The diffusion of GTs is well documented by the Federal Ministry for the Environment, (Nature Conservation and Nuclear Safety) (BMU) (compare table A.2, page 194). The total share of renewable energies of the gross electricity supply in 2005 was 10.4 percent (BMU, 2008, p. 13). In figure 2.2, it can be seen that the installed capacity for WIND increased strongly. The installed capacity for WATER remained at a relatively constant level. SOLAR increased after the implementation of the EEG (after the year 2000) whereas for GEOBIO there was a relatively constant but smooth increase of the total capacity installed .

[19]There remains the question why private investors would not be able to detect this future potential.

FIGURE 2.2: Diffusion of GTs, measured by installed capacity in MWh (INCAPMWh)



Data source BMU (2008).

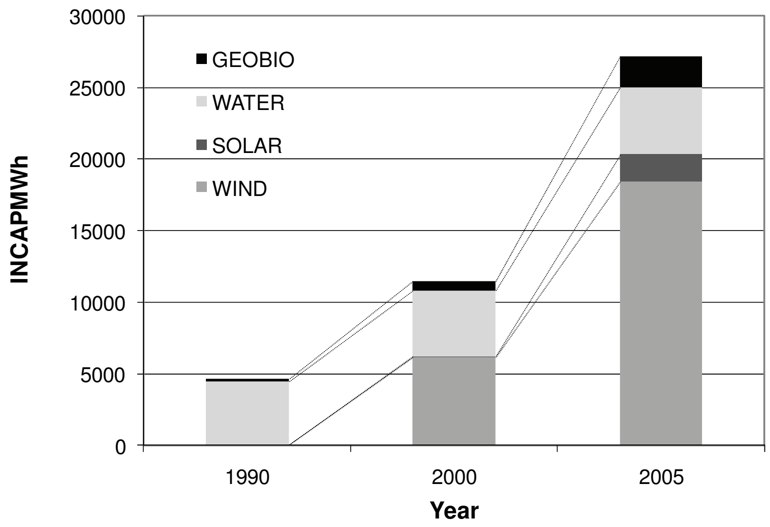
Figure 2.3 contains information about the growth of the stock of installed renewable energies (measured by INCAPMWh[20]). By looking at the stock of installed capacity in 1990, 2000 and 2005, the SEG (1990-2000) and the EEG (2000-2005) can be compared. If the connecting lines between the two blocks remain parallel, the installed capacity did not increase over time. It can be seen that under the SEG the stock of WIND increased and WATER remained more or less constant. GEOBIO increased at a lower rate. In the year 2000, SOLAR represented only a small share of total INCAPMWh. Under the EEG, in 2005 the overall share of installed capacity of GTs had more than doubled compared to the year 2000. Within five years there was a doubling of the installed capacity for GEOBIO. WATER still remained at a relatively constant level. In contrast to this, the stock of SOLAR increased notably. The share of WIND also grew by a large scale. The stock soared by about 200 percent.

The German government set a target that the share of gross energy consumption produced by renewable energies be 12.5 percent by 2010. This target was reached in 2007 (BMU, 2008, p. 8). The long-term political target is to reach a share of 30 percent of electricity produced from GTs in 2020. On the EU level ambitious targets have also been installed. Until 2020 a share of 20 percent of total energy consumption shall be provided by GTs.[21]

[20]Installed capacity of electricity measured in megawatt-hours.

[21]Note, that with respect to this political target, the debate is not only about electricity but also about technologies that allow to substitute conventional energy consumption like gasoline or heating with bio fuels or geothermal energy.

FIGURE 2.3: Stock of GTs, measured by installed capacity in MWh (INCAPMWh)



Data source BMU (2008).

2.4.2 Costs Related to the Renewable Energy Sources Act

As the German network for electricity is separated into four regions and is run by a different operator in each region, a clearing mechanism is needed to make sure that the costs for the network operators related to the feed-in tariffs are fairly allocated (Langniß et al., 2008, pp. 5). The average costs of remuneration are about 10.87 cents/KWh. This is approximately twice as much as the market price for conventional energy. In 2006, the total costs for remuneration were about €5.6 billion (four times the costs in 2001).[22] The costs related to the EEG can be translated into a price per KWh. The EEG (in 2006) accounted for an additional 0.7 cents/KWh, which is about 3.7 percent of the average price for electricity (calculated with a price for private consumers of 19.4 cents/KWh) or 11.6 percent, respectively, if the market price for electricity is 6.0 cents/KWh (Langniß et al., 2008, p. 2). At first glance the numbers are not really astonishing and seem to be surprisingly low. Therefore, one could argue that the EEG was able to reach its political targets at relatively low costs. Such a conclusion would be far to easy because of the long-lasting cost-effects related to the EEG. It has to be mentioned that according to the forecasts for 2013, annual remuneration will increase to €12.6 billion (Langniß et al., 2008, p. 2).

In the reference year 2006 about half of the money collected under the EEG went into WIND. Twenty per cent of the money went into SOLAR. Even though the monetary

[22]Of course from this total number the market value of the output has to be subtracted. The total costs related to remuneration are therefore smaller and are about €3.7 billion.

support for photovoltaics is relatively high, SOLAR produces a rather small share of about 4.3 percent of all remunerated renewable electricity (Langniß et al., 2008, pp. 2).

The main findings can be summarized as follows: From a static perspective, costs seem to be rather low. As it turned out in section 2.3, many studies state that the German feed-in system performs better than the British RO. The strength related to FITs can obviously be found in the connection between supply of green electricity and demand for GTs within one policy instrument. This argument seems to be important, as the market for GTs had first of all to be developed. A market-based approach might underestimate the important connection between demand for the technology and its supply. This might be a factor generating relatively high costs for supply of green electricity under the British RO. Nevertheless, it is predicted that the costs for the EEG will also increase during the next years. On the one hand, guaranteed FITs give necessary stability for investors and the increase in electricity prices under the EEG in 2006 seem to be considerably low. On the other hand, it might be that some of the investments will turn out to deallocated resources over several decades so that problems related to the future development of electricity prices should not be underestimated.

This short description of the concept of environmental regulation, as well as the overview of diffusion and costs related to the SEG and EEG, shall be used as background information for the following theoretical section. The basic assumption of the model is that the GT sector is assumed to generate positive externalities. What seems to be interesting, in taking arguments of political economy into account, is to look at whether the feed-in tariffs can be considered to be *optimal* from a *short-term perspective* in order to evaluate the efficiency/inefficiency related to the EEG from a *long-term perspective*. This question shall be further elaborated by using a political economy approach.

2.5 Political Economy Approach

The model presented in this section builds on a model developed by Tanguay et al. (2004). A distinction has to be made between the theory of public interest (TPI) and the economic theory of regulation (ETR).

2.5.1 Theory of Public Interest

TPI is based on the microeconomic theory to detect market failure, which is used as an argument to justify political intervention. Market failure, like the problem of externalities, can be corrected with the authority of the state. The aim of political intervention is to reinstall optimal resource allocation. The equilibrium derived under TPI can be considered as the optimal solution for the problem of failed markets (the optimal solution of course is unrealistic in a sense that it builds on the assumption of zero transaction costs as well as complete information).

Even though there are many doubts regarding the positive impact of the GT sector, the argument of positive externalities shall be used as a justification for why it is rational for politicians to support the GT sector. The market created by politicians, by installing a law enabling the diffusion of GTs, might generate positive welfare (because of job creation, positive environmental effects or the export of the technology in the near future) so that this can be interpreted as a positive externality (if benefits are higher than the related costs).

As discussed in section 2.3, the institutional setting of the EEG is constructed in order to allow diffusion of different GTs *j*. The FIT can be interpreted to have generated a *policy induced demand for* GTs. From an economic perspective, diffusion of GT *j* can be considered to be "desirable" as long as it is accompanied by positive externalities. Under the assumptions of complete information and non-existing "state failure" one can calculate the optimal policy induced demand for a certain GT. This optimal demand will determine the optimal size of the GT sector and will ensure that marginal increase in demand is equal to marginal welfare gains.[23]

2.5.2 Economic Theory of Regulation

Even though economists sometimes seem to ignore the fact that beside market failure there can also be the problem of state failure, it is common knowledge that democratic systems fall far short of generating optimal resource allocation. Even if they tried to maximize a social welfare function, there is no way to aggregate preferences in a way that the outcome is efficient (Arrow, 1951). Additionally, governments often try to make decisions favoring special interests. In this case, the established policy simply reflects the relative electoral weight of different interest groups.[24]

The political weight depends on votes or other factors able to generate political power, such as monetary and non-monetary contributions. This model seems to fit very well with the evolution of the green technology sector in Germany under the "red-green coalition" (1998-2005). The ETR model is closely linked to the theory of the "demand" for industrial regulation developed by Stigler (1971). In his "economic theory of regulation" he developed a model in which demand for regulation (in our case policy induced demand) comes from interest groups that can be considered able to benefit from legislation. The supply for the enhanced well-being of interest groups is distributed by

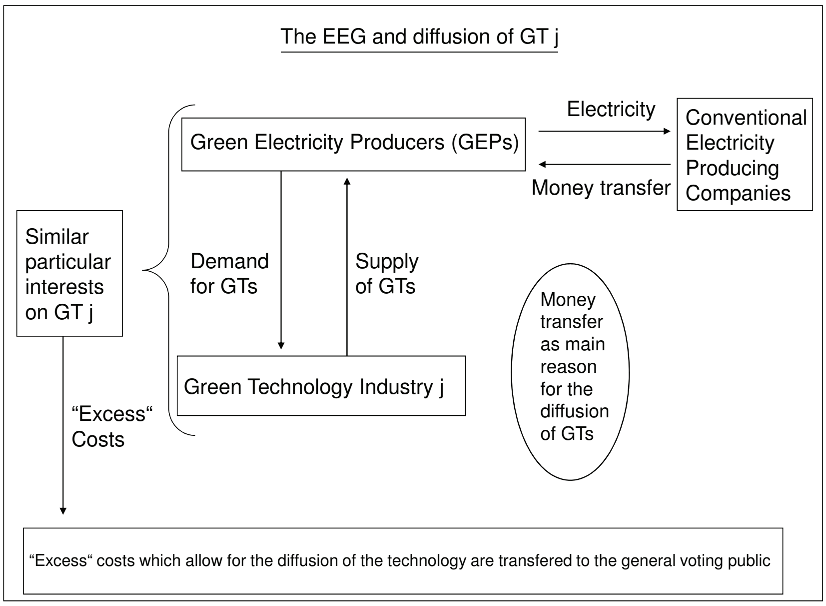
[23]The welfare gains will be related to future exports of the technologies. There might also be positive externalities due to job creation in the GT sector or positive environmental effects.

[24]This fact was mainly highlighted by Olson (1965). He states that in the political process small interest groups often exert more influence than larger groups. One of the reasons is that for larger groups it is more difficult to organize themselves because of higher costs.

the incumbent government which aims to maximize current political support. Therefore, politicians can be considered to be political entrepreneurs (Schumpeter, 1987a) in our model. Politicians try to maximize votes in order to be re-elected.

According to this model, regulation is not only the result of market imperfections. What is declared to be market failure in many cases is also linked to state failure (this might also explain the problems related to the British RO system). As a result, the welfare effects might be rather low or in some cases even negative. The success of special interest groups depends on their ability to organize their interests and their importance to the incumbent government. The incumbent government uses its coercive power in favor of special interest groups with the aim of being re-elected. The model developed by Stigler (1971) is also useful to explain the success of the GT sector in tapping resources. Nevertheless, there is one important difference between the model used in this paper and the approach by Stigler (1971). The Stigler model explains why producer protection might prevail over consumers' interest. In our model green electricity producers (GEPs) can be both, consumers and producers of electricity. As figure 2.4 shows, the institutional design for the GT sector is constructed in a way that some "privileged" producers of green technology (owner of the GTs) and the GT industry *j* both profit from the policy induced demand.

FIGURE 2.4: Mechanism related to the EEG



At first glance, it also seems that the big energy companies have to pay the bill. But this is obviously not the case as long as demand for electricity is inelastic. The higher costs related to the policy induced demand for GTs will finally be transferred to citizens in form of higher energy prices. From this perspective, the EEG fits very well with what Peltzman (1976) calls the "law of diminishing returns to group size". One can argue that the interests of the GT sector and those citizens who gain from the EEG simply outweigh the interests of society as a whole because they are better organized, better informed or simply because they influence the political outcome more actively.[25] It also turned out in section 2.4 that the price per KWh of electricity which the EEG can be blamed for, is relatively low. Consumers may face cost illusion with respect to the EEG.

2.6 Theoretical Model

The EEG is constructed in such a way that the money enabling the expansion of GTs is paid by the electricity producing companies which then are assumed to transfer the costs to the consumers (general voting public). This is shown in figure 2.4. The users of GTs produce green electricity and the output (electricity) can be fed-in into the electricity network. GEPs can be households, communities, small companies, farmers and others. The remuneration per KWh electricity depends on the GT j (for the different feed-in tariffs compare table A.2, p. 195). This mechanism generates an "artificial" demand for electricity produced with GTs. Therefore, the possibility to feed-in electricity for a guaranteed remuneration has an indirect impact on the production and diffusion of GTs. Figure 2.4 also shows that GEPs, as well as companies producing GTs, have an interest to at least keep the feed-in tariffs at a constant level. It also seems to be clear that both interest groups would not be against political decisions in favor of an increase in remuneration. In contrast to this, it can be expected that political decisions towards a reduction in feed-in tariffs would be accompanied by counter-lobbying of GEPs as well as GT producers. The "excess costs" for electricity production are transferred to the general voting public. Therefore, two markets are assumed to have the same interests. Namely GEP and GT producing companies. That FITs combine demand for GTs with supply of green electricity can be demonstrated as follows: In a first step we look at the GEP market and in a second step at the GT industry j.

[25] This does not mean that there are no limits for an optimal group size. Two opposite effects can be distinguished. On the one hand, one can argue that the larger the group the higher the influence on the government. On the other hand, the organization costs also increase with the group size. As the share of the rents will decrease, the increasing organization costs put limits on the growth of the group size. Compare also Peltzman (1989).

2.6.1 Green Electricity Production Level

In the case that the government does not regulate demand for green technologies, the market share is set to zero. $ENPV_j^{GEP}$ is the expected net present value for the investment into GT j. Therefore,

$$ENPV_j^{GEP} < 0$$

with

$$ENPV_j^{GEP} = -p_j + \frac{ES^{t1}}{(1+r)} + \frac{ES^{t2}}{(1+r)^2} + \cdots + \frac{ES^{tn}}{(1+r)^n}. \tag{2.2}$$

The length of the periods is given by n, p_j stands for the price of GT j, r is the opportunity cost of investment and ES is the expected surplus a GEP can make in period t. In each period the individual surplus of GEP i is given by

$$ES_{ij}^{tg} = x_{ij}^{tg}(FIT_j^{tg} - c_j^{tg}). \tag{2.3}$$

x_i^{tg} is the quantity of electricity produced by the particular producer i in period tg ($g \in [1, n]$),[26] c_j^{tg} are marginal costs and FIT_j^{tg} is the feed-in-tariff for technology j in period tg. Note that it is rational for GEP i to invest into GT j if $ENPV_j^{GEP} \geq 0$. Figure 2.5 shows the construction of the inverse demand curve (GEP market). It is assumed that there is a linear relationship between feed-in tariffs and $ENPV$.

2.6.2 Green Technology Production Level

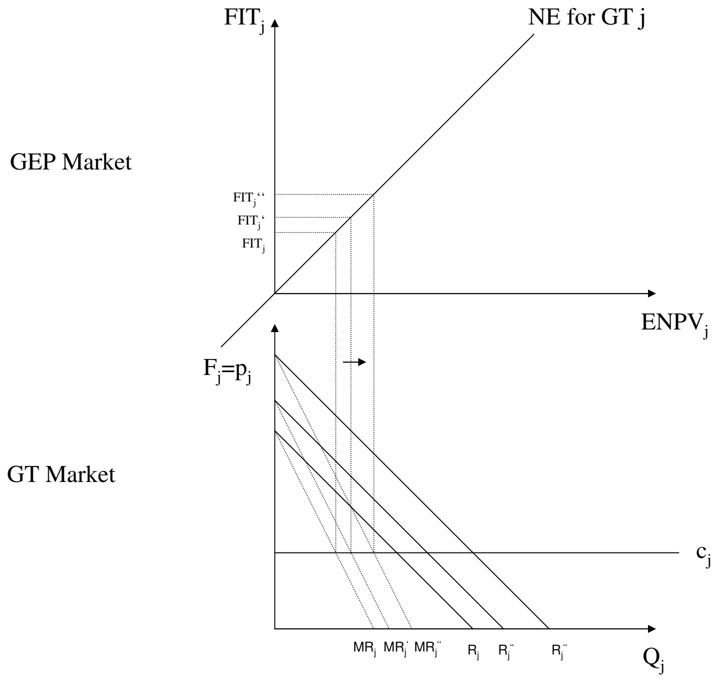
Consider N_j to be identical firms operating in different sectors (SOLAR, WIND, WATER, GEO and BIO). Firms are assumed to compete in their particular sector. The GT market is described by imperfect competition à la Cournot.[27] Marginal costs (c_j) are assumed to be constant for a given period t ($c_j > 0$).[28] If the different GT industries j are compared, it is plausible to assume different production costs c_j for the technologies. The sector-specific demand is assumed to be linear and will be zero without policy induced demand for

[26] Note that x_i^{tg} has to be different between different GEPs as the input factor to produce electricity (e.g. sun, wind or water) is exogenous and differs between regions.

[27] It is plausible not to assume complete competition in this case, because the GT sector is dependent on monetary transfers (in the following simply called policy induced demand). If productivity gains lead to lower production costs, firms make higher profits because the feed-in tariffs are relatively constant. It also seems to be clear that high research and development R&D expenditures can only be financed by the companies if enough rents remain within the firm. Among others, Dröge and Schröder (2005) state that with respect to the GT sector imperfect markets can be assumed.

[28] Note, that this assumption only holds for a given point in time t. This assumption does not contradict the assumption of learning curves discussed in subsection 2.3.3, meaning that over time decreasing marginal costs are assumed to be $c_{t+1} < c_t$. Nevertheless, for every period marginal costs can be taken from the "learning curve" and can be assumed to be constant at the given point in time.

FIGURE 2.5: Deviation of the inverse demand curve



GTs (there is no intersection between MR and c_j). Inverse demand without induced demand is given with

$$p_j = 1 - Q_j, \tag{2.4}$$

where p_j stands for the price of the technology produced by the GT industry j and Q_j is the total output produced by the N_j firms in the industry j. As the feed-in tariffs generate induced demand for GTs we integrate the effect as an indirect marginal subsidy labeled as pid_j (policy induced demand) into the model. Therefore

$$\begin{aligned} p_j - pid_j &= 1 - Q_j, & (2.5) \\ &= 1 + pid_j - Q_j. & (2.6) \end{aligned}$$

Because of the symmetry assumption at the firm level, the output is assumed to be the same for each firm so that $Q_j = N_j q_j$. The *residual* demand on the firm level can be written as

$$p_j = 1 + pid_j - (N_j - 1)q_j - q_j. \tag{2.7}$$

Note that $(N_j - 1)q_j$ is the demand of all other firms. The marginal revenue at the firm level is given by

$$MR_j = [1 + pid_j - (N_j - 1)q_j] - 2q_j. \tag{2.8}$$

The EEG allows the GT sector to diffuse. Firms maximize their profits at $MR = c_j$. Taking (2.8) into account the quantity of output produced by one single firm is given by

$$q_j^* = \frac{1 - c_j + pid_j}{(N_j + 1)}. \tag{2.9}$$

Multiplying q_j with N_j leads to the total output Q_j^* which is

$$Q_j^* = \frac{N_j(1 - c_j + pid_j)}{(N_j + 1)}. \tag{2.10}$$

Using (2.10) for the market demand gives p^* which is

$$p_j^* = 1 + pid_j - \frac{N_j(1 - c_j + pid_j)}{(N_j + 1)}. \tag{2.11}$$

The results from (2.9) and (2.11) can be used to describe the profit of one single firm. This profit is given by

$$\pi_j^* = (p_j^* - c_j)q_j^* = \frac{(1 - c_j + pid_j)^2}{(N_j + 1)^2}. \tag{2.12}$$

Total profits generated by the GT industry j are given by $\pi_{jT}^* = N_j \pi_j^*$.

2.6.3 Political Process

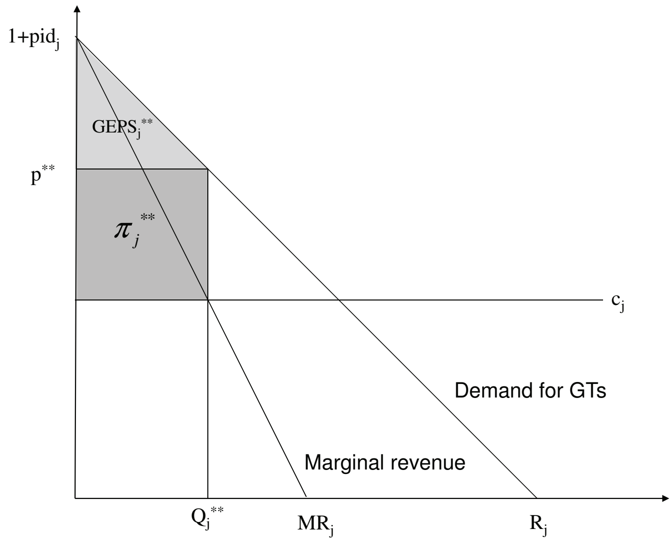
TPI transfers

TPI policy induced demand leads to the optimal outcome without any state failure. It is assumed that welfare W (compare equation 2.13) generated by the GT industry j derives from three different sources. The first positive effect is given by the GEP surplus ($GEP = 1/2 * Q_j^* * (1 + pid_j - p_j^*)$) generated by those who buy GTs. They receive a state guaranteed positive remuneration for the electricity fed-in. Additionally firms earn a profit which is denoted by π_{jT}. The third term enters with a negative sign into the equation and is given by the policy induced demand minus the positive effect (b_j) expected from GTs times Q_j^*. The optimal solution can be found by choosing the policy induced demand pid_j able to maximize welfare(compare figure 2.6).

Optimal pid_j^* generates an optimal welfare level W_j^*. It follows

$$\max_{pid_j} \quad W_j(pid_j) = GEP_j + \pi_{jT}^* - (pid_j - b_j)Q_j^*. \tag{2.13}$$

FIGURE 2.6: Optimization of welfare under TPI (for A=B)



The partial derivative from (2.13) with respect to pid_j leads to

$$\frac{\partial W_j}{\partial pid_j} = \frac{N_j}{(N_j+1)^2}[b_j(N_j+1)+1-c_j-pid_jN_j]. \quad (2.14)$$

Therefore the optimal policy induced demand pid_j^{TPI} is given by the solution for the first order condition which is

$$pid_j^{TPI} = \frac{b_j(N_j+1)+1-c_j}{N_j}. \quad (2.15)$$

Equation 2.15 gives an interesting insight. Note that for $b_j = 0$ and $c_j < 1$ there would still be an optimal policy induced demand. This is related to the fact that in the model it is assumed that governments are able to correct for market imperfections in the case of oligopolistic markets.

By substituting pid_j^{TPI} into the equations for price, total output and total profit, the corresponding welfare level can be calculated. This leads to

$$p_j^{TPI} = \frac{b_j + 1 + c_j({}_jN_j - 1)}{N_j} \tag{2.16}$$

$$Q_j^{TPI} = b_j + 1 - c_j \tag{2.17}$$

$$\pi_{jT}^{TPI} = \frac{(b_j + 1 - c_j)^2}{N_j^2} \tag{2.18}$$

$$W_j^{TPI} = \frac{(b_j + 1 - c_j)^2}{2} \tag{2.19}$$

ETR transfers

ETR policy induced demand leads to an outcome which takes the political process into account. In democratic societies it is very likely that policies are not in line with the interests of the general voting public (our TPI regime) because of vested interests. The policies established to fulfill the interests of specific interest groups reflect the relative electoral weight of those interest groups in terms of monetary and non-monetary contributions.

The underlying assumption of the model is that the incumbent government takes the political support expected by the interest groups into account when choosing an FIT generating a policy induced demand pid_j. This can be done following the approach proposed by Tanguay et al. (2004) (compare also Grossman and Helpman (1994), p. 838). Welfare (W) and political support can be modeled as a linear function (V).[29] Political support for the GT industry j (V_j) is derived from *four different sources*: First, industries operating in the GT sector make profits.[30] Second, political support is related to job creation in a certain GT industry j. We assume that there is a positive correlation between diffusion of GTs (Q^*) and labor demand in the GT industry j. Third, political support is highly sensitive to electricity prices. In our model we assume that regulation implemented via $FITs$ effects electricity prices positively. There is the assumption that electricity producing companies are able to pass the costs related to the pid_j to the consumers of electricity (demand for electricity is relatively inelastic). The fourth argument that enters into the political support function are the feed-in tariffs. We assume that producers of green electricity are somehow organized and therefore look at the (pid_j) which is positively dependent on FIT_j. An increase in FIT_j increases pid_j and therefore would be perceived positively by $GEP\ j$. Hence, a decrease would be perceived

[29] V represents monetary as well as non-monetary political support.

[30] This might lead to an increase in monetary contributions for the political parties supporting the expansion of GTs.

negatively. This allows us to model the welfare of the incumbent government denoted by G.

$$\begin{aligned}\max_{pid_j} G(pid_j) &= \alpha W_j(pid_j) + (1-\alpha)V_j \\ &= \alpha W_j(pid_j) + (1-\alpha)[\pi^*_{jT} \\ &\quad +Q^* - pid_j Q^* + pid_j(FIT_j)]. \end{aligned} \tag{2.20}$$

Maximizing equation 2.20 relative to pid_j leads to

$$pid_j^{ETR} = \frac{(\alpha-1)((1+N_j)^2 + N_j(N_j c_j + 1)) - \alpha N_j b_j (1+N_j) - N_j}{N_j^2(\alpha-2)}. \tag{2.21}$$

An interesting question that occurs is whether policy induced demand under the ETR regime is bigger or smaller compared to the TPI regime. By calculating the difference between pid_j^{TPI} and pid_j^{ETR} we can shed some light on this question. As a result it turns out that

$$pid_j^{TPI} - pid_j^{ETR} = \frac{(1-\alpha)((N_j+1)^2 + N_j c_j (N_j+1) - 2b_j N_j (N_j+1))}{N_j^2(\alpha-1)} \tag{2.22}$$

Whether the result from equation 2.22 is positive (support under ETR is too low) or negative (support under ETR is too high) depends on the value of the parameters. It can be observed that the size of the marginal costs c_j relative to the positive externality b_j plays an important role for the result. All in all the result has to be interpreted in the direction that the diffusion of GTs under ETR is very likely to be inefficient.

As shown in figure 2.7, for any $\alpha < 1$ the question whether pid_j is too big or too low depends on marginal costs c_j relative to the positive externality b_j. As we assume learning curves, the value for c_j has to change over time. The value related to the positive externality may also change over time depending on the actual knowledge about the negative externality related to conventional energy technologies.

2.6.4 Comparative Static

For the TPI, as well as for the ETR, the policy induced demand "should" increase, the more positive externalities (b_j) are linked to the GT industry j by keeping marginal production costs c_j constant. Therefore, in the model, a government seeking to maximize a linear combination of the social welfare function will increase demand for a certain GT j if the positive externality increases (e.g. with new knowledge about the impact of the GT industry j for social welfare).

FIGURE 2.7: Inefficiencies under the ETR regime

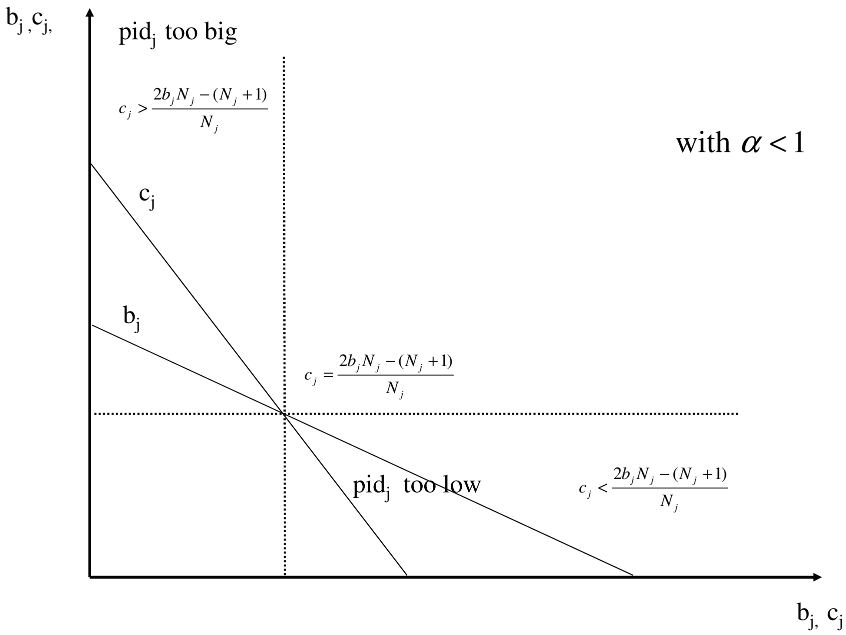


TABLE 2.2: Comparative static

pid_j	TPI	ETR
c_j	-	+,-
b_j	+	+
N_j	+,-	+,-
α	NA	+,-

This result is in line with the argument that under certain circumstances policy induced demand for certain GTs j is welfare enhancing.

It can also be observed that the optimal transfers shifted to a certain GT industry j may either increase or decrease with N under TPI and ETR. For TPI the result depends on the value of b_j compared to c_j. For $c_j < (1 + b_j)$ we have a negative relationship. Theoretically the increase in N stands for an increase in competition leading to the result that the dead-weight-loss becomes less important. Governments can more and more focus on the positive externality b_j and do not have to take market imperfections into account by setting the FIT. Under ETR the political reaction of the incumbent government depends on the question of whether pid_j is too high or too low compared to the TPI regime. If the number of firms producing green technologies increases, the outcome of positive externalities also increases. As everything else has been kept constant, it is rational to adapt policy induced demand to the price reduction caused by the increase in competition.

What is somehow puzzling is the negative sign for the TPI system for an increase of c_j. However, an increase in c_j leads to an increase in p_j, meaning that the $ENPV_j$ for some agents becomes negative. As the absolute value for b_j remains constant, the relative price to produce the positive externality will also increase. The implication of this result is the following: if marginal production costs decrease, pid_j should increase. For the ETR c_j can enter positively and negatively into the equation. The result depends on the marginal production costs c_j in comparison to the positive externality b_j. If c_j in comparison to b_j is high, pid_j is supposed to increase. If production costs decrease, it might also be that pid_j becomes too low. Because the share of electricity produced with GT j might affect general electricity prices positively, political leaders might not adjust pid_j in an optimal manner. Therefore, if c_j relative to b_j is high, pid_j will be too high and if c_j relative to b_j is low, there is an additional possibility that pid_j is too low.

The sign for α again depends on the relationship between c_j and b_j. If pid_j under the ETR regime is too low, an increase in α is positively related to an increase in pid_j. In the case that pid_j under the ETR regime is too high, there will be a negative correlation between an increase in α and pid_j.

Of course the results of our model for the ETR regime are highly dependent on the model specification. One can easily implement other assumptions leading to the result that pid_j in the ETR regime is always too high or too low. Nevertheless, we tried to base the assumptions for the political support function on the positive analysis of the previous sections. What the model is able to show is that governments might have difficulties calculating the welfare optimal pid_j. Additionally, we are able to show that diffusion of a certain GT j under TPI is highly sensitive to the positive externality b_j. A further implication of the model is that governments have to be aware of the market structure. As shown in App. A.2, under complete competition optimal pid_j is simply b_j. In contrast to this, under oligopolistic markets the incumbent government has also to correct for market imperfections leading to the counterintuitive result that a decrease in marginal costs has to be accompanied by an increase in pid_j. However, in reality, we see for the technology with the highest FIT (namely SOLAR), that its FIT is negatively correlated with c_j (compare table A.2 p. 195). This is in line with the theoretical prediction of our model under the ETR regime. Even though this second result seems to be interesting, we do not want to highlight it too much as the real world might be more complicated and the political support function might look different to what we have proposed. This does not change the general result of the theoretical model that CCPs, as such, very likely turn out to be inefficient, and the only economic argument for diffusion of GTs is related to a certain positive externality b_j.

2.7 Conclusion

The aim of this study was to assess the institutional setting enabling the diffusion of GTs (under the SEG and EEG) in Germany from a political economy perspective. The first part of the study was intended to set the necessary background to understanding the following theoretical model. As a result of the model, it turned out that the EEG as an institution generates inefficiencies. The level of diffusion of different GTs is highly dependent on political lobbying and other aspects that distort economic efficiency. The institutional analysis that compared the SEG with the EEG found that the SEG can be considered successful because for the first time it allowed for competition in the energy sector. Only by looking at positive effects like competition and the structural change in the energy market, can the EEG also be considered a success. Its related costs (in 2006) seem still to be at a manageable level. Therefore, one could argue that the inefficiency-costs related to the EEG have to be accepted in order to foster structural change in the energy sector. From a dynamic perspective this conclusion seems to be too trivial. Wrong political decisions today may implement long-lasting cost effects on future generations (because feed-in tariffs are guaranteed over a time horizon of twenty years). On the one hand, this may result in the aim to "reduce the costs of energy supply to the national economy", formulated in the EEG, not being achieved. If the guarantees for the feed-in tariffs have too long a time horizon, this problem will become even worse. On the other hand, a long-term time horizon is needed by investors and therefore should not fall below a critical threshold. This highlights the importance of adjusting the induced demand for different GTs based on actual knowledge of the positive externality and changes in the market structure, as well as changes in marginal production costs. The strength related to the EEG can be found in the connection between demand for GTs and supply of green electricity within one policy instrument. In the early stages of structural change in the energy system this seems to have been important. Theoretically, FITs could be adjusted to achieve pre-defined environmental standards (Baumol and Oates, 1971). This optimistic interpretation is highly sensitive to the parameter α and therefore the weight given to the TPI regime. If the industry is well established (supply of GTs is well established) it does not seem to be overconfident to believe that tradable certificates become a serious alternative to FITs in order to enhance efficiency related to the supply of green electricity.

Chapter 3

Renewables and Innovations*

3.1 Introduction

Structural change of the energy system is part of the political agenda. The German Federal Ministry for the Environment considers renewable energy technologies to be "key technologies" for future energy supply. In Germany, the share of renewable energies of total energy production has increased steadily in the past two decades. Diffusion increased markedly from the late 1990s on. From 1998 to 2008, the share of renewable energies of total electricity production increased from 4.8 percent to 15.1 percent. In 2008, the share of green technologies (GTs) of total energy production was 9.5 percent. Diffusion rates also differ between the different GTs available. Electricity produced with water (in 2008) accounted for 23.0 percent of all electricity produced by GTs, wind's share was 43.5 percent, solar 4.3 percent, and biomass accounted for about 22.1 percent (BMU, 2008, p. 15).

Even though there has been a significant growth in the GT sector in the past ten years, GTs in Germany are still operating at a low scale (energy produced with WIND turns out to be an exception). With the decision to phase out the use of nuclear power (in the year 2000), electricity producing companies are still heavily dependent on other non-renewable energy sources, such as COAL and GAS (IEA/OECD, 2007, p. 120). This is not surprising as transition from non-renewable energy technologies to a system mainly based on renewable energy technologies needs time. So far, there is still uncertainty about the point in time for this achievement. Innovations play a highly relevant role in the possibility of transition, its speed and the related costs.

Diffusion of GTs, at a certain level, depends crucially on the institutional setting. The relatively high production costs for energy produced with GTs, as well as monopolistic market structures, have made the diffusion of GTs difficult without governmental support. Market entry became possible in Germany for the first time under the "Electricity

*This chapter is mainly based on Wangler (2010b). I am indebted to Andreas Freytag, Guido Buenstorf, Marco Guerzoni, Frenken Koen and Jan Nill for helpful comments on an earlier version of this work.

Feed Law" (SEG) (implemented in January 1991). Investment into GTs became economically highly attractive under the "Renewable Energy Sources Act" (EEG) (implemented in April 2000). However, demand is policy induced as other technologies exist that can produce the same outcome (namely electricity) for lower prices. The institutional setting has been designed in a way that electricity produced with GTs can be sold on the market (under the EEG for a guaranteed remuneration specific to a certain GT j as shown at table A.2, page 195).

The policy induced demand for GTs in Germany provides an opportunity to test a theory that has become known in the literature as the so-called "Schmookler hypothesis" (Schmookler, 1962, 1963): Higher demand (here proxied with the *change* of installed capacity in GTs) has a positive impact on firms engaged in innovative activities (here proxied with patent counts). The econometric analysis of this chapter contributes to the recent literature by looking at four important questions. First, we try to answer the question of whether the policy induced demand for GTs was accompanied by innovative activity. This is interesting as innovations also indicate the future economic values market actors relate to GTs. The next question we try to answer concerns the impact of public R&D expenditures on innovations. Our third question is related to the impact of electricity prices on innovative activity in the different GT industries. We also take the institutional change under the SEG and the EEG into account and test for a structural break.

The chapter is structured as follows: Section 3.2 is a critical assessment of the structural change in the energy system in Germany under current policies. In section 3.3 we analyze studies of the relationship between demand and innovation, as well as technological lock-in. We further review institutional change in the German energy sector by studying differences between the SEG and EEG. We use the results as background to formulate a hypothesis for our econometric model. Description of the data, variables, econometric model and estimation results follows in section 3.4. In section 3.5 we draw a conclusion.

3.2 Structural Change in the Energy System

Energy production in Germany is still highly dependent on conventional energy technologies. They have the major characteristic that *non-renewable/ exhaustible* energy sources[1] are used as an input. Non-renewable energy sources have the shortcoming that they are either responsible for externalities in the form of CO_2 emissions[2] (as in

[1] A definition for exhaustibility is given by Dasgupta and Heal (1979), p. 153:"an exhaustible resource is [...] used up when used as an input in production and at the same time its undisturbed rate of growth is nil".

[2] CO_2 emissions represent one big part of total greenhouse gas (GHG) emissions which are seen to be highly responsible for global warming (IPCC, 2007, p. 5).

the cases of COAL or GAS), or that there are unsolved externality problems (as in the case of NUCLEAR energy). In comparison to this, renewable energy systems are able to produce energy without causing marked harm to the environment, at least in form of producing CO_2 emissions. However, energy production from non-renewable energy sources is more cost intensive and substitution for conventional energy production is still far from a reality.

Two distinct problems are often combined when the discussion is about structural change of the energy system and diffusion of GTs. The first problem is related to *externalities* and the second to transition from a non-renewable energy system to a system mainly based on renewable energies in order to implement long-term sustainability.

If the discussion is about the externality problem one can argue that a substitution of conventional energy technologies by GTs has to reduce externalities and, consequently, their diffusion has positive environmental impacts. Another option would be to apply instruments enforcing the internalization of the externality directly by the non-renewable energy technologies.

Apart from the externality problem, there is an additional argument why diffusion of GTs may have positive impacts. This argument is related to the problem of non-sustainability in the energy system. Sustainability requires transition from non-renewable energy sources to a system that mainly builds on GTs ("backstop technologies"). The point in time of transition can be influenced by policy-makers ("transition management"). The European Union, for instance, has implemented a directive that in 2020 the percentage of total energy produced from renewable sources has to be at least 20 percent (COM, 2008). The aim of sustainable energy supply is also used as an argument for diffusion of GTs under the EEG.[3]

Even though the argument for sustainability seems to be convincing at first glance, there are concerns regarding the use of sustainability as an adequate normative argument for transition management in the energy sector. One important aspect involves environmental and resource economics. Extraction of a non-renewable energy source is a decision between expected profits to be earned in the future by leaving the resource in the ground and profits that can be earned by extraction of the resource. If it is envisaged that development of GTs will reduce expected profits for the owners of non-renewable energy sources, diffusion of GTs may be accompanied by an increase in the speed of extraction of non-renewable energy sources. Thus, from an international perspective, investment in GTs may not lead to an increase in sustainability (Sinn, 2008).[4]

[3]Article 1(1) EEG: "facilitate a *sustainable* development of energy supply, particularly for the sake of protecting our climate and the environment, to reduce the costs of energy supply to the national economy, also by incorporating external long-term effects, to conserve fossil fuels and to promote the further development of technologies for the generation of electricity from renewable energy sources" (EEG, 2009).

[4]However, there is also no empirical evidence that diffusion of GTs translates 1:1 into world market energy prices. The total impact of this "rebound effect" is an empirical question.

Two problems become obvious. On the one hand, there is the problem that it is difficult to justify diffusion of GTs aiming to substitute for conventional energy technologies. On the other hand, a first best solution would require that all externalities from non-renewable energy sources are internalized. Obviously, this is not the case. Not subsidizing GTs would generate distortions in competition between conventional energy technologies and green technologies. Both problems have to be evaluated with care when thinking about the optimal level of diffusion of GTs.

3.3 Theoretical Background and Hypothesis

3.3.1 Innovations and the role of demand

One reason for studying innovations is related to the importance of the impact they have on endogenous growth and economic development (Schumpeter, 1934). Firms (and entrepreneurs) may seek profit and be motivated to innovate or imitate with the aim of continuously increasing profits. Economic actors, therefore, search for better techniques and the selection of successful innovations takes place through the market. The dynamics behind this process are best described with the notion of *creative destruction* (Schumpeter, 1942).

From an economic perspective, it is in the core interest to detect the driving forces behind innovations. For many years there has been an ongoing debate on the question of whether demand drives innovation, or if it is the other way around. The importance of demand to innovation is closely connected to the research done by Schmookler (1962) and Griliches (1957). However, the argument as such can be traced back to Hicks. He made the observation that "a change in the *relative prices* of factors of production is itself a spur to innovations and to inventions of a particular kind – directed at economizing the use of a factor which has become relatively expensive" (Hicks, 1932, p. 124). The relationship between demand, and the timing and the location of an invention, has been studied by Griliches (1957). Schmookler focused on the causality between demand and innovation. He stated that "new goods and new techniques are unlikely to appear, and to enter the life of society without pre-existing – albeit possibly only latent – demand" (Schmookler, 1962, p. 1). According to this reasoning, demand is the main driver in stimulating inventive activities. Schmookler used patent statistics to study four different industries (railroads, agricultural equipment, paper and petroleum). He found a linear relationship between demand and investment in capital goods in the particular sectors. His line of argument can be summarized as follows: market actors have incentives to innovate as long as improvements in production technique or product quality have a chance of achieving a higher mark-up per unit. The more units that are sold on the market, the higher the profits that can be earned. There are more incentives for economic activities, measured as inventions, the bigger the size of the market (Schmookler, 1962).[5]

The theoretical argument put forward by Schmookler has also been criticized (for an early critique see Salter, 1960; Rosenberg, 1974; Mowery and Rosenberg, 1979).[6] Scherer (1982), re-ran Schmookler's analysis and found much weaker evidence for the underlying demand hypothesis. He used a broader dataset and included several types of industries. Firms with market power are able to use their strategic advantage to increase market share. In contestable markets, market power can encourage firms to innovate and to create demand endogenously. This makes the simple demand story more complicated. The significance of the results is further dependent on technological opportunities of the underlying industries. Kleinknecht and Verspagen (1990) have shown that Schmookler's dataset contains reverse causality problems. There is the important implicit result that even though it is true that at a given point in time t the size of the market S has an impact on the probability to innovate C ($P_t : S_t \rightarrow P_t(S_t)$), there is the endogenous effect that innovation is able to increase the size of the market by itself ($S_t : P_t \rightarrow S_t(P_t)$). Both, demand and supply have to be relevant (Pavitt, 1984).[7]

However, beside the fact that the underlying relationship is more difficult than initially perceived, the intuition of Schmookler's reasoning, that demand positively affects innovations, is not falsified (cf. Fontana and Guerzoni, 2008, p. 930). Testing the Schmookler hypothesis with data containing information about diffusion of GTs has one major advantage. Theoretically, demand can be treated as exogenous as diffusion of GTs is policy induced. The previous arguments build a background for formulating the first hypothesis. We refer to them as our Schmookler hypothesis. We distinguish between the size of the market (hypothesis 1a) and the change in size of the market (hypothesis 1b).

Hypothesis 1a: The size of the market (S) positively affects firms in a GT industry j to engage in innovative activities.
Hypothesis 1b: Increase in market size (ΔS) positively affects firms in a GT industry j to engage in innovative activities.

3.3.2 Technological lock-in and the energy system

As stated at the beginning of this section, in markets characterized by self-selection and creative destruction, a direct link between innovations and growth can be drawn

[5]For a simple formal description compare Fontana and Guerzoni (2008).

[6]Rosenberg (1974), p. 105, states that: "[..] technical problems and their relative complexity stand independently of demand considerations as an explanation of the timing and direction of inventive activity. Therefore any analytical or empirical study which does not explicitly focus upon both demand and supply side variables is seriously deficient".

[7]For a survey about the discussion on demand-pull and supply-push see Freeman (1994) among others.

(Schumpeter, 1934, 1942). This mechanism, however, does not guarantee optimality of the result. Even in competitive markets self-selection processes can be accompanied by suboptimal results (market failure). In markets characterized through learning curves and/or economies of scale, especially,[8] there is the possibility that the economic system locks-in to a technology that can be considered to be suboptimal *ex-ante*. This problem has been highlighted by David (1985) and further developed analytically by Arthur (1989, 1994).[9]

Arthur (1989) distinguishes, in his first example, between two technologies (A and B) competing on the market for adoption. The early market entrance of a certain technology (A) can make it difficult or even impossible for a competing technology (B) to "get started", as there is technological lock-in (Arthur, 1989, p. 119).[10] In the case of GTs the problem is different to the described relationship, as technology selection does not take place over the self-selection process of the market. In the specific case of the energy sector one can argue that demand depends on political decisions. If there is a lock-in to suboptimal equilibria the major reason is wrong political decisions (state failure, not market failure). We nevertheless stick to the previous example and propose to treat A as a vector of conventional non-renewable energy technologies (e.g. NUCLEAR power plants or COAL power plants regime) and B as a vector of GTs (e.g. SOLAR, WIND, WATER, GEO and BIO).[11] Following the logic of technological lock-in, it seems plausible that if A is the dominant technological regime, B is very limited with respect to innovations and diffusion (Unruh, 2000) without policy induced demand. Hypothesis 2 is formulated to test the theory of technological lock-in. If technological lock-in is present, we expect that electricity prices have no impact on innovative activity in the GT sector.

Hypothesis 2: Increasing electricity prices have no impact on innovative activity in GT industry j.

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[8]Adaptive expectations and network externalities are additional reasons behind a technological lock-in (Arthur, 1994).

[9]The example of QWERTY is well-known. QWERTY is the current standard used in type-writing. Because a superior system has been developed that is able to substitute for QWERTY, from a pure technical perspective, the lock-in to the QWERTY system has to be explained by high switching costs and cannot be considered as optimal from an ex post perspective.

[10]Examples for the suboptimal selection process of markets are given by the US television system, the example of the US programming language FORTAN, or the example of QWERTY (Arthur, 1984; David, 1985; Hartwick, 1985).

[11]This distinction would be misleading in the case that those technologies incorporated in B are not able to substitute conventional energy in the long run. In this case, A and B cannot be treated as substitutes ex-post. This would make it difficult to find rational arguments in support of GTs.

In contrast to hypothesis 2, one could also argue that due to the creation of a niche for GTs under the SEG and EEG, electricity prices could have an impact, as some partial lock-out from *A* has already taken place.[12]

3.3.3 Eco-innovations and the double externality problem

As this study deals with innovations in GTs (so-called "eco-innovations"[13]), we have to take into account the "double externality problem" (Rennings, 2000). Like other innovations, eco-innovations are able to create positive externalities (Arrow, 1962) and, additionally, their diffusion is connected to environmental specific positive externalities (Rennings, 2000, p. 325).

This double externality problem (problems related to cost-internalization) reduces incentives for firms to invest in environmental friendly R&D. Suboptimal market allocations can occur, as under certain conditions "technology push and market pull alone [...] [are not] strong enough [for self-enforcement of eco-innovations]" (Rennings, 2000, p. 326). Public R&D expenditures may help to push for eco-innovations. In order to test the technology push factor we formulate our next hypothesis.

Hypothesis 3: Public R&D plays a significant role in innovations within GTs.

3.3.4 Transition policy in the GT sector (from the SEG to the EEG)

Pull factors for GTs have been implemented through the SEG and EEG. The switch in the energy regime from conventional energy production *A* to an energy regime that mainly builds on energy produced with green technologies *B* is therefore dependent on the institutional setting. We distinguish three different institutional stages that roughly describe institutional change in the German energy system.

The first stage is characterized by a monopolistic electricity market with almost no competition. *A* is considered to be the main source of electricity supply. Due to the cost argument, as well as the problem that no institutional setting exists to facilitate feed-in of electricity produced with *B* into the electricity network, diffusion of *B* is very limited.[14] The first stage characterizes the German energy market until 1991 (Toke and Lauber, 2007, p. 683).

[12] An increase in electricity prices for GT producers can indicate a higher market potential for GTs. However, regulation in the energy sector towards an increase of GTs may also drive electricity prices affecting the electricity price endogenously.

[13] "Eco-innovations are all measures of relevant actors (firms, politicians, unions, associations, churches, private households) which; (i) develop new ideas, behavior, products and processes, apply or introduce them and (ii) which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets."(Rennings, 2000, p. 322)

[14] Note that in some geographical areas WATER (which is considered to belong to *B*) is very cost-efficient and therefore was traditionally one main source of electricity supply.

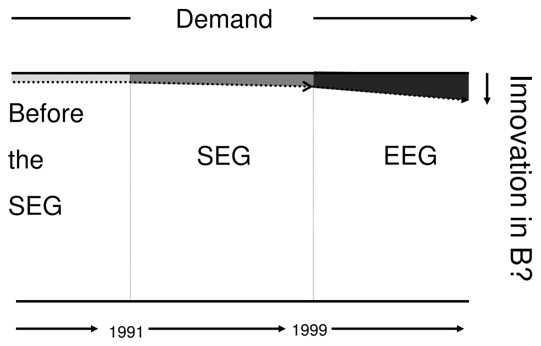
The first change in the energy system was brought about by the "Electricity Feed Law" (SEG). The SEG entered into law in January 1991 (Toke and Lauber, 2007, p. 683). The SEG was important insofar as it allowed small and medium electricity producing companies to feed-in their electricity to the grid. The remuneration was based on 75 percent (for WATER and BIO), and 90 percent (for SOLAR and WIND) of the average market price for electricity. The SEG allowed for some initial competition in the energy market and the first decentralization. Nevertheless, diffusion of B was limited because remuneration was lower than the average market price for electricity produced with A (compare BGBl, 1990). The institutional arrangement under the SEG held from 1991-1999. The SEG can be seen as a necessary requirement for bringing contestability to the electricity market.

The end of the 1990s brought the liberalization of the energy market and, additionally, the so-called "Renewable Energy Sources Act" (EEG) entered into law in April 2000. It consists of elements best described as "command and control", because only some selected technologies get a defined remuneration for electricity feed-in. The EEG is designed in a way that discrimination between different technologies takes place through different remuneration rates. Degression rates for the feed-in tariffs also differ. Discrimination was a necessary condition in order to implement diversity. Under the EEG, until 2003, the range of remuneration was from 6.5 $Cent/KWh$ for electricity produced using WATER and BIOGAS, increasing to 51.62 $Cent/KWh$ for SOLAR. The highest feed-in tariff, except for SOLAR, was for BIO (biomass) at 10 $Cent/KWh$. The German government has since modified the EEG two times (for details on the differences compare BGBl, 2000; EEG, 2004, 2009).

The institutional arrangements described above created a policy-induced demand for GTs (compare also figure 3.1). Figure 3.1 connects the institutional change with diffusion of GTs. The expected structural break between the SEG and the EEG is characterized through different slope parameters related to the dotted arrows representing diffusion of GTs under the SEG and diffusion of GTs under the EEG. The following hypothesis is intended to test whether a structural break can be observed by comparing the SEG (1990-1999) with the EEG (from 2000 on).

Hypothesis 4: Demand driven innovation under the EEG is significantly higher compared to the SEG.

FIGURE 3.1: Technical change under the SEG and the EEG



3.4 Empirical Strategy

3.4.1 Data and Descriptive Statistics

We constructed a panel covering the period from 1990 to 2005. The sectors of interest are wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO) and biomass (BIO).[15] Our panel therefore contains 16 observations over time and five sector-specific observations.

Inventions as a proxy for innovations are measured by patent counts PAT, $APAT$.[16] The variable PAT describes the sector-specific patent counts of granted patents and $APAT$ are all patents applied for in Germany in all IPC classes (the database for PAT is DEPATIS net). We build on work done by Johnstone et al. (2010), as we use a modified version of the patent classification proposed in their paper to identify innovations in different GT industries (see table B.1, App. B, p. 200). We use the application date for all patents that have been granted (inventions). The data contains only those patent counts with priority in Germany (double counting excluded).

We also have information about sector-specific public expenditures on research and development RuD and the installed capacity of the different technologies (measured in MWh) $INCAP$. Prices are measured by $CPIE$ (consumer price index for electricity). Electricity consumption is measured by the consumption of KWh per capita ELC. The

[15] The five sources of the data are the German Patent Office (GPO), the International Energy Agency (IEA), Eurostat (ES), The German Statistical Office (GSO) and the German Federal Ministry for the Environment (BMU). For a detailed description of the data compare appendix B.1, p. 198.

[16] There is the critique that "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in 'quality', in the magnitude of inventive output associated with them" (Griliches, 1990, p. 1669). However, using patents as a proxy for innovation is common and seems appropriate as there are only a few economically significant inventions which have not been patented (Dernis et al., 2000; Dernis and Khan, 2004).

variables PAT, RuD and $INCAP$ contain sector-specific information. The variables $CPIE$ and ELC are aggregated observations with country specific information. The variables are summarized by table 3.1.

TABLE 3.1: Summary of the data

	Obs	Mean	Std. Dev.	Min	Max	Measure
PAT	80	76.5125	85.67025	3	297	Counts
$APAT$	80	50281.13	7286.154	37252	59685	Counts
RuD	80	17.47135	22.97052	0	91.178	Mio. Euro
$INCAP$	80	2213.532	3695.865	0.01	18428	MWh
$CPIE$	80	109.3919	15.03489	85.18	134.04	2004 indexed to 100
ELC	80	6601.992	257.3511	6246.21	7111.05	KWh per capita

Patent counts (*PAT*) as a proxy for innovations

Figure 3.2 shows a time trend of granted patents (patent counts at application date). It is interesting to see that granted patents for SOLAR started to decrease under the EEG before they increased again after 2002. For WIND, a decline of the patenting intensity can also be observed after 2001. Part of the decline could be explained by a time lag between the application date and the date of patent granting. In order to avoid this problem, we restricted our panel to the year 2005, even though our database on patent counts goes to 2007. We make the implicit assumption that applied patents will be granted within a time frame of two/three years.

If one takes into account that patenting activity can also be interpreted as a stock of knowledge, even though the patent counts decrease, the stock of knowledge does still increase. It is also notable that SOLAR has the highest patenting activity, followed by WIND. In contrast to this, GEO and BIO generate relatively low knowledge stocks.

Public *$R\&D$* expenditures (*RuD*)

Figure 3.3 shows the industry specific $R\&D$ funding by the federal government. It can be seen that there was a decrease in public $R\&D$ funding for SOLAR after 1993. Compared to this, there was a relatively low level of reported public $R\&D$ expenditures for technologies like WIND, WATER, BIO or GEO. The figure shows that most $R\&D$ expenditures went into SOLAR, followed by WIND. BIO and GEO received relatively low public $R\&D$ transfers. There is no reported $R\&D$ support for WATER.[17]

Installed capacity of GTs (*$INCAP$*) and change of installed capacity (*$\Delta INCAP$*), measured in *MWh* to proxy the change in size of the market (S)

Figure 3.4 shows the installed capacity of renewable energies under the SEG and EEG. It

[17] It might be that RuD does not display all direct payments going to GTs. One first hint is that expenditures of the local government are not measured by RuD. Nevertheless, RuD incorporates all $R\&D$ expenditures of the federal government reported to the IEA.

FIGURE 3.2: Patent counts (PAT)

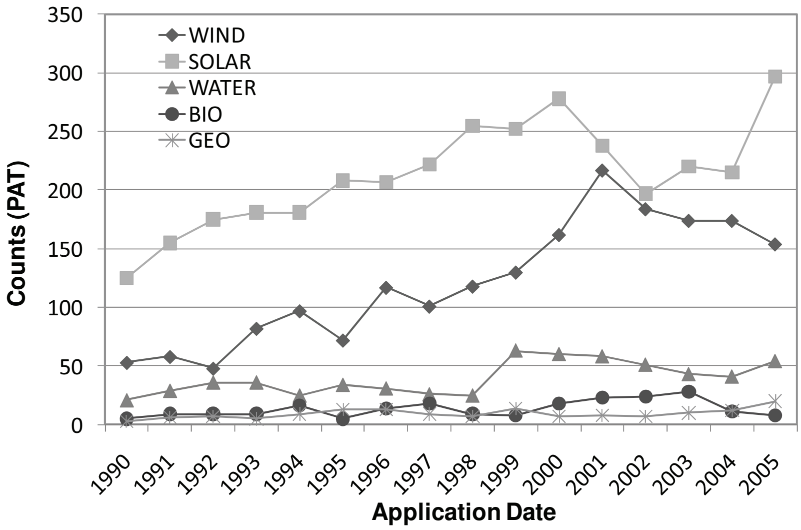


FIGURE 3.3: Public expenditures on research and development (RuD)

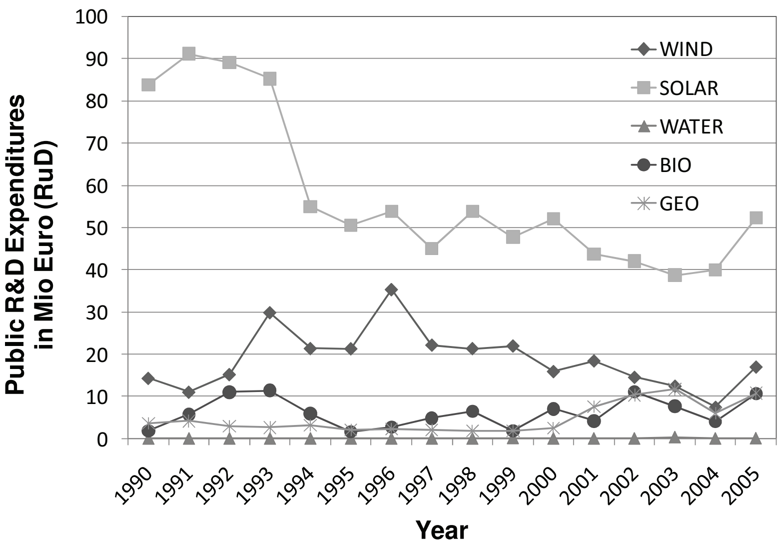
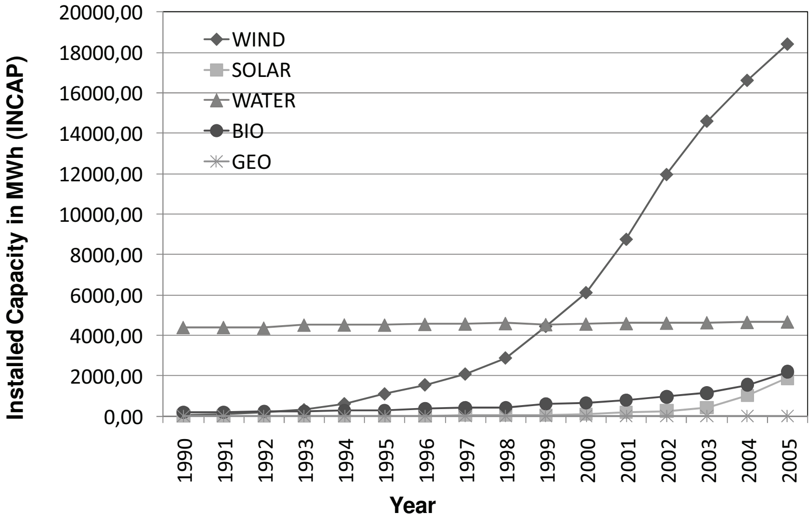


FIGURE 3.4: Installed capacity of green technologies (INCAP)



can be seen that until 1999, WATER was the most important renewable energy source. After 1999, the share of WIND increased, with high growth rates, and its installed capacity exceeded that of WATER. Until 2005, the installed capacity of SOLAR was still at a lower level than that of BIO. The installed capacity of GEO was almost zero. Figure 3.5 represents corresponding growth of the installed capacity.

Consumer price index electricity ($CPIE$), a marked based indicator for the incentives to innovate

Figure 3.6 gives insights into electricity prices which decreased until the year 2000 and increased again after the year 2000.[18]

3.4.2 Econometric Model

The aim of the model is to test the following relationship:

$$PAT = f\left(\underset{+}{INCAP/\Delta INCAP}, \underset{0}{CPIE}, \underset{+}{RuD}\right).$$

For our dataset we assume that $T \rightarrow \infty$ and our independent variable consists of a vector with count data. Therefore, two major problems are related to our data. On the

[18]Having the liberalization of the market for electricity in mind, the decrease in electricity prices may indicate the welfare gains due to liberalization. It might be the case that regulation related to the EEG had some impact on this development.

FIGURE 3.5: Change of installed capacity of green technologies

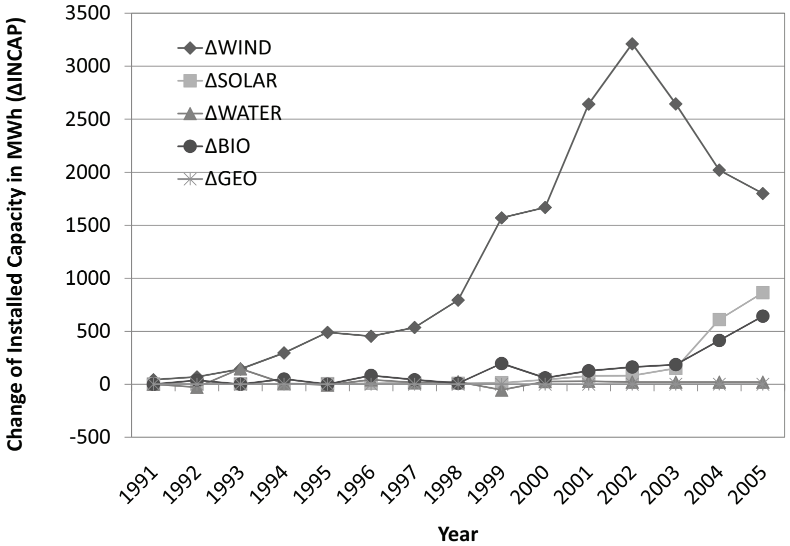
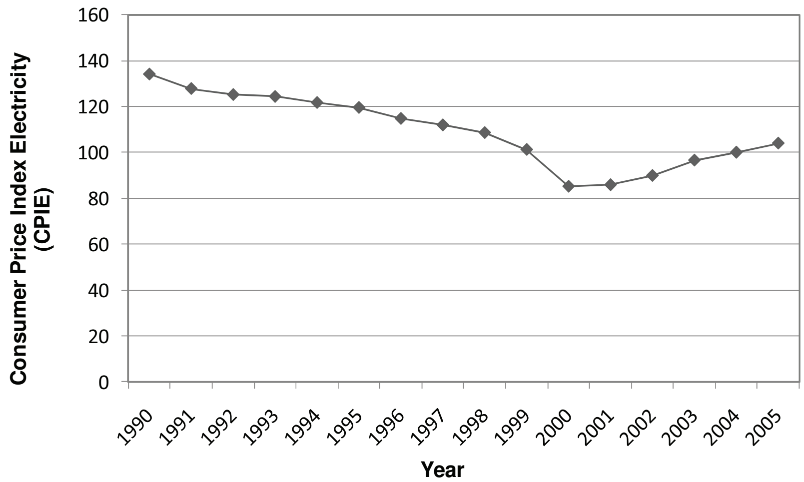


FIGURE 3.6: Consumer price electricity (CPIE)



one hand, observations over time may not be independent from each other and, on the other hand, (as we are dealing with count data) standard errors are not assumed to be normally distributed.

The estimation model can be formalized as follows (Wooldridge, 2002a, pp. 247):

$$y_{it} = \beta^T x_{it} + c_i + u_{it}, \tag{3.1}$$

where $i = 1, \dots, n$ indexes the technologies listed within the different patent classes (compare table B.1, p. 200) and $t = 1, \dots, T$ indicates time. The error term u_{it} is idiosyncratic and c_i allows to control for group specific heterogeneity (fixed effects model).

The count data characteristic of patents[19] suggests estimation coefficients, with models for event counts like the negative binomial model or the Poisson model (Maddala, 1983; Cameron and Trivedi, 1998; Wooldridge, 2002a). The negative binomial model is based on a Poisson distribution with an unobserved error parameter ν, implementing heterogeneity in the variance. The intensity parameter φ is explained by a vector of all explanatory variables X.

Formally:

$$PAT_{i,t} \rightarrow NegBin(\varphi; \sigma),$$

equals

$$PAT_{i,t} \rightarrow Poisson(\varphi) \quad if \begin{cases} \varphi = \widetilde{\varphi}\nu = exp(\beta X) \\ \nu \rightarrow \Gamma\left(\frac{1}{\sigma}; \frac{1}{\sigma}\right). \end{cases}$$

The standard deviation for the expected value $E(PAT_{i,t}) = \varphi$ is given by $V(PAT_{i,t}) = \varphi(1 + \sigma^2\varphi)$. Thus, with $\sigma \rightarrow 0$ the intensity is φ and the model converges towards a Poisson distribution (Johnstone et al., 2010, p. 146). We follow this argument and use the negative binomial model as our baseline model.

In contrast to the negative binomial model, there is the striking feature of the linear model (or some standard non-linear estimation methods like AR(1)) that one can easily correct for serial correlation. Calculating first differences for the observations over time can already help to get reduce the problem of first order serial correlation (Wooldridge, 2002b, p. 365). Non-linear AR(1) estimation methods offer additional opportunities to handle first order serial correlation (Wooldridge, 2002b, p. 350). However, these estimation methods may cause a bias in our estimates because of the wrong assumption about the functional form. Therefore, we propose the following estimation strategy: The basic model is estimated with the negative binomial model. In addition to this, we show estimation results for the first differences fixed effects OLS model and AR(1).

[19] An event count "is the realization of a non-negative integer-valued random variable" (Cameron and Trivedi, 1998, p. 1).

If the estimated coefficients show comparable results (same sign and significance) to the negative binomial model, we can conclude that first order serial correlation is not inflating the significance of our estimates.

We try to test hypothesis 1a with the variable $INCAP$, hypothesis 1b with $\Delta INCAP$, hypothesis 2 with $CPIE$ and hypothesis 3 with RuD. The structural break (hypothesis 4) is taken into account with the use of period dummies (compare table 3.3, page 80). Model specifications for the standard model are given for

$$\begin{aligned} PAT_{i(t-1)} &= \beta_0 + \beta_1 z_{i(t-2)} + \beta_2 (INCAP_{it}/\Delta INCAP_{it}) \\ &\quad + \beta_3 (RuD_{i(t-1)}) + \beta_4 (CPIE_{i(t-2)}) + c_i + u_{i(t-1)}, \end{aligned} \tag{3.2}$$

and for hypothesis 4 we have

$$\begin{aligned} PAT_{i(t-1)} &= \beta_0 + \beta_1 z_{i(t-2)} + \beta_2^{SEG} (INCAP_{it}/\Delta INCAP_{it}) + \beta_3^{EEG} (\Delta INCAP_{it}) \\ &\quad + \beta_4 (RuD_{i(t-1)}) + \beta_5 (CPIE_{i(t-2)}) + c_i + u_{i(t-1)}. \end{aligned} \tag{3.3}$$

In the model, t indexes time and i indexes different industries operating within the GT sector,[20] SEG stands for the period from 1990-1999 and EEG represents the period from 2000-2005. If the variables are indicated with $(t-1)$, a one year time lag is used in order to incorporate dynamic effects into the model, $(t-2)$ and $(t-3)$ are two year and three year time lags. Δ is used as a symbol for first differences. $z_{i(t-2)}$ describes two observable characteristics integrated as control variables, namely ΔELC_{t-2} and $APAT_{t-2}$. ΔELC_{t-2} is implemented into the model because electricity prices may also react to electricity consumption. $APAT_{t-2}$ allows to control for endogenous institutional changes in the German patent system.[21] The variable β_0 denotes the intercept. The error component c_i is group specific (individual heterogeneity) whereas $u_{i(t-1)}$ represents the idiosyncratic error term (dependent on i and t).

Note, that in the model foresightness is integrated as there is a one year time lag between our dependent variable $PAT_{i(t-1)}$ and the dependent variable $(INCAP_{it}/\Delta INCAP_{it})$. With respect to the other lag structures, strong assumptions are made. They are theoretically motivated by previous contributions in the literature (Brunnermeier and Cohen, 2003; Griliches, 1990, 1998; Hall et al., 1986, cf.). A criticism might be that private R&D expenditures are not integrated as an explanatory variable into the econometric model. As we do not have information on private R&D, we have to stick to the model presented

[20]Table B.4, p. 203 shows the correlation matrix for the variables integrated into the model (Correlation matrix 3).

[21]It might be possible that overall patents have increased (e. g. due to institutional changes) and therefore most of the variance in patenting activity would follow a trend which is observable in overall patent counts.

above. From a theoretical point of view it has to be taken into account that firms operating within an industry compete with each other. There is the implicit assumption that firms have to innovate (with process or product innovations) to be able to increase market shares. Hence, $INCAP$ should indirectly capture at least parts of successful private $R\&D$.[22]

With respect to the construction of the panel, we took some guidance from Johnstone et al. (2010). They run a panel on the international level, combining patent counts with data from the IEA.[23] Johnstone et al. (2010) run the regression with a negative binomial model. We use the negative binomial model as our benchmark but make serious attempts to take the problem of first order serial correlation into account.

Robustness of our estimates is further demonstrated with test statistics like the Baltagi-Wu LBI test and the use of time dummies (compare table B.2, page 201). We also calculate the variable $RELPAT$ which is the ratio between PAT and $APAT$. For $RELPAT$ we are not limited to the negative binomial regression ($RELPAT$ is not count data) which makes the use of standard estimation models like OLS appropriate.

3.4.3 Estimation Results

Starting with the Hausman test the results indicate that random effects is the appropriate estimation method. In some of the cases we also calculate fixed effects to show robustness of the results (compare in particular table B.2, page 201). The basic model to test hypothesis 1-3 is shown in table 3.2 (page 79). We start the estimation with only a few variables and proceed by integrating additional variables in further steps. In column 6 (model to test hypothesis 1a, hypothesis2 and hypothesis 2) and column 7 (model to test hypothesis 1b, hypothesis 2 and hypothesis 3) the core model is presented. Estimations are done with the negative binomial model. Based on this model we find support for hypothesis 1a, hypotheis 1b, hypothesis 2 and hypothesis 3. These results are further tested by the regressions presented in table B.2 (page 201), table B.3 (page 202) and table 3.4 (page 81). Our findings are now discussed by taking the results from the additional regressions into account.

Hypothesis 1a and hypothesis 1b: We find support that the size of the market and/or an increase in the size of the market positively affects the probability that firms, operating within different GT industries, are engaged in innovative activities. A positive correlation is supported by the results reported for $INCAP/\Delta INCAP$ in

[22]However, as can be seen from the estimation results of our OLS regression, less than fifty percent of the variance is captured by our model. Having information on private $R\&D$ may further increase the explanatory power of our model.

[23]There are additional important differences. $\Delta INCAP$ was not part of the sample and WATER was not integrated. We run the regression excluding WASTE due to the fact that this variable does not contribute much to sustainable electricity supply. For more details see table B.1, p. 200.

TABLE 3.2: Estimation result 1a negative Binomial regression (neg. Bin) and first differences model (FD)

estimation method	**neg.Bin.** (random effects)	**neg.Bin.** (random effects)	**neg.Bin.** (random effects)	**neg.Bin.** (random effects)	**neg.Bin.** (random effects)	**neg.Bin.** (random effects)	**OLS FD** (random effects)	**OLS FD** (random effects)
Independent Variable	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}
$INCAP$	0.0000556** (8.33$e-06$)	−−	−−	−−	0.0000317** (7.72$e-06$)	−−	0.0049697+ (0.0029219)	−−
$\Delta INCAP$	−−	0.0003788** (0.0000462)	−−	−−	−−	0.0002097** (0.000052)	−−	0.0330318** (0.0085457)
RuD_{t-1}	−−	−−	−0.0021942 (0.0062704)	−−	0.0079735** (0.002883)	0.0068344* (0.0030065)	0.9292521** (0.3506719)	0.9201498** (0.3179317)
$CPIE_{t-2}$	−−	−−	−−	−0.0136821** (0.0018688)	0.0023306 (0.0055219)	0.0023844 (0.0054758)	−0.5225558 (0.4224488)	−0.2824146 (0.3899379)
ΔELC_{t-2}	−−	−−	−−	−−	0.0002035 (0.0002673)	0.0001285 (0.0002719)	−0.0120087 (0.0161369)	−0.0101671 (0.0146693)
$APAT_{t-2}$	−−	−−	−−	−−	0.00003* (0.0000129)	0.0000283* (0.0000126)	−0.0004177 (0.0013016)	−0.0003805 (0.0011739)
β_0	2.64868** (0.2703001)	2.866002** (0.2861197)	2.397688** (0.2321561)	4.802875** (0.3544461)	1.937776 (1.281859)	2.009899 (1.257838)	1.537938 (3.172943)	2.222963 (2.665193)
time dummies	*No*	*No*	*No*	*No*	*No*	*No*	*No*	*No*
R-sq	–	–	–	–	–	–	0.1807	0.32390
Wald chi2(5)	44.46	67.18	0.12	53.60	83.72	84.52	–	–
Nr. of observations:	75	75	70	70	65	65	60	60
Nr. of groups:	5	5	5	5	5	5	5	5

Significance: ** $\leq$ 1%,* $\leq$ 5%,+ $\leq$ 10%

TABLE 3.3: Estimation result 2 (model with period dummies)

estimation method	**neg.Bin.** −− (fixed effects)	**neg.Bin.** −− (fixed effects)	**AR(1) FD** (fixed effects)	**AR(1) FD** (fixed effects)
Independent Variable	PAT_{t-1} −−	PAT_{t-1} −−	−− $RELPAT_{t-1}$	−− $RELPAT_{t-1}$
$INCAP^{SEG}$	$6.65e-06$ (0.0000279)	−−	$3.24e-07^{*}$ ($1.52e-07$)	−−
$INCAP^{EEG}$	0.0000298^{**} ($7.76e-06$)	−−	$3.42e-07^{*}$ ($1.43e-07$)	−−
$\Delta INCAP^{SEG}$	−−	0.0001987^{**} (0.0000616)	−−	$5.90e-07^{**}$ ($2.12e-07$)
$\Delta INCAP^{EEG}$	−−	0.0002046^{**} (0.0000523)	−−	$6.08e-07^{**}$ ($2.21e-07$)
RuD_{t-1}	0.0068447^{*} (0.002893)	0.0060129^{*} (0.0030548)	0.0000403^{**} (0.0000127)	0.0000272^{*} (0.0000117)
$CPIE_{t-2}$	0.0028118 (0.0054942)	0.0016896 (0.0056752)	$-3.55e-07$ ($8.77e-06$)	$2.14e-06$ ($8.71e-06$)
ΔELC_{t-2}	0.0002251 (0.0002658)	0.0001219 (0.0002714)	$-1.67e-07$ ($2.98e-07$)	$-1.64e-07$ ($2.96e-07$)
$APAT_{t-2}$	0.0000287^{*} (0.0000126)	0.0000263^{*} (0.0000131)	−−	−−
β_0	2.049183 (1.253973)	2.224346^{+} (1.291999)	-0.0004298^{*} (0.0001677)	-0.0002484^{+} (0.0001377)
time dummies	*No*	*No*	*No*	*No*
R-sq	–	–	0.0120	0.0206
Wald chi2	85.93	83.91	–	–
p-value Chow-test	0.3621	0.8283	0.7198	0.5628
Nr. of observations:	65	65	55	55
Nr. of groups:	5	5	5	5

Significance: $^{**} \leq 1\%, ^{*} \leq 5\%, ^{+} \leq 10\%$

table 3.3 (column 2-5), table B.2 (page 201, column 2-7) and table B.3 (page 202, column 2-8).

Hypothesis 2: Our hypothesis is that electricity prices do not significantly affect the probability for innovate activity when looking at the different GT industries. This view is supported by assuming a one-year time lag between PAT and $CPIE$ as shown in table 3.2 (page 79, column 6-9). The estimation results reported in table 3.3 (page 80, column 2-5), table B.2 (page 201, column 2-7) and table B.3 (page 202, column 4 and 5) support this view. However, in table B.3 (page 202, column 2-3 and column 6-8) we also report the estimation results for a two-year time lag between PAT and $CPIE$. These additional estimations show a different outcome. Electricity prices positively affect the probability of patenting if the time lag is bigger than one year. Based on this result, we

TABLE 3.4: Reverse causality

estimation method	**OLS** (fixed effects)	**AR(1)** FD (fixed effects)	**OLS** (fixed effects)	**AR(1)** FD (fixed effects)
Independent Variable	$\Delta INCAP$ $--$	$\Delta INCAP$ $--$	$--$ $INCAP$	$--$ $INCAP$
PAT_{t-1}	12.33627** (1.914261)	5.630782** (1.655493)	73.12402** (12.16215)	3.182065* (1.461352)
$CPIE_{t-2}$	−10.47017 (8.701615)	−3.946515 (5.576607)	−62.13559 (55.28523)	−6.396556 (6.017495)
RuD_{t-1}	−0.9970726 (5.800703)	−6.817154 (4.577341)	−23.99885 (36.85445)	−2.590538 (3.9163)
ΔELC_{t-2}	−0.1973399 (0.4556235)	−0.0006138 (0.1771254)	−2.09386 (2.894779)	0.0563747 (0.1570209)
$APAT_{t-2}$	−0.0123203 (0.019199)	−0.0009091 (0.0154699)	−0.082883 (0.1219799)	0.0067159 (0.0152988)
β_0	1142.529 (1891.871)	28.68449 (32.09113)	8061.845 (12019.9)	822.1719** (31.16902)
time dummies	*No*	*No*	*No*	*No*
R-sq	0.1832	0.2408	0.0657	0.0236
Number of observations:	65	55	65	55
Number of groups:	5	5	5	5

Significance: $^{**} \leq 1\%, ^{*} \leq 5\%, ^{+} \leq 10\%$

have to reject hypothesis 2. An increase in electricity prices can increase the probability to be engaged in innovative activities with a two-year time lag.

Hypothesis 3: The positive significant result for RuD is relatively stable. It is supported by the estimation results presented in table 3.2 (page 79, column 6-9), table 3.3 (page 80, column 2-5), table B.2 (page 201, column 2-7) and table B.3 (page 202, column 2-8). Public R&D has a positive impact on the probability for innovative activity.

The structural break between the SEG and the EEG (hypothesis 4) is tested by the use of period dummies for $INCAP/\Delta INCAP$ (compare table 3.3, page 80, column 2-5). Interestingly, in column 2 the coefficient under $INCAP^{SEG}$ is insignificant and becomes significant under $INCAP^{EEG}$. This points in the direction of there being some difference for diffusion under the SEG and the EEG. When looking at the differences in coefficients, however, the Chow-test does not report any structural break (the Chow-test is reported on the lower end of table 3.3).[24] The test statistic did not show any significant difference

[24] As reported in column one, the p-value for the Chow-test was reported to be 85.39 percent. In 85.39 percent of the cases we cannot reject HO, indicating that there is no significant difference between the coefficients.

between the coefficients for $INCAP^{SEG}/\Delta INCAP^{SEG}$ and $INCAP^{EEG}/\Delta INCAP^{EEG}$ in all four cases. As we get significant results for $INCAP/\Delta INCAP$ under the SEG and EEG in three of the cases (column 3-5), we have to reject hypothesis 4. One possible explanation might be as follows: Due to the fact that most GT industries (except $WIND$) are still operating on rather low scales (compare figure 3.4), the time span might be too small to capture the dynamics related to structural change within the energy system.

Finally, we have to comment on the estimation results presented in table 3.4 (page 81). It can be seen that innovations increase the size of the market, endogenously. This has to be taken into account by interpreting the result of hypothesis 1. This is in line with the literature and the critique of the Schmookler hypothesis. Finally, the simple demand story is more complicated, as providers of certain products can increase the size of the market endogenously if they innovate.

3.4.4 Robustness of the results

Table 3.2 (page 79) shows in column 8 and 9 the estimation results for the first differences OLS model. It can be seen that the estimation results are similar to those reported for the negative binomial regression in column 6 and 7. This already indicates that first order serial correlation is not driving our estimation results. Further estimations are also reported in table B.2 (page 201), where we explicitly control for first order serial correlation.[25] The Baltagi-Wu test statistic for the AR(1) random effects model presented in column 3 (model with $INCAP$) is reported to be 2.177. For the model in column 5 (model with $\Delta INCAP$) it is reported to be 2.101. As the test statistic is higher than 2 in both of the cases we can conclude that there is no significant autocorrelation for the AR(1) model.

A look at correlation matrix 5 and correlation matrix 6 (page 203) shows, in addition, that multicollinearity is also not a major problem of our model. It has further to be kept in mind that multicollinearity does not cause a bias in the estimated slope coefficients (Berry, 1993).

The robustness of our estimates supports the main findings that can be summarized as follows: With respect to the Schmookler hypothesis (hypothesis 1a, hypothesis 1b), we find that firms operating in different GT industries are engaged in innovative activities. We further find good evidence for hypothesis 3. Whether hypothesis 2 has to be rejected depends on the model assumptions. As one can also expect that price increase positively affects incentives to innovate, it seems plausible to reject hypothesis 2. We also have to reject hypothesis 4.

[25] See the test statistics of the Baltagi-Wu LBI-test reported for the AR(1) model in column 3 and column 5.

3.5 Conclusion

The aim of this study has been to test if policy induced structural change in the energy sector in Germany is accompanied by innovative activity. The empirical findings support the hypothesis that a market size as well as an increase in the size of the market has an impact on firms to be innovative. The empirical findings also show that public R&D expenditures are important. We test for reverse causality and find that innovative activities have a significant impact on the increase in market shares by themselves. Innovations in GTs are a necessary condition if conventional energy technologies are to be substituted for in the future.

That supply is able to react in a very short time period to changes in relative prices (the same is true for innovations), is one of the results demonstrated by the econometric model. Nevertheless, as diffusion of GTs is policy induced, the partial analysis cannot be related to aggregated economic growth. There is a further concern that positive environmental impacts disappear due to the inefficiencies related to the institutional setting. Efficient diffusion of GTs requires a mechanism that allows for more self-selection by the market with respect to the future potential of different GTs j.

Chapter 4

Strategic Trade Policy as Response to Climate Change?*

4.1 Introduction

The problem of climate change is of a global nature. As long as economic growth is not disentangled from an increase in greenhouse gas (GHG) emissions, the problem of climate change is likely to increase. One common argument is that the global problem encourages free-riding and reduces national incentives to contribute to climate change mitigation policies. Thus, international policy coordination seems adequate.

One example of international cooperation aiming to reduce coordination problems is the Kyoto-Protocol (KP). Even though the KP was an attempt to make countries act cooperatively, strategic behavior could be observed at the ratification stage (decision to ratify or to free-ride on the agreement) as well as the implementation stage (over or underinvestment to fulfill the requirements agreed by ratification). Differences in national cost structures combined with strategic interaction between countries makes international policy coordination difficult. A recent example was the negotiations for a follow-up agreement to the KP which took place in December 2009 in Copenhagen (cf. Macintosh, 2010; Nicoll et al., 2010). Despite the global nature of the problem, some governments did start to restructure their energy policies. It seems that they take the climate change problem seriously (e. g. the German government by supporting diffusion of green technologies (GTs)[1]). Interestingly, it turns out that the same countries argue forcefully in favor of more strict environmental standards on the international platform.

The fact that some countries invest relatively more than other countries in the abatement of climate change is somehow counterintuitive if we apply the general

*This chapter is mainly based on Freytag and Wangler (2008). We are indebted to Peter Burgold, Sebastian v. Engelhardt, Hannes Koppel, Simon Renaud, Gert Tinggard Svendsen and Hans-Peter Weikard for helpful comments on an earlier version of this work.

[1]In this paper we define GTs as technologies able to produce electricity using renewable energy sources (e.g. photovoltaics, . . ., wind mills) and therefore have the potential to substitute for GHG emitting conventional energy sources.

wisdom that free-riding of particular countries negatively affects the international competitiveness of non-free-riding-countries. Investment costs related to GTs seem to be a burden that increases the costs of energy consumption within a country. It is therefore an interesting question why some countries are more motivated than others in implementing policy measures that have a seemingly positive impact on the problem of global warming and promote actively high environmental standards at the international level instead of free-riding themselves.

We argue that the initiative for structural change at the national level can be an outcome of international environmental agreements (IEAs) aimed at reducing problems related to climate change. In contrast to the common view, the main argument of our paper is that free-riding by some countries may encourage other countries to increase investment in abatement measures instead of reducing it. Our arguments are based on a political economy framework in combination with international trade policy.[2]

The paper is organized as follows. In section 2, we briefly discuss the costs of global climate change, the global attempt to solve the problem and the specific German policy response. Section 3 is dedicated to the development of our theoretical framework to explain a country's solo run to provide a global public good in climate policy. Our political economy reasoning is empirically assessed using a negbin model in section 4, where we use the patent applications of German green technology firms as a proxy for their expectations about future export sales. Conclusions round off the paper.

4.2 Climate Change and International Policy Coordination

4.2.1 Costs and Benefits Related to Climate Change

Detecting the costs of climate change is a difficult task. Without policy response, costs of changes in temperature are expected to increase at a level of from $5 - 20$ percent of global annual gross domestic product (GDP). The cost of reducing GHG emissions can be lowered to a decrease in world GDP of one percent if countries are able to coordinate their policies (Stern, 2007). Costs and benefits related to climate change also differ substantially between different regions, and simulation models have to take spacial differences into account (Nordhaus and Yang, 1996; Mendelsohn et al., 2000). It might well be argued that it is "cheaper" to react today than in the near future, because doing nothing will increase costs (Kemfert, 2005). However, as stated by Sinn (2008), it may also be the case that the abatement of industrialized countries does not affect the speed of global warming as initially intended because the reduced demand for energy by some

[2]Brandt and Svendsen (2006) argue similarly. They focus on the first mover advantage of the Danish wind and turbine industry to explain the national interest of high environmental standards. Compare also Svendsen (2003). Our approach is different as we focus on the German green technology sector and we use a Stackelberg game with five different possible outcome scenarios.

industrialized countries simply lowers world market prices and increases the demand for energy by those countries which do not intervene to reduce energy consumption (the so-called "rebound effect"). This leads Lomborg (2006) to suggestions of alternatives to the option of cutting GHG emissions.

It can be seen that the estimated costs related to climate change depend strongly on the policy measures implemented (compare among others Klepper and Peterson, 2004, 2005), as well as the scenarios and the underlying assumptions on which the calculation is based. Welfare effects published by the IPCC (IPCC, 2007) and the Stern review (Stern, 2007) are thus critically assessed (Nordhaus, 2007; Weitzman, 2007). Due to the uncertainty, estimates for a particular scenario lie within a certain range and precise accounts of the costs are difficult. Notwithstanding, it becomes clear that there are costs related to investment into mitigation policies, generating problems for national governments to free resources for investments into environmental conservation. The free-riding of some countries may increase the slope of the national cost function. Country specific solo-runs do not make sense, as the climate change problem creates international spillovers.

4.2.2 International Policy Coordination and the Kyoto-Protocol

Based on the former arguments, global environmental problems constitute an international prisoners' dilemma. Once the problem of climate change is acknowledged as a global environmental problem, it has to be treated as a global public "bad". This implies, in turn, that climate protection has the characteristics described as "tragedy of the commons" (Hardin, 1968). Thus, countries have to cooperate to find solutions for the common pool problem (cf. Ostrom, 1990).

The Kyoto Protocol is an attempt to coordinate international policies. By signing the KP countries agreed to a reduction in the emission of GHGs to a specified level measured in percentages of the base year 1990. Between 2008 and 2012 countries are supposed to reduce the average emission of GHG by about 5.2 percent of the 1990 reference-level. Europe agreed to reduce the emissions of GHG by 8 percent in comparison to the emissions of 1990. Germany agreed on an emission reduction of 21 percent (Sachverständigenrat, 2004, p. 121). The KP was coupled with the condition that at least 55 member states, which altogether produce more than 55 percent of the global emissions of CO_2, have to ratify the protocol before it can enter into force (UNFCC, 1998, p. 19).[3]

The 55 percent rule was fulfilled when Russia ratified the KP in November 2004. Therefore, the KP came into force in February 2005. Today, 188 countries and other

[3]The so-called 55 percent rule has important implications: It gives countries the opportunity to free-ride without nullifying the whole agreement. The free-rider problem is thus mitigated and it is more liekely that the agreement will be implemented.

governmental entities have ratified the KP. The United States, the largest single emitter of GHG signed, but did not ratify the KP at the national level.

Altamirano-Cabrera et al. (2007) discuss the KP from a political economy perspective and analyse the influence of political pressure groups on the stability of the agreement. It turns out that strategic interaction between countries is highly influenced by the relative political strength of two different interest groups, the GT industry and conventional industries, respectively. Pressure groups determine the abatement inside a country and influence the stability of international agreements. The probability of cooperating less or acting non-cooperatively increases with the political influence of conventional industries. Considering this and the fact that some countries did act non-cooperatively at the ratification stage or the implementation stage, it is surprising that countries like Germany were willing and able to install high national environmental standards.

4.2.3 Germany's Policy Reaction to Global Environmental Problems

Germany has chosen a mixed strategy to reduce the emission of GHG. On the one hand, there is the market solution (implemented in Europe) of trade with certificates related to GHG emissions.[4] Germany has a target that emissions in 2012 be reduced by about 21 percent, compared to 1990. On the other hand, the government is using incentives to encourage the application of particular (allegedly) climate friendly technologies. For instance, the former "red-green" government coalition[5] passed a law, the so-called "Renewable Energy Sources Act" (EEG), to support renewable energies by the use of technology specific feed-in tariffs. The EEG can be considered as the successor of the "Electricity Feed Law" (SEG) of 1991. The SEG allowed, for the first time, the feed-in of electricity produced with GTs into the electricity network for a remuneration which was lower than the average market price for electricity.

Policy induced demand for GTs can theoretically be justified by the argument of *backstop technologies* (Nordhaus, 1973). The political argument for investment into GTs is to foster the development of GTs and to reduce global warming (EEG, 2009, section 1, purpose). There is an obvious connection between the problem of climate change and industrial policy, as the EEG uses feed-in tariffs to foster diffusion of some particular GT industries. The range in 2003 was from 6.5 Cent/KWh for electricity produced by using WATER and BIOGAS up to 51.62 Cent/KWh for electricity produced with SOLAR.[6]

[4]The importance of defined property rights as an efficient solution for the externality problem has been highlighted by Coase's (1960) seminal paper. For theoretical considerations compare (Baumol and Oates, 1988).

[5]The coalition between the *Social Democrats* and the *Green* party from 1998 to 2005.

[6]The market price for electricity in 2003 was reported by the German statistical office to be 8.78 Cent/KWh on average.

By examining the effects of the EEG relative to a reduction of GHG emissions, the positive environmental impact is strongly debated.[7] Nevertheless, the EEG had the effect that the percentage of renewable energies of the total production of electricity increased from 6.3 percent in 2001 to 11.8 percent in 2006 (BMU, 2007a, p. 8).

4.3 Political Economy Consideration

In comparing conventional energy technologies with GTs, there is a major argument that the outcome (e.g. electricity) can be produced cheaper with conventional energy technologies. If the externality problem is taken into account, this calculation might be wrong. However, as most GTs, so far, are not able to substitute for conventional energy technologies, diffusion of GTs is, first of all, a costly investment into backstop technologies, with uncertainty about its relevance for substituting conventional technologies in the near future.

4.3.1 Two Alternative Explanations for One Country's Solo Run

In our study we look at investment into GTs from a political economy perspective. We argue that welfare effects are not the major concern of politicians. Politicians try to be re-elected and therefore are concerned about vested interests (Schumpeter, 1987a). A decline in the current level of GDP (e.g. because of the decline of traditional industries) might have a negative impact on the probability of being re-elected.

If we base our arguments on a short-run perspective, the free-riding of some countries makes investments into climate protection costly. We, therefore, should not expect that politicians (e.g. in Germany) will invest in the diffusion of GTs to such a great extent, as described previously. The support for most GTs (e.g. photovoltaics) is still not profitable under current relative prices. It is also implausible that politicians in a democracy with limited electoral terms will seriously support a policy which has a long-term time horizon (as is the case with climate change issues). This argument may change once exports of GTs are taken into account. We still have to answer the question about the rationality of the political calculations.[8]

[7]This is because the providers of energy are integrated into the trade with emission certificates. The EEG obliges them to buy the electricity produced with GTs. If the quantity of certificates remains constant, the EEG frees shares of certificates for other sectors and reduces incentives for GHG reduction (Sachverständigenrat, 2004, pp. 122-123). Compare also Traber and Kemfert (2009). However, as most of the industries affected by the emission trading scheme are energy producing companies, this hybrid system may reduce their resistance to diffusion of GTs.

[8]Sometimes, there is not a clear strategy, rather a kind of "window of opportunity" opens for the support of GTs. The fact that the German Green Party was in the government between 1998-2005 supports this explanation. Using the close relationship between the interests of the GT sector and the Green Party as an explanation, "standard" "lobbying" and short-term orientation of politicians can still be used to explain the outcome of the political process.

A standard political economy explanation refers to the median voter model (Black, 1948; Downs, 1957). The government follows the median voters' preferences, which are increasingly directed to protect the climate. Therefore, the government invests relatively more than other countries into climate protection as this is in line with median voter preferences within the country. In addition, the domestic government can lobby for a more ambitious international policy response. This strategy only pays off politically, if the median voter thinks the benefits of the domestic efforts provide a global public good higher than the marginal costs of higher energy prices or costs related to substitution effects in the economy. The likelihood of such a potitical preference for early investment into abatement policies is doubtful, at least when it is about the adoption of a certain GT industry j.

Thus, there has to be a second rationale, namely short-term employment in the GT industries (generating directly observable growth in the GT industry) linked to the argument of future export sales of these technologies. The job creation in a particular GT industry (Hillebrand et al., 2005; Lehr et al., 2008; Blanco and Rodrigues, 2009; Lund, 2009) very likely creates stable (or increasing) transfer flows to the particular GT industries (lock-in effect). Politicians maximize their political support function (in the short run) with this job increase and at the same time justify these transfers by expected future payoffs (e.g. future exports) related to the investment. However, such a strategy requires that, over time, other countries adapt to the higher national standard. From this perspective it becomes clear that the incumbent government has to make use of the instrument of "international lobbying" to prepare future export markets in order to make the (over)investment into GTs profitable. Thus, for investment into GTs it mainly holds in a one-shot game that free-riding behavior of other countries is problematic for the domestic government and its climate abatement targets. From a dynamic perspective, this free-riding behavior in the short run may be a major reason for ambitious unilateral political action, as long as it can be expected that other countries over time have to increase their environmental standards, as well. Obviously such an increase seems to be likely in the context of climate change with its long-term time horizon.

To strengthen this argument we first discuss short-term GDP reaction related to a policy induced demand for GTs. The impact is assumed to be negative. This result builds on the assumption that without a policy induced demand, the domestic market for GTs would fail as there is not an intersection between demand and supply for given prices without subsidies. However, once national institutions are installed and GTs start to diffuse, marginal costs are supposed to decline because of learning effects or some economies of scale. The resulting effect is a comparative advantage for the national GT industry (first mover advantage) as it moves rightwards on the learning curve (see figure 4.1) and institutions like patent laws allow for the commercial exploitation of this advantage.

We, therefore, proceed and combine this argument with a Stackelberg game which shall explore the political economy of climate policy in more detail.[9]

Heterogeneity among countries with respect to the national strength of GT industries may encourage particular countries to progressively support the interests of their GT industries at the international level. Such a policy would be politically promising, as the demand for both climate protection and future jobs seems to be satisfied. The negative impact the GT sector has on the national GDP is expected to decline and growth in the GT industry shifts climate policy towards the preferences of the median voter.[10]

4.3.2 Economy Without Trade in Green Technologies

Without any policy induced demand for a certain GT j there is no intersection between supply and demand and marginal production costs are assumed to be constant. Once there is an intersection between supply and demand (due to a subsidy or regulation in favor of a certain GT j), we assume learning curve effects, thus the cost curve has a negative slope.[11] This is depicted in figure 4.1, where t stands for time, c^{pr} represents the marginal production costs, D_N stands for demand for a certain GT j without policy induced demand (pid_j) and D_S stands for demand for a certain GT j with policy induced demand. We refer to pid_j as diffusion of GTs that results from domestic political intervention. What we have in mind can be interpreted as command and control policies with characteristics similar to those of the EEG. Theoretically pid_j could also represent diffusion of GTs as a result of market-based instruments such as tradable certificates or subsidies. In any case, the parameter is exogenous and can be directly influenced by national legislation.

We start in a world were only one country – in our framework the home country (H) – implements measures that allow for diffusion of GTs. The measure taken is a policy induced demand for renewable energy at a level that allows the GT industry to establish. There is no international trade in GTs as the foreign country (F) free-rides on climate change mitigation policies.

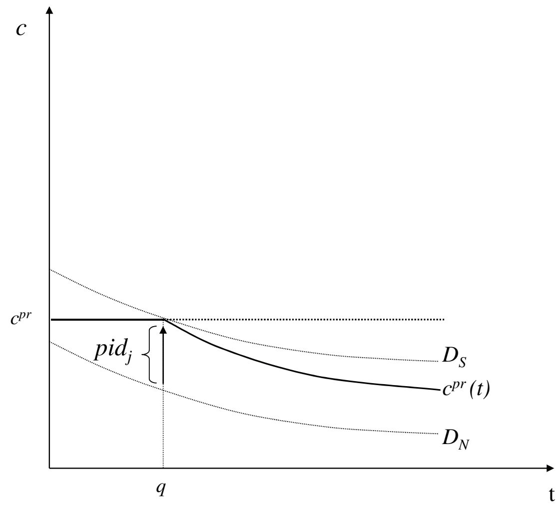
Concentrating on the domestic consequences of supporting renewable energy beyond the market demand for GTs (under the assumption that F does not support the GT sector),

[9] A Stackelberg game seems to be the most appropriate in this case, because producers of GTs start to compete once one country starts to invest into GTs. Within the country firms compete on the industry level such that they cannot make use of their cost advantage in the form of price competition. We expect that competition will be about exported quantities.

[10] The empirical evidence shows that governmental changes in Germany did not lead to real changes within the German system that is used to support diffusion of GTs, even though the Green Party has been a member of the opposition since the year 2005.

[11] There are studies which support this assumption. For photovoltaics and wind mills see Nemet (2006) and Madsen et al. (2005).

FIGURE 4.1: Learning curve effect



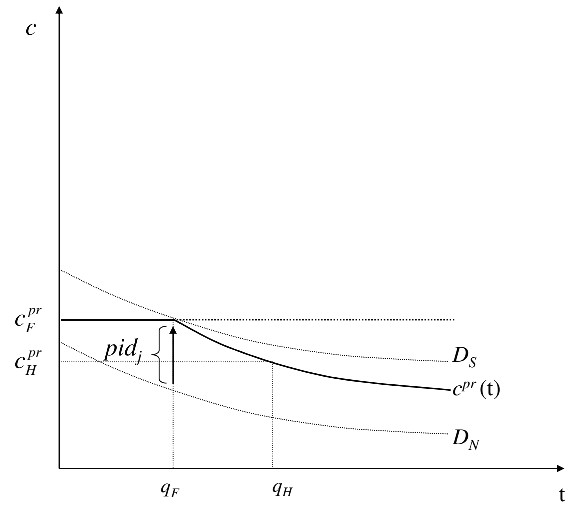
the balance is negative. Because conventional substitutes for producing energy exist, the creation of the GT sector generates *costs* in H that can be translated into a reduction in the level of national GDP. In addition to the environmental regulation, these costs reduce the initial comparative advantages of other industries (that use energy as input and compete in international markets) and additional pressure comes from the short run free-riding strategy in country. In other words: $Y_H^{n1} < Y_H^i$ (Y_H^{n1} stands for "new GDP1" with policy induced demand for GTs and without exports, the latter for the GDP without policy induced demand for GTs). This line of arguments is well known and can directly be applied as an explanation for the free-riding problem, resulting in an international prisoners' dilemma.

4.3.3 Open Economy Considerations

Because we assume that H enters the market of GTs before F, it moves rightward on the cost curve.[12] Hence, considering exports does lead to a change in the results. If F decides later to enter the GT market and starts its own production, it has to start at a higher point on the cost curve. Figure 4.2 shows that c_F^{pr} are expected to be higher than c_H^{pr}. The support for a certain GT industry in F could be the result of H's government successfully "lobbying" for a global environmental standard or due to a change in the national government in F. It also might be that median voters' preferences in F change.

[12]For a general discussion of learning curve effects and competitive markets see Rasmusen et al. (1997).

FIGURE 4.2: Different marginal production costs



It is highly sensible to use a framework of strategic trade policy to explain why $H's$ government has strong incentives to support high environmental standards on an international platform. The idea of strategic trade policy can be traced back to Brander and Spencer (1985). The underlying argument is quite simple and can be summarized in the following way: in incomplete markets, market entrance can be characterized by a first mover advantage. The first mover advantage stems from the chance the firm which first enters the market with incomplete competition has to increase market power. In an extreme case, the industry will become monopolistic.

Thus, political support (or more generally a policy induced demand) can help the industry to exploit the rents related to the early market entrance. Even though the terms of trade may deteriorate, as long as price changes exceed the marginal costs related to the political support, the welfare of the country as a whole can increase.[13]

Other theoretical papers also use game theory to evaluate strategic interaction between countries in the case of environmental policy (Barrett, 1994b; Ulph, 1996; Ulph and Ulph, 1997, 2007; Rege, 2000). In our paper, we use the theoretical arguments to explain political rationality, which distinguishes it from former related publications.

The political rationality is explained by five different scenarios. In the first case we assume that *F* decides in a later phase than *H* to implement a transfer scheme per unit

[13]Only if both countries subsidize their industries in order to be the first to enter into the market, a prisoners' dilemma is present and both countries would be better off without the subsidy (Brander and Spencer, 1985, p. 95).

of energy produced by a particular GT (FITs) (what is captured by pid_j). We assume that producers located in *F* are also able to produce GTs, but they operate on a higher marginal cost curve. This allows the GT sector in *H* to enter the market in *F* as a Stackelberg leader (scenario 1).[14] Alternatively, high environmental standards might be the result of supranational negotiations (scenario 2). The high environmental standards increase the demand for GTs indirectly.[15].

There may also be a different outcome, depending on *F*'s reaction. For example, what if *F* decides to support GT firms located in *F* directly with a subsidy on marginal production costs (scenario 3).[16] Two cases are possible under this scenario. In case (3a), *H* is not able to export its technology, because the subsidy to the foreign GT sector is too high and industries located in *H* are not able to compete with *F* (however, the subsidy in *F* may encourage foreign direct investments (FDIs) or the GT industry in *H* also lobbies for direct subsidies in order to become competitive). In case (3b), if the GT industry in H is so competitive that it was exporting GTs before *F* started to subsidize national industries, *H* can continue to export, if it is still able to compete with the GT industry located in *F*. It is also possible that *H* competes with the GT industry in *F* in a "third" market (e. g. country *I*) (scenario 4).[17] There is, further, the possibility that a firm located in *H* is making a direct contract with politicians in *F* (scenario 5), and, again, two cases have to be distinguished: In case (5a), *F* simply buys *H*'s technology. In this case, the GT industry would sell a *package* of GTs to *F*. This scenario can also be used to integrate the clean development mechanism into the model. In case (5b), the contract is combined with a local content clause.[18]

We restrict the analysis to these five scenarios, because they cover relevant cases and seem to be sufficient to show the incentives which politicians in *H* have (1) to use industrial policy to support the national GT industry even though other countries free-ride,

[14] As stated by Frondel et al. (2008a), there was a huge increase in the demand for photovoltaics when Germany started to support GTs by subsidizing each unit of energy produced by GTs directly over the EEG. The increase in demand was so strong that most of the modules were imported from Japan (Frondel et al., 2008a, p. 6). It seems plausible to interpret this in the sense that Japan had a first mover advantage to enter the German market, as we model it with the Stackelberg game. However, the empirical evidence also shows that the German solar industry was quite fast in catching up.

[15] Many papers use an endogenous growth setting to model the costs of technological abatement related to high environmental standards ((an overview is given by Löschel, 2002; Jaffe et al., 2002b). High environmental standards set the incentive to invest in abatement, such that it leads to endogenous technological change (Xepapdeas, 1995; Rosendahl, 2004; Golombek and Hoel, 2008)

[16] We assume that this scenario is the most likely one. The government in *F* would probably have political difficulties increasing the costs for its industries with a higher environmental standard without using the argument of new jobs in its own GT-sector.

[17] In this case, *I* is not able to produce GTs but has an incentive to buy them (e. g. because of high international environmental standards or as a result of cost reductions and innovations). Among others, the competition related to a "third" market has been studied by Maggi (1996).

[18] One example of local content clauses related to the implementation of GTs is the Canadian province of Québec. A precondition for obtaining support for the installation of windmills in Québec is that 30% of the wind mills have to be produced locally (FAZ, 2007, p. 16).

(2) to support high environmental standards at a supranational level and (3) to cooperate with the GT industry on international interests.[19] Initially, we discuss scenario 1 and scenario 2. The results for the other scenarios are summarized in table C.1 (App. C.1).

Expectations Related to Exports of GTs (scenarios 1 and 2)

Without any support being given to the GT sector the initial GDP of both countries is the same. This means that $Y_H^i = Y_F^i$ (Y_F^i stands for the GDP without any support for the GT industries in F). H is *faster* in implementing GTs than the other country.[20] If we compare the GDP levels of both countries after H has decided to implement a GT sector, in the short run we have the case that $Y_H^{n1} < Y_F^i$.

We do not assume a monopolistic market in the GT sector in H but all GT industries in H are supposed to be symmetric and able to supply GTs at the same marginal costs. Finally, expected exports of GTs $_j$ ($j = Photovoltaics, \ldots, WindMills$) from H to F are looked at from an aggregated level. Politicians and representatives of the different GT industry's in H are aware of their advantage in international competitiveness. Therefore, both groups expect to benefit from an increase in environmental standards in F. This means that there is an expected gain related to the export of GTs.

The expected price-demand function is given by $p^e = A^e - q^e_{H_j} - q^e_{F_j}$ (where A^e represents the expected size of the GT market with exports, $q^e_{H_j}$ stands for the expected quantity sold by the GT industry $_j$ located in H and $q^e_{F_j}$ stands for the expected quantity sold by the GT industries$_j$ located in F). Expected profits of the GT industry$_j$ located in H, due to export of its technology to F, can be formulated as follows:

$$\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^{pr}_{H_j} + pid^e_{F_j}) - c_{l_j}. \tag{4.1}$$

If industries in H and F are operating on different cost curves, as depicted in figure 4.2, then equation 4.1 can be solved as a Stackelberg game (compare App. C.2, p. 205). We argue that H enters the export market as Stackelberg leader.

We then get as an expected outcome that $q_H^{e*} > q_F^{e*}$ and exports (in contrast to the short-term considerations) contribute positively to Hs level of GDP. The result $q_H^{e*} > q_F^{e*} > 0$ can be interpreted as potential extra gains for the GT industry in H – if F was free-riding in the short run and decides later to support diffusion of GTs without discriminating against Hs industry. This is one reason why there might be a strong interest in H investing heavily in the diffusion of GTs and "lobbying" for high environmental standards internationally. Thus, once the GT industry has been successful in establishing itself at the national level, the GT industry (in both H and F) and the government (in H) have common interests at the international level.

[19] For an example look at http://www.exportinitiative.de.

[20] We argue that this is due to the political process. Beside this, both countries can be assumed to be *symmetric*.

How does this result translate into H's changes in GDP (Y)[21]? We can substitute the calculated values for $q^{e*}_{F_j}$ and $q^{e*}_{H_j}$ into equation 4.1 and obtain the expected profit $\pi^e_{H_j} > 0$. This profit can be directly translated into national welfare gain ($\pi^e_{H_j} = y^e_H > 0$). This leads to the result that $y^e_H > 0$ reduces the loss in GDP related to the pid_{H_j} without any exports in the short run. With exports, the expected new GDP $Y^{e^{n2}}_H$ ($Y^{e^{n2}}_H = (Y^{n1}_H + y^e_H)$ is bigger than Y^{n1} (the GDP without any exports of GTs). So far we have the case that $Y^i_H > Y^{e^{n2}}_H > Y^{n1}_H$. The model implies that exports of GTs can generate welfare gains which enter positively into the GDP of H compared to the first situation which is described by Y^{n1}_H.[22] Therefore, the national government and the particular industry have another strong incentive to promote the technology.

Finally, just how realistic the expectation is that there is a long-run net benefit for country H from subsidizing its GTs has to be discussed. As Table C.1 (App. C.1, p. 204) shows, "only" in scenario 3, case (a), does the first mover advantage not lead to higher exports because of direct support in F for the GTs there. However, as q^{e*}_F is also bigger than zero, one can expect that the industry in F also gains. This implies less resistance in F.[23] All other scenarios are characterized by increasing exports, but not necessarily by increasing the GDP compared to the situation without policy induced demand for GTs. However, this problem can be politically mitigated, as the complexity of the economy may allow the government to attribute the export gains directly to its climate policy, whereas the job losses in downstream industries can be traced back to many factors. Governments may find a lot of explanations for the latter. Thus, there are at least three political economy arguments that politicians in H use in support of the GTs, strategically. All three have an interest in a market that allows for diffusion of GTs in F, because

- GT industry $_j$ expects higher profits,
- national governments can reduce the political costs caused by the policy induced demand for GTs,
- the GT industry in F can also generate profits which is important to reduce resistance against international standards.

The intuition behind the framework presented is to analyze political incentives which we now try to incorporate into an econometric model.

[21] Note that the welfare analysis is limited to the GDP and therefore ignores welfare gains due to the reduction of GHGs. In our study benefits of climate change protection are not taken into account. A cost-benefit analysis therefore would come to very different results.

[22] Above a certain threshold, it might be the case that the gains are bigger than the losses, such that $Y^{e^{n2}}_H > Y^i_H > Y^{n1}_H$.

[23] In addition, legal contracts for F might render scenario 3, if F is a WTO member and cannot just increase restrictions on GTs. That reduces incentives for opposition in F.

4.4 Empirical Approach

To strengthen our theoretical argument we propose an econometric model. With this model we try to assess empirically whether the alleged strategy of the government and the GT interest groups is indeed observable in reality. The question is whether or not the link between climate policy and industrial policy has an influence on export expectations related to GTs (eventually leading to an increase of GDP beyond the free-riding status quo). This is, of course, difficult to estimate, as expectations cannot be modeled easily. We argue that expectations about future export sales and thus profits ($\pi^e_{H_j}$) are best expressed in patent applications and grants in foreign target countries ($PATENT^{HF}$). The econometric model is therefore constructed in a way that it tries to proxy equation 4.1 ($\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^{pr}_{H_j} + pid^e_{F_j}) - c_{l_j}$) econometrically.[24] As shown by the further calculations (equation C.4) exports of GTs can have a positive impact on the countries level of GDP.

We build the model on the assumption that diffusion of GTs (as a result of *pid*) reduces marginal production costs. This relationship $pid_{H_j} : c^{pr}_{H_j} \rightarrow c^{pr}_{H_j}(pid_{H_j})$ is proxied with installed capacity (measured in MWh) of industry specific technologies (pid_{H_j}) in H. We further assume that in the equilibrium without trade in GTs pid_{F_j} is lower than pid_{H_j} (such that $c^{pr}_{H_j} < c^{pr}_{F_j}$) and politicians located in H make use of international "lobbying" to create or to further increase pid_{F_j} in order to be able to exploit their comparative advantage in future trade sales (in the model described as intra-industry trade). Formally: $\pi^e_{H_j}$ proxied by $PATENT^{HF}$ and $c^{pr}_{H_j}(pid_{H_j})$ proxied by $(INCAP^H)$ gives the functional form that we are interested in. This then leads to the relationship ($INCAP^H : PATENT^{HF} \rightarrow PATENT^{HF}(INCAP^H)$). Thus, if there is a positive correlation between $PATENT^{HF}$ and $INCAP^H)$, we see a rationale for politicians located in H to actively support the interests of the different GT industry's at the international level. As controls we add public expenditures on research and development in the home country (RuD^H), energy prices in the foreign country ($CPIE^F$), as well as electricity consumption in the foreign country (ELC^F). We also control for structural change in the patent system with the variable ($APATENT^F$) which measures all patent applications in the specific country (this variable can also be interpreted as a proxy for A^e). Due to a lack of information we have to ignore the costs of lobbying (c_{l_j}). As our model makes use of future expectations, we don't have information on $q^e_{H_j}$, $q^e_{F_j}$, and $pid^e_{F_j}$ which is expected to be significantly higher than the observed variable pid_{F_j}).

The positive relationship between the patent system and trade has been highlighted by different authors (Markusen, 1995; Maskus and Penubarti, 1995; Rafiquzzaman, 2002). Coe and Helpman (1995) analyze empirically the impact of international *R&D* spillovers on economic growth. They come to the result that the relationship is positive. Beneficial

[24]Only those variables without *e* ("expectations") are observable.

effects turn out to be the stronger, the better the economy is internationally integrated. Overall, the rates of international *R&D* turn out to be very high. Thus, we see a certain confirmation of our political economy logic, if GT patents German firms file abroad are partially correlated with German climate policy.

4.4.1 Related Previous Studies

An increasing number of studies analyze the impact of environmental regulation on GTs. Rose and Joskow (1990) investigate the impact of fuel prices on the adoption of fuel-saving technologies on the electric utility industry (database comes from industries located within the US). In their study they also control for firm size and find that large firms are likely to adopt new technologies earlier than small firms and publicly-owned enterprises. Jaffe and Stavins (2005) study the impact of high energy prices on insulation for new home construction. They find a positive correlation between the two variables. With respect to the interpretation of the results, they underline that individual decisions to invest in insulation are strongly affected by the costs of insulation material. Other studies examine the relationship between environmental regulation and the probability for adaptation of environmental friendly technologies (Jaffe and Palmer, 1996; Gray and Shadbegian, 1998; Kemp, 1998; Kerr and Nevell, 2003). One of the main results is that the response to environmental regulation is different. This outcome can mainly be explained by firm specific heterogeneity.

Further studies look at a causal relationship between environmental regulation and industry specific competitiveness. Mainly, these papers are based on a contribution which became known as the "Porter hypothesis". The main idea is that countries with stricter environmental regulation force their industry to invest in abatement. One of the results may be that the industry located in the country becomes more competitive compared to its competitors located in other countries with lower environmental regulations (Porter, 1990; Porter and Linde, 1995).[25] Some rare studies are able to find support for the positive relationship (Porter and Linde, 1995; Berman and Bui, 2001b,a). However, besides theoretical concerns against the "Porter hypothesis", many empirical papers come to the conclusion that there is significant negative impact from environmental regulation on firms operating in the specific industry (Bartik, 1985; Jaffe et al., 1995; Becker and Henderson, 2000; Greenstone, 2002).

Only a few studies connect environmental policy to the diffusion of environmental friendly technologies. One important study, based on patent counts, addressing questions related to international diffusion of environmental technologies is Lanjouw and Mody (1996). The authors use patent data from the United States, Japan, Germany and other countries to analyze the impact of pollution abatement costs on environmentally

[25] For a review of some literature related to the "Porter hypothesis" compare Jaffe et al. (1995).

friendly innovations. They come to the conclusion that in countries with comparative advantages in industrial production – such as the United States, Japan and Germany – the majority of the patents for environmentally friendly technologies are owned by domestic inventors. By contrast, in the case of developing countries most innovations are "imported" from industrialized countries. Another major result of their study is related to regulation in one country and inventive activity in other countries with high innovative capacities. It turns out that environmental regulation in one particular country has an impact on innovative activity in other countries.[26]

In his study based on patent counts, Popp (2006) assesses differences at the international level. The study analyses the impact of stringent sulfur dioxide (SO_2) standards and nitrogen dioxide (NO_X) standards on the environment. The result is that the number of domestic patents increases with environmental regulation at the national level. Nevertheless, at the international level there is no significant impact. Popp (2006) interprets the results in a way that indicates domestic inventors tend only to react to national environmental regulation, whereas regulation in other countries does not have an influence. Additionally, the author is able to show that innovations may be made in one country, even though they have already been made in another country. Therefore, inefficiencies occur due to transaction costs and probable protection (scenario 3). Nevertheless, innovations developed in other countries are, to some extent, used as a building block for emission reduction in other countries. The following econometric model is related to this literature, but the underlying motivation is a political economy perspective.

4.4.2 Using Patent Counts as Indicator

Patents can be defined as "a document, issued by an authorized governmental agency, granting the right to exclude anyone else from the production or use of a specific new device, apparatus, or process for a stated number of years" (Griliches, 1990, p. 1662). From an international perspective, this implies that inventors with patents in a foreign country have the advantage of also protecting their knowledge in foreign market places. The rationality behind patenting abroad should be positively correlated with export expectations or the aim to sell licenses of a certain technology to the foreign country.[27]

The idea to use patent data as a proxy related to environmental innovation and competition at a national or international level is not new. A good overview of the

[26]They show this using the example of regulation on vehicle air conditioners in the United States. Even though the United States was one of the first countries with standards on vehicle air, many innovations came from foreign inventors.

[27]This is somehow clear, because if H is the leader in a certain technology, the follower F cannot export to H as long as inventors in H have applied for a patent. Because patent applications are costly, it is plausible to assume that patent applications abroad go in hand with the commercial value of the invention related to the foreign marketplace.

advantages and possible shortcomings of using patent counts as an indicator for environmental innovation is given by Popp (2005a). Patents have the main advantage of being a good proxy for international relations because "since inventors can apply for patents in multiple countries, patents can also be used to track the diffusion of technologies across-countries" (Popp, 2005a, p. 210).

The empirical approach we use to test the theoretical framework looks at the patents, with a priority on the German Patent Office (GPO) applied by German inventors and which are also protected at the European Patent Office (EPO), Japanese Patent Office (JPO) and the American Patent Office (APO), respectively. Therefore, we are able to consider the protection of knowledge in different markets. The patent counts we use also contain information about the dynamics of patent application over time. The number of patents issued can therefore also be interpreted as diffusion of innovation and expectation for future export receipts.

Beside these advantages, there are also shortcomings.[28] It is important to mention that by using patent counts as an indicator only a small area of innovations will be covered. There are many inventions/innovations that are not patentable at all. It might also be better for strategic or cost reasons to keep the innovation secret, instead of applying for a patent. Especially with respect to incremental innovations, this seems to be very likely. Therefore, regarding our study, patents can only measure a proportion of innovations related to green technologies. Because our analysis is constructed on aggregated data, we lose all the important information also captured by patents, such as the location of inventors, the firms operating in the GT industry or information about the value of the patent.[29] We also use the predefined list of patent classes from chapter 3 (table B.1, App. B) to extract the patents of the overall sample. Even though key words have been used to find out whether these groups are exactly the international patent classification (IPC) classes where the technologies of interest will be patented, it might be that patents are applied in other groups which are not captured by our list.[30] With respect to patent applications and patents granted, there might be a large difference. By evaluating long-time series, structural breaks due to institutional reforms of the patent system can also not be excluded. Time trends may exist in overall patenting behavior that may already explain some of the changes. Being aware of this problem we will include in our regression the count of all patents issued in countries abroad to cover some of these endogenous effects.

[28]A good overview of advantages and disadvantages related to the use of patent data is given by Griliches (1990).

[29]The count of patent citations could be used as an indicator measuring the value of a certain patent e. g. compare Jaffe et al. (2002a).

[30]Note that the extraction of the data has been done by a algorithm able to get rid of the problem of double counting of a certain patent. Therefore double counting cannot be considered to be a problem in our study.

4.4.3 Data Sources

The time frame of the dataset is from 1992 to 2002.[31] The institutional settings analyzed are the SEG (1990-1999) and the EEG (2000-2002+). The four sources of the data are the German Patent Office, the International Energy Agency (IEA), Eurostat and the Federal Ministry for the Environment (BMU). The industries of interest are Wind, Solar, Water & Ocean, Geothermal and Biomass.

In the regression proposed in subsection 4.5 patent applications ($PATENT^{HF}$) are used as a dependent variable. $PATENT^{HF}$ measures patents filed to German inventors at the EPO, the JPO and the APO. As for the timing, we use the *priority date* which is the date of the patent application at the GPO.[32] If the patent is granted in the foreign country, protection begins with the priority date. The huge time lag that may occur by regressing patents applied in foreign countries on their priority dates is not as problematic as it seems to be at first glance. As inventors who desire patent protection in other countries have the possibility of using the *patent cooperation treaty* (PCT) they have only a time span of one year to name the foreign countries in which protection is desired. Note that this information is very important with respect to our assumptions about the time lags implemented in the regression analysis (see closer specification of time lags and period dummies). For patents granted in a foreign country, the protection will go back to the application date in the home country. Nevertheless, between application in the home country and the granting of the patent in the foreign country, a time lag of more than four years is plausible. Therefore, for the regression analysis, we only use data from 1992 until 2002 (even though the dataset contains information until 2005).[33]

4.4.4 Descriptive Statistics on Patent Counts

Looking at the evidence shows that patents in the wind mill industry, solar industry and biomass industry have generally increased after 1998. For the other two industries, there is no observable trend. Figures 4.3-4.7 display the development since 1990-2005.

It can be seen that, especially in the case of WIND, patent counts have decreased considerably since 2002. The explanation for this is in the huge time lag we are confronted with in looking at patent applications in foreign countries.

[31] The data range is from 1990-2005. We restrict the analysis to twelve years of observation, because we assume that patent applications abroad before 1992 were not relevant. Additionally there is a problem of a huge time lag between patent application in Germany and the date when the patent is granted in a foreign country. As the dataset we use contains patent counts of patents that have already been granted in Germany and the foreign countries, after 2002 we lose a lot of information, leading to biased results. The reason for this is that there might be patents that have been applied for in foreign countries but have not been granted, so far. A summary of the data included in our dataset is provided in App. C.3, p. 206.

[32] Because nearly all patent applications are first filed in the home country of the inventor (Popp, 2006, p. 52), we can look at patents with priority at the GPO applied for protection in other countries.

[33] The dotted line in figures 4.3-4.7 is intended to show the decline in patent counts due to the time lag.

FIGURE 4.3: Patent applications in WIND

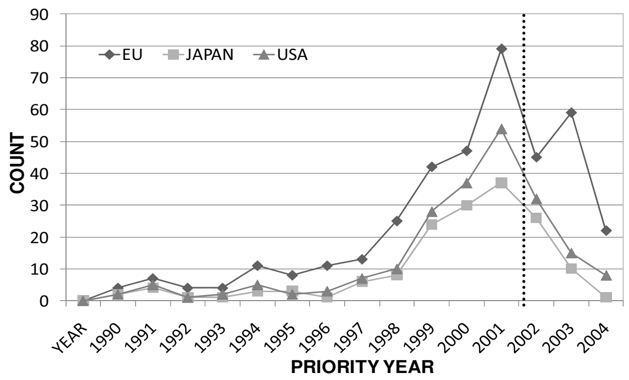
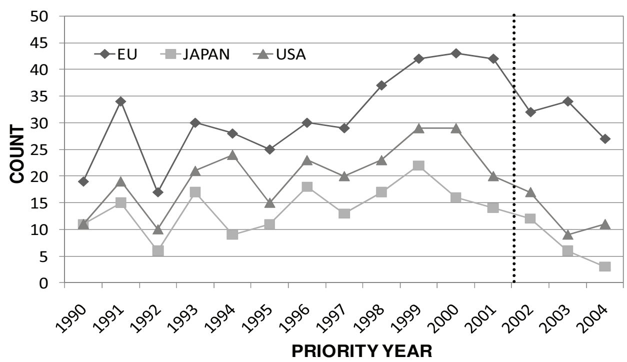


FIGURE 4.4: Patent applications in SOLAR



4.4.5 Hypotheses

We use $PATENT^{HF}$ as a proxy for export expectations as described in our strategic trade policy framework. Strategic knowledge protection in foreign countries represents the first "mover advantage" from the theoretical part. Results not published in this paper are strongly supportive of $\Delta INCAP^{H}$ being significantly positively correlated with patents filed at the German Patent Office (Wangler, 2010b). $INCAP^{H}$ (which we indicate by $c^{pr}_{H_j}(pid_{H_j})$ in the theoretical part) is our main variable of interest. We argue that feed-in tariffs in Germany are used strategically under the EEG to generate comparative advantages. $INCAP^{H}$ is therefore used as a proxy to test whether it is true that the

FIGURE 4.5: Patent applications in BIO

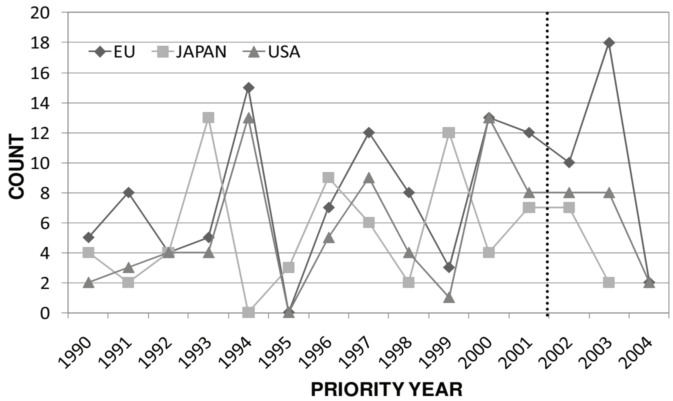
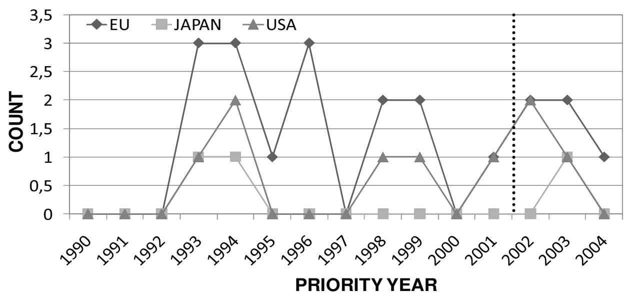


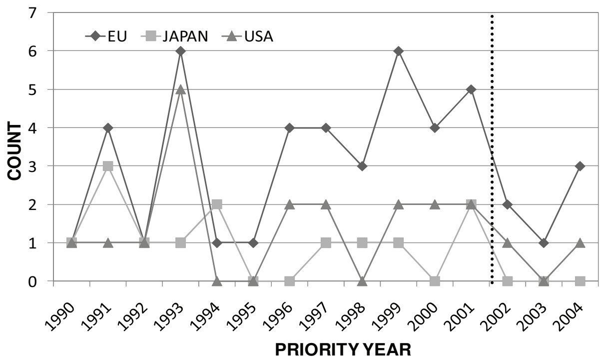
FIGURE 4.6: Patent applications in GEO



strategic use of feed-in tariffs did generate positive export expectations captured by $PATENT^{HF}$. If we connect the theoretical framework to our empirical data then we should also expect a positive relationship between RuD^{H} and $INCAP^{H}$. This leads to hypothesis 1a (H1a) and hypothesis 1b (H1b).

H1a: There is a positive relationship between public $R\&D$ expenditures RuD^{H} and international patent applications.

FIGURE 4.7: Patent applications in WATER



Source figure 4.3-4.7: EPO, compare App. C.3, p. 206.

H1b: There is a positive relationship between installed capacity of GTs in Germany $INCAP^H$ and international patent applications.

The third variable of the model is the installed capacity of renewable energies in the specific region $INCAP^F$. As an increase of $INCAP^F$ enhances export expectations to the foreign region it should be positively correlated with patents filed in this region in order to protect knowledge. This leads to hypothesis 2 (H2):

H2: An increase in installed capacity abroad $INCAP^F$ has a positive impact on international patent applications.

In addition to these three hypotheses there is the general assumption that there are significant differences with respect to region (r) and time (t). H3a and H3b capture the spacial dimension. H3c is related to the time dimension. To test H3c we implement time dummies for the SEG and the EEG. We suppose a significant change in coefficients as Germany started to connect industrial policy with the climate change issue under the EEG.

H3a: There are differences between EPO, JPO and APO, because the markets are different from each other.
H3b: Most dynamics take place in Europe.[34]
H3c: There are differences regarding the international diffusion under the SEG and EEG.

It is important to mention that hypothesis $H1b$ and hypothesis $H3c$ are of particular interest. Both hypothesis are very closely related to the theoretical framework where we argue that under the EEG feed-in, tariffs are used as a tool to indirectly support the implementation of certain GT industries.

4.5 Econometric Model

Model Specification
The *core* model that shall be estimated is

$$PATENT^{HF} = f\Big(\underset{+}{RuD^{H}}, \underset{+}{INCAP^{H}}, \underset{+}{INCAP^{F}}\Big).$$

$APATENT^{F}$, $CPIE^{F}$ and ELC^{F} are added to the core model as controls.[35] The variable $APATENT^{F}$ is integrated into the model because it contains information about the total number of patent applications in the specific region. It may be that the industrial structure in the region (indicated with many patent applications) is the driving force behind patent applications in the GT industry j.[36]

The dataset is constructed on three dimensions: (1) Time t, (2) Technology i and (3) Region r. A simple approach would be to estimate the regression for the EPO, JPO and APO separately. In this case there would be the estimation of three different panels. For each panel the estimation would be

$$\begin{aligned} PATENT^{F^r}_{i,t} &= \beta_0 + \beta_1 RuD^{H}_{i,t-1/2} + \beta_2 INCAP^{H}_{i,t} \\ &\quad + \beta_3 INCAP^{F}_{t-1} + \beta_4 APATENT^{F}_{t-1} \\ &\quad + \beta_5 ELC^{F}_{t-1} + \beta_6 CPIE^{F}_{t-1} + \alpha_i + \epsilon_{i,t}. \end{aligned} \tag{4.2}$$

[34]Europe has the highest share of renewable energies (6.9 percent) compared to the other countries of the analysis (Johnstone et al., 2010, p. 134).
[35]Compare also Popp (2001, 2002).
[36]Note that this variable is also important because it takes away some problems related to endogeneity.

The cross-section with different technologies ($WIND, SOLAR, WATER, GEO, BIO$) is indexed by $i = 1, \ldots, 5$, and $t = 1993, \ldots, 2002$ represents time.[37] The dependent variable is a vector with patent applications by German inventors in the other regions ($PATENT^r_{i,t}$), measured by the number of patents granted in r (at priority date). The independent variables include a vector with German technology specific public $R\&D$ expenditures ($RuD^H_{i,t}$), diffusion of the specific technology in Germany measured in MWh ($INCAP^H_{i,t}$), diffusion of all green technologies (not industry specific) in region r ($INCAP^F_t$) and all patents filed at region r ($APATENT^F_t$). (ELC^F_t) is a vector with electricity consumption per capita in region r and ($CPIE^F_t$) is a vector with the price index for energy. Because of collinearity of patent applications regarding $r = EPO, JPO, APO$, we integrate the third dimension with the same regression. In order to do so, we build region specific interaction terms. Fixed effects are integrated into the model by α_i in order to capture unobservable technology specific heterogeneity. All the residual variation is captured with the error term $\epsilon_{i,t}$.

As proposed by Johnstone et al. (2010), we use a negative binomial regression for estimation of the model from equation 4.2 but extend the panel about the third dimension (r). Poisson models as well as negative binomial models have been suggested in order to estimate count data (Maddala, 1983; Cameron and Trivedi, 1998; Wooldridge, 2002a). The events we "count" are the patent applications in different international levels indicated by r. Formally, we can define an event as a count of a non-negative integer-valued random variable. The assumption is that the count of the event (captured by $PATENT^{F^r}_{i,t}$) follows a negative binomial distribution. Due to the underlying assumptions of the negative binomial distribution, the patent count follows a Poisson distribution with an unobserved error parameter ν implementing heterogeneity in the variance. The intensity parameter (φ) is therefore explained by a vector of all explanatory variables (X).

Formally

$$PATENT^{F^r}_{i,t} \rightarrow NegBin(\varphi; \sigma),$$

equals

$$PATENT^{F^r}_{i,t} \rightarrow Poisson(\varphi) \quad if \begin{cases} \varphi = \widetilde{\varphi}\nu = exp(\beta X) \\ \nu \rightarrow \Gamma\left(\frac{1}{\sigma}; \frac{1}{\sigma}\right) \end{cases}$$

The description from above implies that expected value $E(PATENT^{F^r}_{i,t}) = \varphi$ with standard deviation $V(PATENT^{F^r}_{i,t}) = \varphi(1 + \sigma^2\varphi)$. Therefore with $\sigma \rightarrow 0$ intensity is given by φ and the model converges towards a Poisson distribution (Johnstone et al.,

[37] Correlation matrices for the two models (one year time lag and two year time lag) are presented at table C.4 and table C.5, appendix C, page 209 and page 210. It can be seen that high correlation exists among ELC and $APATENT$ (for EU,JAPAN and USA) what might cause a problem of multi collinearity within the regression. The overall regression results, however, do not change if these variables are left out of the regression. As the omission of variables can cause a bias in coefficients, we decided to present the results including the variables ELC and $APATENT$.

2010, p. 146). The estimation is done for 5 technologies and 11 years (1992-2002) with 3 regions. This leads to a sample with 180 observations.

4.5.1 Closer Specification of the Time Lags and Period Dummies

Because our dataset allows for dynamic model specifications, time lags have to be implemented to be in line with economic theory.[38] Because the priority date indicates the application date in Germany, we expect a one year or a two year time lag for RuD^H. For $INCAP^H$ no time lag is assumed. As the diffusion of the technology in Germany can only take place when the technology is already developed, this assumption makes sense. For $INCAP^F$, $APATENT^F$, ELC^F and $CPIE^F$ a one year time lag is assumed. We justify this assumption with reference to the PCT. As stated above, according to the PCT, most of the patents applied at the national level extent to patent applications in foreign countries within a time frame of one year. This is a very pragmatic way of dealing with the problem of a time lag of four or five years between the patent application at a national patent office and the patent granting of a foreign patent office. For RuD^H and $INCAP^H$, as well as for $CPIE^F$, we implement period dummies from 1992-1999 (for the SEG) in the first period, and 2000-2002 (for the EEG) in the second period.

4.5.2 Estimation Results

The results of our reference model are presented in Table 4.1 (estimation results under assumption of a one year time lag for RuD^H). It can be seen that an increase in domestic public *R&D* expenditure does not affect the patenting behavior of German firms abroad. We find a negative but insignificant relation between the public *R&D* expenditures. We therefore have to reject hypothesis 1a. We get the opposite result for hypothesis 1b. Under the SEG and EEG strong support for hypothesis 1b can be found. As seen, the evidence for hypothesis 2 is mixed but rather weak. Otherwise, there are differences in the regions (as some coefficients are different with respect to their signs), which somehow confirms hypothesis 3a. The EU is not specifically attractive for German firms, which contradicts hypothesis 3b. To test hypothesis 3c we use a Chow-test and compare $INCAP^H_{1992-1999}$ with $INCAP^H_{2000-2002}$. We find significant differences for EPO (p= 0.0580) and JPO (p=0.0713). For APO the difference is not significant under conventional statistical terms (p= 0.1220). The three results together give evidence for hypothesis 3c. However, the coefficients indicate a decrease in this relationship instead of an increase, which can be interpreted to suggest that efficiency decreased under the

[38] For a more detailed discussion on time lags related to patent data compare Hall et al. (1986). Brunnermeier and Cohen (2003) also make an econometric study and make the assumption that there is no lag at all. The result from Griliches (1998) also suggests that with respect to *R&D* the time lag can be assumed to be rather small.

EEG. Installed capacity in Japan is relevant for patenting there, and general patenting behavior is positively correlated with green patenting in the United States.

TABLE 4.1: Fixed effects negative binomial regression

$PATENT^{HF}$	EPO	JPO	APO
$lag1RuD^{H}_{1992-1999}$	-0.0049777 (0.0084893)	-0.0033792 (0.0104979)	-0.000487 (0.0082184)
$lag1RuD^{H}_{2000-2002}$	-0.0181687 (0.0131117)	-0.0207956 (0.0178787)	-0.0241105 (0.0147366)
$INCAP^{H}_{1992-1999}$	0.0002195^{***} (0.0000659)	0.0003652^{***} (0.0000929)	0.0003087^{***} (0.0000816)
$INCAP^{H}_{2000-2002}$	0.000108^{***} (0.0000263)	0.0002239^{***} (0.0000361)	0.0002005^{***} (0.0000313)
$lagINCAP^{F}$	0.0000161 (0.0000279)	0.0008603^{**} (0.0005283)	-0.0000788 (0.000058)
$lagAPATENT^{F}$	$-194e-06$ (0.0003891)	$-0.0000594)$ (0.0002586)	0.0011413^{**} (0.0005508)
$lagCPIE^{F}_{1992-1999}$	0.0022767 (0.0185545)	-0.0023875 (0.0178013)	0.0011234 (0.020191)
$lagCPIE^{F}_{2000-2002}$	0.0092491 (0.0158542)	0.0009691 (0.0177275)	0.0070262 (0.0170407)
$lagELC^{F}$	-0.0084317 (0.0054865)	-0.0087497^{**} (0.0040787)	0.0025994^{***} (0.0008591)
β_0	32.48477 (28.06769)		
Wald chi2	214.33		
Nr. of observations:	165		

Significance: $^{***} \leq 1\%, ^{**} \leq 5\%, ^{*} \leq 10\%$

4.5.3 Robustness of the Results

As a robustness check we present an additional model (table 4.2) with a two-year time lag for public *R&D* expenditures. It can be observed that compared to our reference model (table 4.1) the results for *R&D* change. Under the SEG, public *R&D* gets significant for EPO and APO. Thus, if the model is correctly specified with a two-year time lag for public *R&D*, we cannot reject hypothesis 1a under the SEG for EPO and APO for the period from $1992-1999$. For our main variable of interest, $INCAP^{H}$, under the SEG hypothesis 1b is only confirmed for JPO. For EPO and APO it has to be rejected. Under the EEG, $INCAP^H$ remains significant, confirming hypothesis 1b. It can be seen that the right specification of the lag structure for public $R\&D$ is crucial for the econometric model. The comparison between the different lag structures shows that slight model specifications change the significance of some indicators. We therefore try to motivate the assumptions implemented into the econometric model, theoretically.

Further econometric problems might be due to multicollinearity between the observations. However, leaving some variables out of the model may cause omitted variable bias problems. Serial correlation might be an additional problem. In table C.3 (p. 208) we therefore present a model estimated by a simple first differences ordinary least squares (OLS) model. We still get significant results for $INCAP^H_{2000-2002}$ in JPO and APO. Our main hypothesis for the paper is that feed-in tariffs are used strategically under the EEG. This hypothesis is still partially confirmed under the specified models presented in table 1 and table C.3 (App. C.3, p. 208). If we run a Poisson model instead of a negbin model (table C.2, App. C.3, p. 207) some of the results change and become significant but the overall picture remains the same.

Even though the model is sensitive to model specification, different estimations have shown that $INCAP^H$ is a quite robust predictor for $PATENT^F$ under the EEG. As the theoretical model from section 4.3 mainly refers to this time period, the econometric model offers important insights related to our theoretical reasoning.

4.6 Conclusion

We analyse the climate change debate from a perspective of political opportunity and economic rationality. We use a strategic trade policy framework to explain the political interests behind the climate change debate. In contrast to the strategic trade policy literature, we do not intend to justify or to nullify strategic trade policy. The result of our welfare analysis clearly shows the expected gains related to exports of GTs. Politicians might use the problem of climate change as an instrument to support the national GT industry at the international level. From this perspective, high environmental standards are in the political interest of these countries. Environmental standards can be used by a government as an instrument to convince other countries to open their markets for GTs. As shown theoretically, the welfare effects of one country's industrial policy therefore strongly depend on the policy reaction of other countries.

The theoretical framework and the empirical evidence also show incentives for GT enterprises to lobby their case and prepare for future markets. It seems as if the German green industry, indeed, anticipates future export sales via patenting abroad. The main driver we identify for this behavior is the installed capacity of GTs in Germany. This seems fairly plausible and can be interpreted as positive experience creating new

TABLE 4.2: Fixed effects negative binomial regression

$PATENT^{HF}$	EPO	JPO	APO
$lag2RuD^{H}_{1992-1999}$	0.0124475*	0.0112177	0.0169526**
	(0.0072587)	(0.0100838)	(0.007521)
$lag2RuD^{H}_{2000-2002}$	0.007152	0.0037132	0.0048226
	(0.0107887)	(0.0160282)	(0.0126935)
$INCAP^{H}_{1992-1999}$	0.0000967	0.0002333**	0.000125
	(0.0000729)	(0.000104)	(0.0001025)
$INCAP^{H}_{2000-2002}$	0.0000872***	0.0001909***	0.0001545***
	(0.0000283)	(0.0000389)	(0.0000395)
$lagINCAP^{F}$	0.0000675	0.0035497	0.0002025
	(0.0001194)	(0.003328)	(0.0003636)
$lagAPATENT^{F}$	0.0028577	−0.001055	0.0038894
	(0.0040687)	(0.0010724)	(0.0037222)
$lagCPIE^{F}_{1992-1999}$	−0.0023775	−0.009236	−0.0082064
	(0.0250123)	(0.0233636)	(0.0258147)
$lagCPIE^{F}_{2000-2002}$	0.0649717	0.0547221	0.0583138
	(0.0790413)	(0.0794015)	(0.079379)
$lagELC^{F}$	−0.0458226	−0.0312807	0.0048331
	(0.0539446)	(0.0298639)	(0.0030676)
β_0	147.7299		
	(173.8297)		
Wald chi2	163.21		
Nr. of observations:	150		

Significance: $^{***} \leq 1\%, ^{**} \leq 5\%, ^{*} \leq 10\%$

expectations. Although the results are encouraging, we need better evidence to confirm our political economy reasoning.

Nevertheless, this logic and the empirical evidence suggest that one can expect the German government to continue its efforts to lobby for an international environmental agreement and strong climate protection standards valid world-wide. International experience, however, also suggests that other countries will not open their markets easily. Instead, the German policies may be replicated and other countries may subsidize their own GT industry, which renders the German policy unsuccessful.

Chapter 5

Is Regulation by Milestones Efficiency Enhancing?*

5.1 Introduction

In real life, a number of long-term projects rely on intermediate targets or milestones. For individual choice problems imposing additional constraints may be detrimental to efficiency. External regulation does not make much sense if individuals are able to cope with problems on their own. However, this is different for collective choice problems. In the economic domain, we do indeed observe milestones mainly in social contexts. For instance, governments often announce official targets for budget reductions. Another prominent example is the GATT and its aim of continuous liberalization of international trade – a target which cannot be easily operationalized. Nevertheless, intermediate targets have been regularly set in trade rounds. At the end of each round, the negotiating parties agreed on an agenda to stepwise reduce trade barriers within a certain period.

A third example is environmental protection. Here investments in climate protection could be imposed by an international environmental agreement (cf. Barrett, 1994a, 2003). Such an agreement often includes a final target which should be reached at a certain date, e.g., reduction of total emissions until 2050 by about 50 percent, based on the 1990 emissions (IPCC, 2007).[1] Under such circumstances, milestones can proxy intermediate abatement targets to keep total emissions below a critical threshold (e.g., the emission reduction targets in the context of the Kyoto Protocol). If the international community fails to meet these intermediate targets, it will become more difficult to reach the final threshold, making catastrophic events more likely.

*This chapter is mainly based on Freytag, Koppel, Güth and Wangler (2010). We are grateful to Christoph Engel, Gerhard Riener, M. Vittoria Levati, Michael Huettner, Oliver Kirchkamp and Sebastian Vergara, for valuable comments. We also would like to thank seminar audiences at the 2010 ESA world meeting in Copenhagen and the 2010 IAREP/SABE/ICABEEP conference in Cologne for their feedback. We are indebted to Christian Streubel for programming assistance.

[1] Without national commitments (“the business as usual” scenario) estimations predict a temperature increase with possibly catastrophic consequences (Stern, 2007; Solomon et al., 2009; Latif, 2010).

The rationale behind such milestones is to increase the intermediate credibility of policy announcements through a commitment to testable intermediate targets. Governments may thereby overcome pressure from vested interests and measure long-term goal achievements by short-term goal achievements. The above examples illustrate that milestones are often seen as disciplining factors for policy makers. In global economic policy making, the evidence seems clear – GATT has achieved considerable progress in the field of comprehensive international liberalization. Thus, applying a similar tool to climate policy may also be reasonable.

However, there is neither convincing empirical evidence nor a sound theoretical basis for this in the global governance literature or, more specifically, on how to promote efficiency by imposing additional restrictions like milestones. We do find evidence for markets, e.g., labor markets. Falk and Kosfeld (2006), for instance, have shown that an employer may suffer from imposing a minimum performance threshold for her employees. Similarly, Berninghaus et al. (2008) found that downward wage flexibility, if exploited, may encourage shirking. In a more general sense, we will add to this literature, but not in a one-off interaction task but a recursive interaction task.

We conduct a recursive game in which all players can gain by reaching a certain commonly known final target. The game can, however, be more strictly regulated by imposing intermediate targets to be reached earlier. In this way, regulation imposes additional risks of failure. Our main milestone hypothesis predicts that additional regulation via milestones, i.e., intermediate performance targets, is efficiency enhancing.

Although our leading example is environmental protection to prevent global warming, we abstain from inventing a novel game and test the milestone hypothesis with a familiar experimental workhorse to compare our findings to those of other experiments. More specifically, we use the familiar linear public goods game (see Ledyard, 1995, for an early survey of experimental studies) by interpreting contributions as investments protecting the environment, e.g., investments in emission reduction to limit or prevent global warming.

Thus, milestones and contribution targets set lower bounds for emission reduction in our experiment. If one of the milestones or the final target is missed, the rather dramatic effect will be that all players sustain a total loss with a given probability. This implies additional (subgame perfect) equilibria, beside the usual free-riding equilibrium, where the sums of the contributions accumulated at a certain point reach the targets exactly.

We test the milestone hypothesis as treatment effects with milestones as one treatment variable. Whereas for all treatments the final target is the same, we distinguish between high milestones (H) and considerably lower ones (L), the latter rendering the milestones rather inessential. We compare the H versus L effects in three different scenarios, leading to $2x3 = 6$ different treatments. The three scenarios vary the individual marginal productivity of contributions and the probability of a total loss if one of the targets is not reached.

In spite of the impressive tradition of public goods experiments (Ledyard, 1995), there are few studies which focus on environmental protection. Milinski et al. (2008) introduce and experimentally analyze a collective-risk social dilemma framed as a dangerous climate change. The players were split into groups of six and endowed with €40 each. They could repeatedly contribute €0, €2, or €4 to a "climate change account" over ten rounds. If they failed to reach the threshold after the last round, they sustained a total loss, with a probability of 90%, 50%, or 10%, respectively. Results show that even with a losing probability of 90% half of the groups failed to reach the threshold.

Fischbacher et al. (2010) rely on a linear public goods game, however, with only one trial contribution target with rather similar effects. But they do not address the question whether milestones would be efficiency enhancing. On the other hand, they made their final target stochastic by assuming that players would receive either private or common stochastic signals whose sum would determine the final target. We compare our findings with earlier related findings in the concluding section.

Section 6.2 describes our experimental design, including all treatments and the experimental protocol. In section 5.3 we present our results. Our conclusions in section 5.4 round off the paper.

5.2 Experimental Design

5.2.1 General Setting

To capture environmental protection problems, e.g., avoiding global warming, we rely on a linear public goods game (Isaac et al., 1985) as our experimental workhorse. Thus, monetary contributions mean investing in emission reduction for the sake of less global warming, whereas "free riding" stands for voluntarily abstaining from any individual attempt to protect the environment.

In all treatments, five players, respectively participants $i = 1, \ldots, 5$, are endowed with $e = 65$ tokens, which they can either keep or repeatedly contribute over six periods $t = 1, \ldots, 6$. Individual contributions $c_{i,t}$ must satisfy $0 \leq c_{i,t} \leq 10$, guaranteeing that after six periods each participant has some tokens left. In all treatments, furthermore, all players i sustain a total loss, i.e., what they have kept and what they could have gained from accumulated contributions $C^6 = \sum_{t=1}^{6} \sum_{i=1}^{5} c_{i,t}$ by all five players, with a certain probability $p \in (0,1)$ if the contribution target of $C_6 = 150$ tokens is not reached

($C^6 < C_6$). Assuming constant individual marginal productivity ($\alpha \geq 0.2$) of individual contributions $c_{i,t}$, the payoffs for players $i = 1, \ldots, 5$ are thus

$$U_i = \begin{cases} e - \sum_{t=1}^{6} c_{i,t} + \alpha C^6 & \text{for} \quad C^6 \geq 150 \\ (1-p)(e - \sum_{t=1}^{6} c_{i,t} + \alpha C^6) & \text{if} \quad C^6 < 150. \end{cases}$$

Under the condition that $\alpha < 1 \leq 5\alpha$, opportunism in the sense of own monetary payoff concerns suggests to reduce own contributions in both ranges, $C^6 < C_6$ and $C^6 > C_6$, as long as this does not mean that C^6 becomes smaller than C_6, whereas $\alpha > 0.2$ renders efficient maximal individual contributions (in the sense of payoff maximization). Due to the discontinuity of the payoff function U_i at C_6, there exist many strict but only two symmetric and strict equilibria, leading to results

$$E^0 = \left[\sum_{t=1}^{6} c_{i,t}^0 = 0 \quad \text{for} \quad i = 1, \ldots, 5 \right] \text{and} \left[\sum_{t=1}^{6} c_{i,t}^* = 30 \quad \text{for} \quad i = 1, \ldots, 5 \right] = E^*,$$

respectively.

Together with the efficiency outcome with $\sum_{t=1}^{6} c_{i,t}^+ = 60$ for $i = 1, \ldots, 5$, these serve as our benchmarks when we discuss actual behavior.[2] Since, in case of E^0, no individual player i can guarantee that the target of 150 is reached, it is obvious that E^0, based on 0-contributions throughout, is a (subgame perfect) equilibrium. This also holds for E^* since increasing $\sum_{t=1}^{6} c_{i,t}$ above 30 is clearly suboptimal, and contributing less than 30 would yield maximally 65 but only with probability p, whereas a player's payoff from E^* is $U_i = 150\alpha + 35$, which is at least 65 due to $\alpha \geq 0.2$.

Note that target C_6 could already be reached within three periods by all five players, contributing maximally ($c_{i,t} = 10$) in each of the three periods. Thus, viewing the first three periods as a base game with already two strict (symmetric) equilibria reveals that "finite-horizon Folk Theorems" (Benoit and Krishna, 1987) can be applied, showing that there exist also nonstationary pure strategy (subgame perfect) equilibria.

In all treatments, subjects receive periodic feedback information, i.e., after each period $t = 1, \ldots, 6$ all five players $i = 1, \ldots, 5$ are informed of the individual contributions $c_{j,t}$ of all players $j = 1, \ldots, 5$ and can thus react accordingly when deciding on their next contribution $c_{i,t+1}$. Obviously, this allows for reciprocity and a variety of disciplining actions by future dealings on which the so-called Folk Theorems are based (Aumann et al., 1981; Axelrod and Dion, 1988; Benoit and Krishna, 1985).

[2] It is clear that the efficiency benchmark requires $\alpha > 0.2$.

5.2.2 Milestones

Regulation is implemented by means of milestones (M), i.e., contribution targets on the way to reaching the final target of $C_6 = 150$, namely C_2 after period 2 and C_4 after period 4. Not reaching the intermediate targets has the same consequences as not reaching C_6. Although players $i = 1, \ldots, 5$ may sustain a total loss already after periods 2 and 4, they will, in the experiment, first decide successively for all six periods $t = 1, \ldots, 6$. Only then will it be decided randomly in view of C^2, C^4, and C^6 whether or not they will sustain a total loss already after period 2 if $C^2 < C_2$, after period 4 if $C^4 < C_4$, or finally if $C^6 < 150$.

Introducing these milestones, changes the payoff function to

$$U_i^M = \begin{cases} e - \sum\limits_{t=1}^{6} c_{i,t} + \alpha C^6 & \text{if} \quad C^2 \geq C_2 \,\&\, C^4 \geq C_4 \,\&\, C^6 \geq C_6, \\ (1-p)(e - \sum\limits_{t=1}^{6} c_{i,t} + \alpha C^6) & \text{if} \quad \begin{cases} C^2 < C_2 \,\&\, \geq \text{ for the other} \\ \text{two restrictions} \quad \text{or} \\ C^4 < C_4 \,\&\, \geq \text{ for the other} \\ \text{two restrictions} \quad \text{or} \\ C^6 < C_6 \,\&\, \geq \text{ for the other} \\ \text{two restrictions,} \end{cases} \\ ((1-p)+(1-p)^2)(e - \sum\limits_{t=1}^{6} c_{i,t} + \alpha C^6) & \text{if} \quad \begin{cases} C^2 < C_2 \,\&\, C^4 < C_4 \,\&\, C^6 \geq C_6 \\ \text{or} \\ C^2 < C_2 \,\&\, C^6 < C_6 \,\&\, C^4 \geq C_4 \\ \text{or} \\ C^4 < C_4 \,\&\, C^6 < C_6 \,\&\, C^2 \geq C_2, \end{cases} \\ ((1-p)+(1-p)^2+(1-p)^3))(e - \sum\limits_{t=1}^{6} c_{i,t} + \alpha C^6) & \text{otherwise,} \end{cases}$$

where $C^2 = \sum\limits_{t=1}^{2} \sum\limits_{j=1}^{5} c_{j,t}$ and $C^4 = \sum\limits_{t=1}^{4} \sum\limits_{j=1}^{5} c_{j,t}$. Comparing U_i with U_i^M clearly reveals that implementing milestones on a sufficiently high level means implementing "regulation," where, in view of the environmental interpretation, the regulating agency is Mother Nature. We predict a milestone effect, i.e., a more efficient performance with stricter milestones. In order to test this effect, we distinguish two cases:

1. strict milestones (H): $C_2 = 50$ and $C_4 = 100$, and
2. less strict milestones (L): $C_2 = 5$ and $C_4 = 10$.

For the case of "strict milestones" (H) we set the intermediate targets such that contributions necessary to reach the final target of C_6 increase linearly. For the less strict case we do not omit the milestones but lower them by a factor of 10 which should render them inessential such that payoff U_i^M approximates U_i. The "philosophy" of such a manipulation is, of course, that the two cases, H and L, rely on the same verbal instructions and differ only in two numerical parameters, namely C_2 and C_4, which should not induce any difference in (sub)conscious demand effects between H and L, where "L" stands for –extremely– "low milestones."

5.2.3 Scenarios

We consider three different scenarios to test the potential milestone effect by comparing treatments with strict (H) and less strict milestones (L).

In the baseline scenario (B), we set $\alpha = 0.4$ and $p = 0.5$ in combination with a group size of five subjects.[3] Since the probability of sustaining a total loss seriously increases the free-riding "disincentives" the efficiency benchmark, $\sum_{t=1}^{6} c_{i,t}^{+} = 60 \quad \text{for} \quad i = 1, \ldots, 5$ may be expected more often than in usual public goods experiments.

Our experimental design might be criticized since linearly increasing total payoffs, even above the final target, may not adequately capture environmental protection. We therefore propose an alternative scenario (S), in which reaching the final target of C_6 merely preserves the status quo, i.e., a mean payoff of 65 tokens, and overshooting is not beneficial at all, i.e., removing the efficiency of $C^6 > C_6$. This is done by lowering the constant individual marginal productivity to $\alpha = 0.2$. Compared to scenario B, incentives to cooperate are, of course, smaller, also below C_6.

This manipulation changes two aspects: it questions the efficiency benchmark and reduces the free-riding "disincentives," as measured by the expected payoff of a unilateral deviation from the E^*-equilibrium to constant 0-contributions (free riding). The difference in expected payoffs between the E^* -equilibrium and the payoff of a unilateral deviation to constant 0-contributions for scenario B is $95 - 56.5 = 38.5$ tokens, whereas it is 20.5 tokens for scenario S only. Since by comparing these scenarios, the two aspects mentioned above cannot be disentangled, we consider a third scenario (P) and preserve the equilibrium and efficiency benchmarks of the baseline scenario by setting $\alpha = 0.4$ but keeping the free-riding "disincentive" equal to that of scenario (S) by lowering the probability of a total loss from $p = 1/2$ to $1/3$.[4] Altogether, this $2X3$ factorial design results in six treatments as listed in table 5.1.

[3] One might argue that setting $\alpha = 0.4$ is unrealistic in a climate change setting since investments in emission reduction are usually seen as preserving the status quo. This is because sustainability is the main argument for policy intervention.

[4] The probability is calculated by comparing the individual payoff that results when all players $i = 1, \ldots, 5$ play E^* to the individual payoff that results when a player deviates from E^* by free riding: $(95 - 20.5) = (1 - p)(65 + 0.4x120)$, implying $p = 38.5/113 \approx 1/3$.

TABLE 5.1: 2*x*3 factorial treatment design

		Milestones	
		H	L
P	$\alpha = 0.4; p = 1/3$	PH	PL
B	$\alpha = 0.4; p = 1/2$	BH	BL
S	$\alpha = 0.2; p = 1/2$	SH	SL

5.2.4 Experimental Protocol

We ran 12 separate sessions for the six treatments. Three hundred sixty student participants were recruited from various disciplines of Friedrich Schiller University of Jena using the ORSEE software (Greiner, 2004). The experiment was programmed and conducted with the software z-Tree (Fischbacher, 2007). In each session, the 30 participants per session were subdivided into two equally large matching groups and played the 6-period recursive game repeatedly. After each play of the 6-period recursive game the 15 participants of a matching group were randomly rematched to form three new groups with five players each who interacted in the next round of play. Since participants were only told that they were randomly rematched, they could expect that each of the 29 other participants might become an interaction partner. This should discourage reputation effects even more (participants can, of course, try to establish some reputation within the same rounds, i.e., across the six periods of a given round).

After entering the computer laboratory of the Max Planck Institute of Economics in Jena, participants received written instructions (see App. A.2 for translated material), which were read aloud to ensure common knowledge. After answering questions privately participants had to answer a few control questions. The experiment only started when all participants had answered all control questions correctly. One session with altogether 12 rounds lasted, on average, 90 minutes, including reading instructions, answering control questions, and payment. Average payoffs were €17, with a minimum of €2.5 and a maximum of €29, including the €2.5 show-up fee.

5.3 Results

To begin with, we describe our findings on the group level, followed by a closer look at individual behavior. We first state the “Results” and then proceed to validate them by descriptive and statistical data analysis.

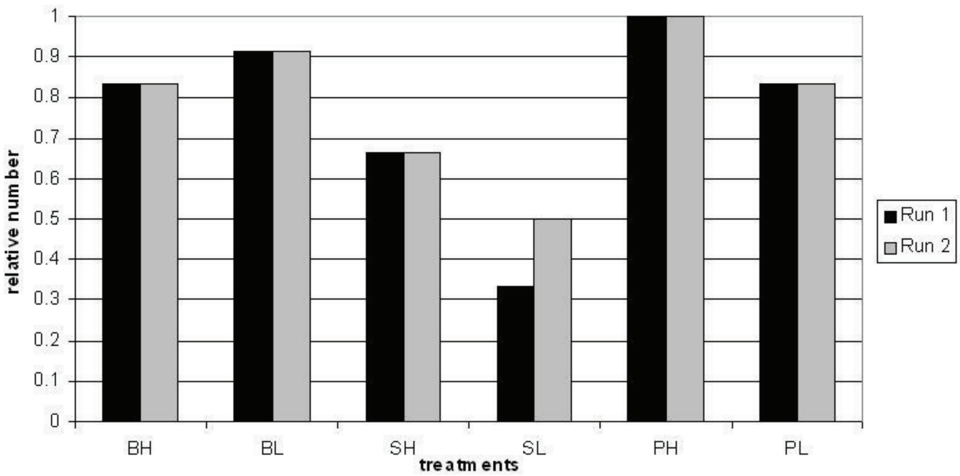
RESULT 1: Equilibrium play E^* and E^0 is negligible.

Only three out of 144 groups ended up in the E^* outcome, investing 150 tokens in total (two groups in treatment SH and one in treatment SL). One group in treatment SL was able to coordinate on the fair share equilibrium of contributing five tokens in each round. No groups totally free rode or contributed the maximum possible. However, we are not interested in testing equilibrium outcomes; rather, we want to study treatment effects and therefore turn to our main question, namely whether regulation by milestones is efficiency enhancing.

RESULT 2: Depending on the scenario, milestones increase the probability of reaching the final target.

Since expected payoffs are lower when the final target is not reached compared to when it is reached, it is more efficient in all scenarios to reach the final target. Figure 5.1 shows the probability of reaching the final target separately for scenario and treatment. In scenario B and P, almost all groups succeeded (10 of 12), and there is no significant treatment effect (H versus L). The picture slightly changes for scenario S with an almost significant milestone effect for the success probability in the first run, where 8 versus 4 out of 12 groups reached the final target (Fisher's exact, $p = 0.110$). However, the effect disappears since after the restart more groups, namely six, succeeded in SL, whereas for SH, there is no change (Fisher's exact, $p = 0.340$).

FIGURE 5.1: Final target reached



RESULT 3 On the group level, milestones increase average group contributions only in scenario S.

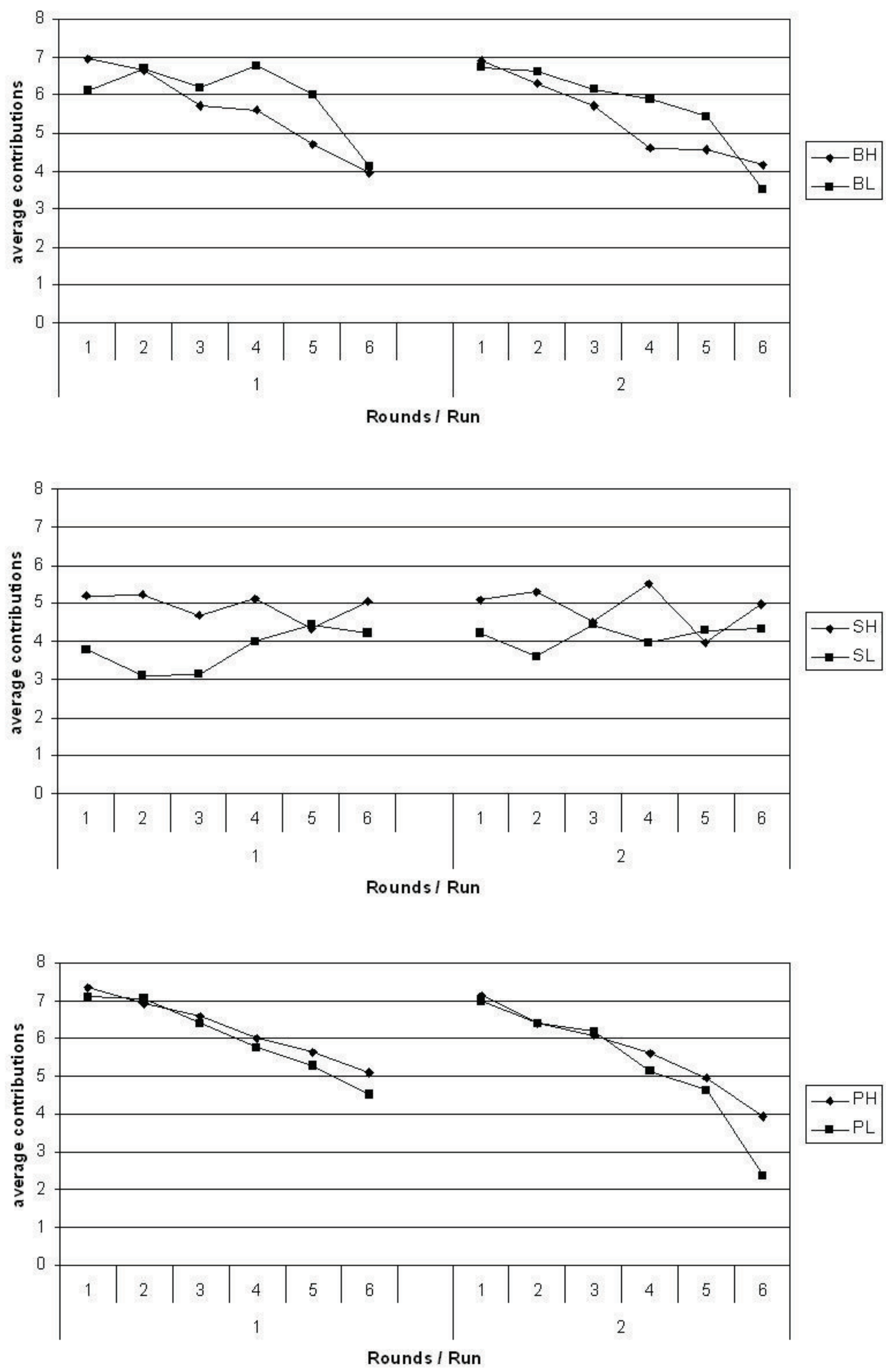
Figure 5.2 depicts, separately for the three scenarios (scenario B on top, scenario S in the middle, and scenario P at the bottom) and treatments, average contributions over the sequence of play, i.e., the six rounds of two runs. In the first run of scenario B, average contributions were lower in the treatment with strict milestones (5.6 tokens versus 5.98 tokens), and it seems that imposing additional risks by intermediate targets is detrimental to efficiency. The effect is not statistically significant (Mann-Whitney-U, $p = 0.2142$), however. For scenario S a significant milestone effect shows up in the first run. Imposing milestones increased contributions by approximately 30 percent from 3.78 to 4.93 tokens (Mann-Whitney-U, $p = 0.0831$) and is thus efficiency enhancing. No significant difference between treatments shows up in scenario P, which also goes for all three scenarios after the restart.

Thus, milestones increased the probability of success and contributions only in scenario S, which features investments in emission reduction as preserving the status quo by ruling out efficiency enhancement below and above C_6.

RESULT 4: An analysis of individual contributions shows that milestones are inspiring the former in scenario S and P.

Accordingly, on the level of individual behavior, the picture for scenario P changes when panel regressions are used. By design, the panel is strongly balanced and consists of 60 subjects per treatment cell (120 subjects per scenario). Taking group heterogeneity into account, we made use of a panel regression with adjusted standard errors on the group level (each group formed one cluster), i.e., in total, there were 24 groups per treatment (48 groups per scenario). Moreover, there were 24 groups for each run and 48 groups for both runs together. Contributions were explained by a dummy for the treatment with strict milestones (PH), dummies for one session of the respective treatments (S_{PH} and S_{PL}), lagged variables on own contributions, average contribution within the group, and accumulated contributions. Regression results are shown in table 5.2. There are no significant treatment effects in the first run (the first two columns). However, in columns 3 and 4, showing regression results for the sequence after the restart (second run), the treatment dummy is positive and significant. Controlling for sessions only (column 3), the effect is significant at the 5 percent level. Additionally controlling for various forms of information which subjects received (column 4) results in a better fit and a significant treatment effect on the 1 percent level, although it is lower

FIGURE 5.2: Average contribution per treatment



in magnitude. More precisely, subjects contribute, on average, 0.766 tokens more to the public good with strict rather than less strict milestones. Taking the two runs together in column 5 and controlling for the restart (including a dummy), the effect is weaker (on average 0.457 tokens more in SH) but still significant at the 5 percent level, whereas the restart dummy has no significant effect.

The effect is stronger in scenario S (see table 5.3). Although we do not find a significant treatment effect after the restart, there is a strong and high effect in the first run. Subjects in treatment SH contributed, on average, 1.080 tokens more with strict milestones, when controlling for the received information (column 2). In contrast to scenario P, the milestone effect disappears after the restart (columns 3 and 4) but is present when we consider both runs, controlling for information and the restart (column 5). Subjects in treatment SH contribute, on average, 0.873 tokens more than in SL, whereas the restart dummy is insignificant. Individual level analysis offers no further insights on scenario B (see appendix D.1).

TABLE 5.2: OLS Panel regression with clustered standard errors on the group level for scenario P

	Run 1 contribution	Run 1 contribution	Run 2 contribution	Run 2 contribution	Both runs contribution
PH	0.872	0.160	1.261*	0.766**	0.457*
	(1.46)	(0.65)	(2.53)	(2.93)	(2.46)
S_{PH}	-0.294	0.308	-0.372	-0.00931	-0.0242
	(-0.36)	(1.07)	(-1.59)	(-0.06)	(-0.13)
S_{PL}	0.956	0.403	1.350*	0.758**	0.483
	(1.18)	(1.02)	(2.29)	(2.83)	(1.68)
Lag contribution		0.479***		0.479***	0.426***
		(7.00)		(8.04)	(10.08)
Lag average contr.		0.320**		0.109	0.171*
		(3.26)		(1.01)	(2.17)
Lag accumulated		-0.00715*		-0.0164***	-0.000674
		(-2.56)		(-4.77)	(-0.34)
Restart					-0.0471
					(-0.29)
cons	5.533***	1.267**	4.606***	2.650**	1.824***
	(19.27)	(3.09)	(9.97)	(2.92)	(3.97)
N	720	600	720	600	1320
$N_{Indiv.}$	120	120	120	120	120
R^2_O	0.0102	0.333	0.0193	0.301	0.227

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Although the non-parametric group level analysis suggests no milestone effect in scenario P, we do find a significant milestone effect on the individual level, controlling for group, session, and information effects. Compared to scenario S, the effect is lower in magnitude and less significant. The milestone effect is therefore not only driven by the exclusion of efficiency above and below targets (scenario *S*) but is also due to higher free-riding "disincentives" (scenario *P* and *S*).

TABLE 5.3: OLS Panel regression with clustered standard errors on the group level for scenario *S*

	Run 1 contribution	Run 1 contribution	Run 2 contribution	Run 2 contribution	Both runs contribution
SH	2.156***	1.080*	1.000	0.473	0.873*
	(3.90)	(2.32)	(1.60)	(0.86)	(2.21)
S_{SH}	-0.100	-0.128	0.333	0.359	0.0898
	(-0.38)	(-0.93)	(1.07)	(1.52)	(0.58)
S_{SL}	1.917**	1.286*	0.844	0.538	0.850*
	(2.82)	(2.56)	(1.32)	(1.08)	(2.15)
Lag contribution		0.343***		0.387***	0.333***
		(3.68)		(4.74)	(5.75)
Lag average contr.		0.0874		-0.0340	-0.0196
		(0.51)		(-0.17)	(-0.16)
Lag accumulated		0.00925**		0.00530	0.00556*
		(2.73)		(1.44)	(2.55)
restart					0.0416
					(0.21)
cons	2.822***	1.052*	3.717***	2.079**	1.949***
	(5.36)	(2.41)	(6.87)	(2.78)	(4.85)
N	720	600	720	600	1320
$N_{Indiv.}$	120	120	120	120	120
R^2_O	0.100	0.232	0.0363	0.165	0.171

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

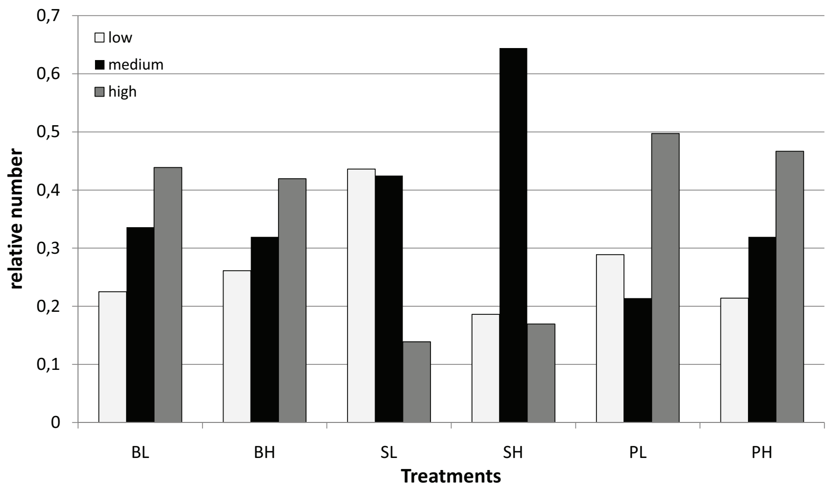
RESULT 5 The milestone effect in scenarios S and P is mainly driven by a higher share of individual contributions between 4 and 6 tokens.

To further scrutinize contributions on the individual level as well as the general sequence of play, we classified contributions as *low* (0-3 tokens), *medium* (4-6 tokens), and *high* (7-10 tokens). Figure 5.3 shows the resulting relative number of contributions for the respective classes in the six treatments in the first run.[5] It further shows that contributions are quite heterogeneous. However, in treatment *SH* most contributions (64.44 percent) fall into the *medium* class. Compared to treatment *SL*, milestones seem to discipline subjects to stay on track to reach the final target as the number of *low* contributions is significantly lower (Fisher's exact, $p = 0.000$) and *medium* contributions are significantly more frequent (Fisher's exact, $p = 0.000$). Though not particularly

[5]In the following, we show results for the first run only. Regarding the second run, the qualitative results for the classification are the same.

strong, a similar pattern is found for scenario P, where we observe a significantly lower frequency of *low* contributions and a significantly higher frequency of *medium* contributions in treatment PH (Fisher's exact, $p = 0.025$ for *low* and $p = 0.002$ for *medium*). No significant difference between contribution classes is found in scenario B (see also the graphical illustration in fig. 5.3). The share of contributions classified as *high* in scenario S is significantly lower than that in scenario B and P (Fischer's exact, $p = 0.000$, for BL vs. SL, BH vs. SH, PL vs. SL, and PH vs. SH), whereas we do not find any significant difference between B and P.

FIGURE 5.3: Contribution classes for B, S, and P



RESULT 6 Milestones stabilize individual behavior over the sequence of play in scenarios S and P.

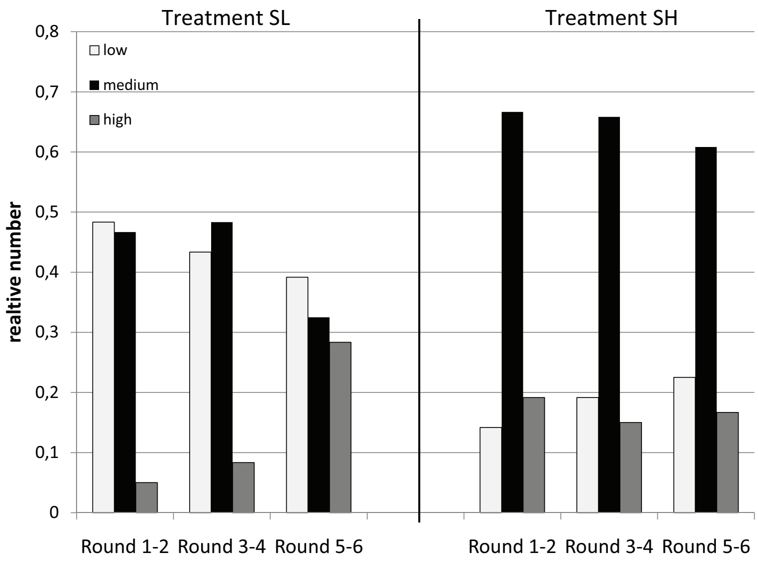
Is the classified behavior stable over the sequence of play? To answer this question, we subclassified, additionally to the above classification, the relative number of contributions into three phases of rounds: *round 1-2* , *round 3-4*, and *round 5-6*.[6]

The results of the classification in scenario S are shown separately for the two treatments (SL and SH) in figure 5.4. There is a relatively stable share of *low* contributions in treatment SL over the three phases (Kruskall-Wallis, $p = 0.3588$), which is significantly

[6]We chose this classification to capture differences in play between rounds including a target. Moreover, results do not change qualitatively if we take every single round into account.

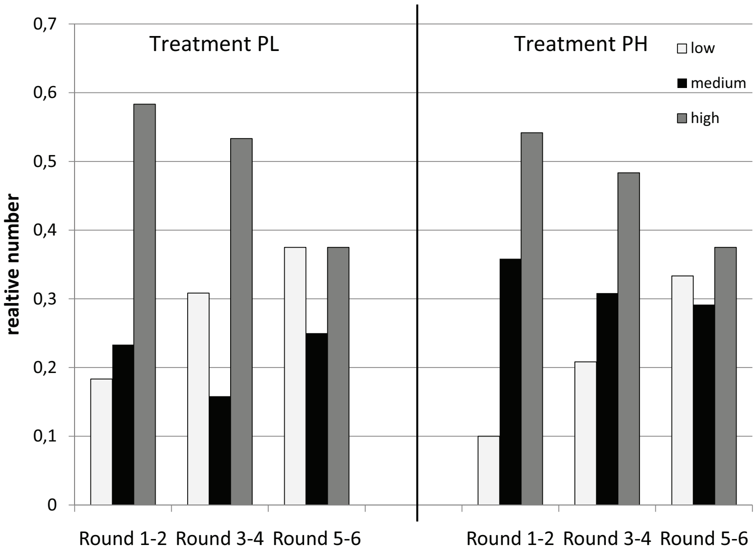
higher than in SH (Fisher's exact, $p = 0.000$ for *round 1-2* as well as *round 3-4* and $p = 0.004$ for *round 5-6*). In contrast, a high and stable share of *medium* contributions is found in treatment SH (Kruskall-Wallis, $p = 0.5946$), which in all three phases is significantly higher than in SL (Fisher's exact, $p = 0.000$ for *round 1-2*, $p = 0.001$ for *round 3-4*, and $p = 0.004$ for *round 5-6*). Thus, the disciplining effect of the milestones operates through *medium* contributions, i.e., subjects seem to coordinate on medium contributions throughout. Subjects in treatment SL tried to make the best out of a bad job in *round 5-6*, with significantly more contributions in the *high* class than in the previous rounds (Fisher's exact, $p = 0.000$). However, as shown in figure 5.1, they often failed to reach the long-term target. The comparison between SL and SH over the sequence of play shows that milestones stabilize average contributions and thereby offer a certain intermediate planning reliability.

FIGURE 5.4: Contribution classes over treatments and rounds for S



In Scenario P (see fig. 5.5), milestones have a significant disciplining effect especially in the first and second phase. The share of *low* contributions for PH is significantly lower than for PL (Fisher's exact, $p = 0.047$ for *round 1-2* and $p = 0.052$ for *round 3-4*). However, low contributions in both treatments increase steadily, indicating that participants anticipated that total contributions would exceed the critical thresholds. We also observe differences for the *medium* contribution class. In phases 1 and 2, *medium* contributions in treatment PH are significantly higher than in treatment PL (Fisher's exact, $p = 0.024$ for *round 1-2* and $p = 0.005$ for *round 3-4*). This finding indicates that, as in scenario *S*, the milestone effect is driven by *low* and *medium* contributions. The overall contribution patterns for both treatments (besides the differences mentioned above) are rather similar.

FIGURE 5.5: Contribution classes over treatments and rounds for *P*



5.4 Conclusions

To investigate if regulation by milestones is efficiency enhancing, we have imposed additional risks of failure. If, in a threshold public goods game featuring a final target after six rounds, the final target is not reached, a total loss is sustained with a given probability. The same consequences can be assumed if a milestone is not reached. Our treatments vary the magnitude of the milestones from less strict (approximately inessential) to strict (essential), the marginal productivity of contributions and thereby efficiency and free-riding incentives as well as the probability of a total loss in case of failure.

We find substantial differences between the three scenarios. Milestones do have a positive impact on efficiency when there is no efficiency benchmark and free-riding "disincentives" are low. The effect is strongest when higher contributions below and above targets are not efficiency enhancing and free-riding "disincentives" are low so that investments in emission reduction can only preserve the "status quo." A moderate effect is found when efficiency can be promoted but free-riding "disincentives" are still low. However, the result is mainly due to second run behavior. Since in the context of climate change, a restart or second chance may not be possible, learning might come too late. In the scenario where efficiency can be promoted and incentives to free ride are low, no milestone effect is found.

Our results are similar to Milinski et al. (2008) who find that half of the groups had difficulties reaching the final target. Note that Milinski et al. framed the game as a climate change, which might have increased contributions. Comparing our findings to Fischbacher et al. (2010), who do not implement any intermediate targets, we confirm their result that more serious losses promote cooperation when the threshold is missed. It is worth mentioning that commonly known targets (the common signal case), which we have implemented in a deterministic way, seem to provide a best-case scenario for environmental protection. Their and our observations imply that, depending on the specific scenario, regulation by milestones can be efficiency enhancing.

Caution should be exercised when generalizing our conclusions. Since we do not capture the advantages of early investments, our scenario is a kind of worst-case scenario for testing the milestone hypothesis. In the case of environmental protection, early investments can be considered superior to late investments. Without early investments, the costs of climate protection may increase because emissions accumulate, making it more difficult to reach a certain emission reduction target (cf. Kemfert, 2005). Moreover, environmental returns might need some time to develop and accumulate. Capturing this, was not within the scope of this paper but would be a challenging topic for future research.

In our experiment, we have implemented and manipulated milestones exogenously. This seems unrealistic when thinking of environmental agreements where milestones are usually negotiated, as has been done in Kyoto. Implementing endogenous milestones in such a setting is problematic as one cannot invoke the punishment of Mother Nature. Before doing so, one has to think of the consequences if a milestone is missed.

In the actual debate on climate change, which discusses the investments in emission reduction needed to protect the climate in the long term, milestones may be essential to overcome the current coordination problem. Intermediate targets, as proposed by international environmental agreements such as the Kyoto-Protocol, might help to solve this problem. However, our results reveal a high risk of failure. This has to be kept in mind when hoping for the milestone effect, especially when discussing coordination problems with possibly catastrophic consequences. Additionally note that the results imply a punishment mechanism, imposed by nature, which is in reality lacking so far and whose implementation by international agreements may lead to another dilemma situation.

Chapter 6

Minimum Participation Rules with Heterogeneous Countries.*

6.1 Introduction

In February 2005 the Kyoto-Protocol entered into force, more than seven years after it had been negotiated. One reason for the delay is that a hurdle had to be overcome. It was agreed in Kyoto that the protocol would not become binding unless ratified by a minimum number of 55 countries that include Annex I countries (UN 1992) responsible for at least 55 per cen of the emissions of greenhouse gases of all Annex I countries in 1990 (UNFCCC 1998, Article 25). Similar requirements, called 'minimum participation rules' (MPRs), are very common in international environmental agreements (IEAs).[1] Rutz (2001) examined a sample of 122 IEAs and found that almost all (98 per cen) contained some kind of participation clause.

IEAs are set up to control transnational spillovers. By their very nature IEAs have to be self-enforcing, meaning that countries decide voluntarily to join the agreement or not. Spillovers imply that, even though countries can reap some gains from cooperation, there are strong incentives to free-ride on an agreement and unilateral action is inefficient. In the case of greenhouse gases, a failure to establish a sufficiently large (and effective) coalition may even trigger catastrophic risks (Stern, 2007; IPCC, 2007).

The design of the agreement is important to overcome the problem of free-riding at the ratification stage. Our study focuses on MPRs as a very common and potentially successful tool to increase IEA participation. MPRs can be designed in different ways. They can be linked to the number of signatory countries[2], to country characteristics (such as baseline emissions), contributions (such as abatement targets) or to combinations of

*This chapter is mainly based on Weikard, Wangler and Freytag (2009). We are indebted to Erik Ansink and Mika Widgrén for helpful comments on an earlier version of this work. Mika has provided stimulating comments on an earlier version this paper just a few weeks before he passed away.

[1]The recent literature on IEAs has been surveyed by Barrett (2003, 2007), Carraro and Marchiori (2003) and Finus (2003, 2008).

[2]In this chapter, the term signatories refers to sovereign states that have ratified the agreement.

these. In the Kyoto-Protocol, for instance, a twofold MPR rule has been implemented (55 countries representing 55 percent of emissions).

It is widely argued that, under the MPR agreed in the Kyoto-Protocol and with the withdrawal of the US from the agreement, Russia (which had become pivotal for the agreement) gained bargaining power (cf. Böhringer and Vogt, 2004; Dagoumas et al., 2006). This argument mainly addresses the distribution of welfare among the countries that finally ratified the agreement. In our study we compare payoffs of pivotal countries under participation and non-participation. Our analysis indicates that countries would prefer to be non-pivotal compared to a situation in which they are pivotal as pivotal countries have hardly any credible threat to not enter the coalition. This result offers an interesting new interpretation for the alleged strength of Russia's position in the Kyoto ratification process. Our paper therefore contributes to the discussion about optimal international policy coordination and gives important new insights on the issue of an MPR for coalition stability with heterogeneous countries.

We analyze the formation of an IEA as a coalition formation game. It is assumed that each country is free to decide whether or not to join a unique IEA. More technically, we analyze a cartel formation game with open membership. We examine both, the choice of an MPR and its effects on equilibrium coalition formation among countries in this model. Our approach follows seminal work by Hoel (1992), Carraro and Siniscalco (1993) and Barrett (1994a)[3] who have proposed a sequential game where a cartel formation game at the first stage is followed by a transboundary pollution game at the second stage. This type of game has been used in a number of applied studies on climate agreements (e.g. Finus et al., 2005; Weikard et al., 2006; Lessmann and Edenhofer, 2010).

Recently Carraro et al. (2009) have proposed an extension of this model framework to study the endogenous choice of an MPR. In earlier work Okada (1993) has shown how inefficiencies in prisoners' dilemma situations can be overcome in an appropriate institutional setting where the players can commit to accept a punishment for deviations from the cooperative action. Okada's model is inspired by the seminal work of Ostrom (1986, 1990) on the role of institutional arrangements as tools for changing incentive structures. In contrast to our model punishment is an important factor determining coalition stability.

Although our approach is in the same spirit as Okada's, we consider a continuous action space and heterogeneous players in the underlying public goods game. Closest to our study is the analysis of MPRs by Carraro et al. (2009). However, it also relies on the assumption of identical countries. Our study relaxes this assumption. We analyze a model with heterogeneous countries and we allow for transfers between coalition members that can be used to set incentives for participation. Following Carraro et al.

[3]Diamantoudi and Sartzetakis (2006) have shown that some of Barrett's (1994) results only hold if the level of abatement is not restricted by emissions.

(2009) we use a 3-stage game. First, there is a unanimous decision on the MPR. Second, each country individually decides whether to ratify the agreement or not. If countries agree on the MPR, the agreement enters into force whenever the MPR is satisfied. If the MPR is not satisfied, then the coalition breaks down into singletons. Third, given the MPR is satisfied, a transboundary pollution game between the coalition of signatories and the non-signatories is played. Else we have a standard transboundary pollution game.

The result of our analysis is that implementation of an MPR is always an equilibrium which strengthens cooperation. More precisely, a stricter MPR always performs at least as well as a less strict MPR. This does not imply that an equilibrium MPR will always require the membership of all countries. An MPR that requires full participation of all countries only results under particular circumstances. We find that in a subgame perfect equilibrium the MPR either requires full participation or it will be set at a level that allows at least one country to free-ride. The grand coalition is always an equilibrium in the first case but not necessarily in the second case.

The structure of the chapter is as follows. In the next section we describe the game. Section 3 provides the formal analysis of the game and determines key features of the equilibrium outcomes. In Section 4 we move to the discussion of our results. This section puts provides additional details on how our study is linked to the literature on minimum participation rules. In section 5 conclusions round off the chapter.

6.2 A Model of a IEA Formation with Minimum Participation

We consider a 3-stage game with a set N of countries as players. As we wish to study coalition formation we assume $|N| \geq 3$. The three stages are *(i)* the minimum participation stage, *(ii)* the coalition formation stage, and *(iii)* the transboundary pollution game. We describe the game in more detail starting from the third stage going backwards.

Stage 3: The transboundary pollution game. At this stage an agreement has become binding for the group of signatories $S \subseteq N$. The case of failure to reach agreement is the special case where $S = \emptyset$. The signatories, acting as one single player, and the non-signatories play a transboundary pollution game. Hence we have $|N| - |S| + 1$ players. Each player j chooses a level of pollution abatement $q_j \in [0, e_j]$ where e_j are the unabated (or baseline) emissions. We assume a uniformly mixing pollutant, as in the case of greenhouse gases. Hence, individual benefits B_j depend on the aggregate level of abatement $q \equiv \sum_{i \in N} q_j$. Abatement costs C_j depend on country j's own abatement. We assume that benefits are (weakly) concave and costs are (strictly) convex. Payoffs of player j (where j is the coalition S or a singleton player $i \notin S$) are given by

$$v_j = B_j(q) - C_j(q_j). \tag{6.1}$$

We assume that countries choose abatement levels simultaneously to maximize payoffs, i.e. singletons maximize their individual payoff while the coalition maximizes the aggregate payoff of coalition members. We allow for heterogeneous countries, i.e. countries may differ with respect to their benefits and cost functions. We assume that the game satisfies the conditions of the formal transboundary pollution game described by Folmer and von Mouche (2000) and that the pollution is uniformly distributed as mentioned before. Hence we assume that abatement is a global public good. Such a transboundary pollution game has a unique Nash equilibrium (Folmer and von Mouche, 2000, Proposition 3), referred to as partial-agreement Nash equilibrium by Chander and Tulkens (1995).

The unique Nash equilibrium of the stage-3 game defines a partition function, i.e. for every coalition $S \subseteq N$ we have the payoffs for the coalition and for all non-signatories. We denote country i's payoff under coalition S by $V_i(S)$. The coalition payoff is $V_s(S)$. A sharing rule must be applied to divide $V_s(S)$ between the members of S. This will be discussed below.

Stage 2: Coalition formation. At this stage each country $i \in N$ decides whether or not to join a unique IEA. Formally, each country i has a binary strategy space with strategies $\sigma_i = 0, 1$. If country i chooses $\sigma_i = 0$, it will not be member of the IEA; if i chooses $\sigma_i = 1$, it will be a signatory, $i \in S$. The group of signatories forms an IEA if and only if the MPR is satisfied. If the MPR is not satisfied, the agreement will not be binding and will be irrelevant. Then the transboundary pollution game will be played by all countries acting as singletons and payoffs are determined by the unique Nash equilibrium of that game. Hence $S \subseteq N$ is effective if the MPR is satisfied, else it is ineffective.

Stage 1: Setting the Minimum Participation Rule. We consider heterogeneous countries. In general, an MPR uses a set of measurable characteristics of countries and it defines a minimum requirement for the aggregate across signatory countries for each characteristic. A simple characteristic is "being a sovereign state". This characteristic corresponds to a minimum number of countries, for example "55" in the case of the Kyoto-Protocol. With heterogeneous countries, however, setting a minimum number of signatories does not seem to be adequate, as countries differ with respect to benefits and cost of abatement. Therefore a natural characteristic is countries' abatement level in the non-cooperative (all singletons) Nash equilibrium of the transboundary pollution game which reflects countries' respective marginal benefits and costs.[4]

Let $q_i^{\emptyset}$ denote country i's equilibrium abatement level in the non-cooperative Nash equilibrium of the stage-3 game. We refer to the vector $\mathbf{q} \equiv (q_i^{\emptyset})_{i \in N}$ as benchmark abatement without an effective agreement. In the following we assume that an MPR refers to the sum of signatories' benchmark abatements. We denote the minimum

[4]One interpretation of our model is that the Nash-equilibrium abatements reflect the historical abatement/emissions levels.

required level of benchmark abatement by $\overline{q}$. Hence, the MPR is satisfied and coalition S is effective if and only if

$$\sum_{i \in S} q_i^{\oslash} \geq \overline{q}. \tag{6.2}$$

In our game the MPR is set as follows. A randomly chosen country suggests $\overline{q}$ which the others accept or reject. As in Carraro et al. (2009) we require a unanimous decision, i.e. if a single country rejects, then no MPR applies and $\overline{q} = 0$.

6.3 Analysis

We conduct the analysis going backward.

Stage 3. As we have indicated before, the transboundary pollution game at stage 3 has a unique Nash equilibrium and determines a partition function. The partition function provides for any given coalition $S \subseteq N$ a coalition payoff $V_s(S)$ and payoffs $V_j(S)$for all singleton countries $i \notin S$. Abatement is a public good in our transboundary pollution game. A larger coalition provides more of the public good as it internalizes more externalities. Overall payoffs increase with coalition enlargement. If a player joins a coalition, the larger coalition will receive a larger payoff than the initial coalition and the joining player acting separately. Moreover, all other singleton countries are also better off. Using the shorthand notation $S_{+j} \equiv S \cup \{j\}$, these properties are formally defined as follows.

> DEFINITION 1 (superadditivity): A cartel partition function is superadditive if and only if for all coalitions $S \subset N$ and all $j \in N \backslash S$, it holds that $V_{S_{+j}}(S_{+j}) \geq V_S(S) + V_j(S)$.

> DEFINITION 2 (positive spillovers): A cartel partition function exhibits positive spillovers, if and only if for all coalitions $S \subset N$ and all $j, k \in N \backslash S$ with $j \neq k$, it holds that $V_j(S_{+k}) \geq V_j(S)$.

Note that in superadditive cartel games with positive spillovers the grand coalition of all players will choose an efficient abatement level and maximize overall payoffs. On the basis of what we just argued we can state our first result without formal proof.

> RESULT 1 The partition function that results from the transboundary pollution game with a uniformly mixing pollutant described before is superadditive and exhibits positive spillovers.

In order to assess individual incentives to participate in a coalition, we need to determine how the coalition payoff is shared between members. Following Weikard (2009) we assume that a sharing rule is applied that satisfies the *Claim Rights Condition*. This condition requires that every coalition member $i \in S$ receives at least its outside option payoff, i.e. what i would receive under coalition $S_{-i} \equiv S \backslash \{i\}$ if this is feasible. Feasibility is warranted if the coalition payoff is at least as large as the sum of the outside option payoffs, i.e. if

$$V_S(S) \geq \sum_{i \in S} V_i(S_{-i}). \tag{6.3}$$

A particular sharing rule that satisfies the *Claim Rights Condition* is sharing proportional to outside option payoffs. In this case $V_i(S) = \frac{V_i(S_{-i})}{\sum_{j \in S} V_j\left(S_{-j}\right)} V_S\left(S\right)$ for all $i \in S$. However, the remainder of the analysis holds for any sharing rule that satisfies the Claim Rights Condition. We refer to this class of sharing rules as "optimal sharing rules" for reasons that will become apparent below.

Stage 2. Now we can move to the coalition formation stage. A Nash equilibrium of the coalition formation game is a vector of ratification decisions $(\sigma_i)_{i \in N}$ such that no single country would prefer to change its decision. We call a coalition S a stable coalition if the strategy profile $(\sigma_i)_{i \in N}$ that corresponds to S is a Nash equilibrium. Stability can be decomposed into internal and external stability (D'Aspremont et al., 1983).

DEFINITION 3 (internal and external stability):

(*i*) A coalition S is internally stable if and only if for all $i \in S$ it holds that

$$V_i\left(S\right) \geq V_i\left(S_{-i}\right). \tag{6.4}$$

(*ii*) A coalition S is externally stable if and only if for all $i \notin S$ it holds that

$$V_j\left(S\right) \geq V_j\left(S_{+j}\right). \tag{6.5}$$

(*iii*) Coalition S is stable if and only if it is internally and externally stable.

To determine the equilibrium coalitions we proceed in two steps. First we discuss internal stability, then external stability. Note that our sharing rule implies that, if the coalition payoff exceeds the sum of outside option payoffs, then payoffs can always be shared such that the coalition is internally stable. Hence to check internal stability it is sufficient to check whether the Claim Rights Condition can be satisfied, i.e. to check condition (3). Next notice that if (3) is not satisfied for S, then S cannot be internally stable. Hence, sharing rules that satisfy the Claim Rights Condition will internally stabilize all coalitions that are possibly internally stable (Weikard, 2009, Theorem 1). It is in this sense that these sharing rules are optimal. Also note that whether (3) holds is determined by the partition function alone and therefore it is not necessary to specify the sharing rule.

A transboundary pollution game with optimal sharing has been examined in McGinty (2007), Weikard and Dellink (2008), Nagashima et al. (2009) and Fuentes-Albero and Rubio (2010). The setting in this study extends the analysis to include MPRs. In essence an MPR makes every coalition inadmissible that does not meet the minimum requirements stated in condition (2). Suppose coalition S forms such that $q_S^{\oslash} \equiv \sum_{i \in S} q_S^{\oslash} < \overline{q}$ and, hence, S is ineffective. In this case a non-cooperative transboundary pollution game is played where all countries $i \in N$ choose their benchmark abatements and payoffs are $V_i(\oslash) = v_i(\mathbf{q}) = B_i\left(\sum_{j \in N} q_j^{\oslash}\right) - C\left(q_j^{\oslash}\right)$. We refer to $V_i(\oslash)$ as country i's benchmark payoff.

The following is straightforward.

> RESULT 2 Every ineffective coalition is internally stable.

Proof. If coalition S is ineffective, then the smaller coalition S_i will also be ineffective. Hence no country can gain by leaving an ineffective coalition. ⧫

To obtain the next result we introduce the notion of a pivotal country.

> DEFINITION 4 (pivotal players): Country $i \in S$ is pivotal for an effective coalition S if and only if coalition S_i is ineffective.

The next result follows by construction.

> RESULT 3 The outside option payoff of a pivotal member of S is its benchmark payoff.

To determine the impact of an MPR on coalition (internal) stability, we need to examine how an MPR affects coalition payoffs and outside option payoffs. It holds that

> RESULT 4 Consider a given coalition S and two MPRs, one less strict $\overline{q}_L \geq 0$, the other more strict $\overline{q}_H > \overline{q}_L$. Moving from $\overline{q}_L$ to $\overline{q}_H$ will never increase coalition payoffs but will reduce them to benchmark payoffs for sufficiently high $\overline{q}_H$.

Proof. If S is ineffective under $\overline{q}_L$, nothing changes if $\overline{q}_H$ applies instead of $\overline{q}_L$. Furthermore, if S is effective under $\overline{q}_H$, then it will be effective under $\overline{q}_L$ and nothing changes. If, however, $\overline{q}_L \leq q_S^{\oslash} < \overline{q}_H$ (S is effective under $\overline{q}_L$ but ineffective under $\overline{q}_H$), then payoffs will be reduced to benchmark payoffs if $\overline{q}_H$ applies. ♦

The next result is the key to understanding how MPRs work in this model.

> RESULT 5 Consider again a given coalition S and two MPRs, $\overline{q}_L \geq 0$ and $\overline{q}_H > \overline{q}_L$. Moving from $\overline{q}_L$ to $\overline{q}_H$ will never increase outside option payoffs but will reduce them to benchmark payoffs for sufficiently high $\overline{q}_H$.

Proof. First, if S is ineffective under $\overline{q}_L$, nothing changes if $\overline{q}_H$ applies instead of $\overline{q}_L$. Next, recall that country $i \in S$ is pivotal if and only if $q_{S_{-i}}^{\oslash} < \overline{q} \leq q_S^{\oslash}$ or equivalently $q_i^{\oslash} > q_S^{\oslash} - \overline{q}$. This implies that an increase of $\overline{q}$ may increase (but never decrease) the number of pivotal countries. If $\overline{q} = q_S^{\oslash}$, every country in S is pivotal. As a country becomes pivotal, its outside option payoff is the benchmark payoff (RESULT 3) which is lower than the initial outside option payoff. The latter holds due to superadditivity and positive spillovers. Finally, if $\overline{q} > q_S^{\oslash}$, then S is ineffective and, trivially outside option payoffs equal benchmark payoffs. ♦

The next result follows as a corollary of Results 2 and 5.

> RESULT 6 Consider any two MPRs, $\overline{q}_L \geq 0$ and $\overline{q}_H \geq \overline{q}_L$. Then every coalition S that is internally stable under $\overline{q}_L$ will also be internally stable under $\overline{q}_H$. The converse does not hold.

Proof. First, from RESULT 2, if S is ineffective under $\overline{q}_H$ then it will be internally stable. If S is effective under $\overline{q}_H$ (and, of course under $\overline{q}_L$), then payoffs are unaffected if $\overline{q}_H$ applies instead of $\overline{q}_L$. Outside option payoff, however may fall (see RESULT 5). Hence, moving from $\overline{q}_L$ to $\overline{q}_H$ may internally stabilize S but it will never internally destabilize S. ♦

Loosely speaking, a stricter MPR will always offer more internal stability than a less strict MPR. Of course, an increase of $\overline{q}$ can make a given coalition S ineffective. However, under a well chosen MPR every possible coalition can be stable and effective as the following proposition shows.

> PROPOSITION 1 With a superadditive partition function, if $\overline{q} = q_S^{\oslash}$, then S is effective and internally stable under optimal sharing.

Proof. It is clear that S is effective. But also every smaller coalition is ineffective and, hence, all countries in S are pivotal. By superadditivity it holds that $V_S(S) \geq V_S(\oslash)$. Because every member is pivotal, $V_S(\oslash)$ is the sum of the outside option payoffs and condition (3) is satisfied. Therefore optimal sharing guarantees internal stability. ⧫

With these results we can move on to examine external stability. Under an optimal sharing rule the following result holds

> RESULT 7 A coalition S is externally unstable if and only if there exists country $j \notin S$ such that S_{+j} is internally stable.

Proof. See Weikard (2009) proof of Lemma 1. ⧫

The next result puts together external and internal stability.

> RESULT 8 Consider any two MPRs, q_L , q_H with $0 \leq \bar{q}_L \leq q_N^{\oslash}$ and $\bar{q}_L > \bar{q}_H$. A move from $\bar{q}_L$ to $\bar{q}_H$ will result in a larger coalition becoming stable for sufficiently high $\bar{q}_H$. With superadditivity and positive spillovers, this will always improve payoffs.

Proof. This follows immediately from RESULTS 6 and 7. If a move from $\bar{q}_L$ to $\bar{q}_H$ internally stabilizes coalition S, then either S is externally stable or, if externally unstable, there exist S_{+j} with $j \notin S$ and S_{+j} is internally stable. We call S_{+j} an internally stable enlargement of S. The argument can then be repeated. Hence, either S_{+j} is externally stable or there exists an internally stable enlargement of S_{+j} , and so on. ⧫

Stage 1. With these results in place we can now turn to the minimum participation stage. Since each country is characterized by $q_i^{\oslash}$, we sort countries according to this criterion and adopt the following notational convention $q_1^{\oslash} < q_2^{\oslash} < \cdots < q_n^{\oslash}$. It is only for mathematical convenience that we assume all inequalities to be strict. Clearly we have by construction

RESULT 9 If country i is pivotal in S, then all countries $j > i$ are also pivotal in S.

Notice that, by comparison, in a game with identical countries, as considered by Carraro et al. (2009), either all countries or none of the countries are pivotal.

At the minimum participation stage, one country is randomly selected to propose the MPR. Then others are asked to accept or reject the proposal. A rejection results in $\bar{q} = 0$. In this case every coalition formed would be effective. Hence, a country would reject a proposal if its expected payoff under the proposed MPR would be less than the expected payoff under $\bar{q} = 0$. We denote the set of stable coalitions under $\bar{q} = 0$ by $\mathcal{S}$. As we will usually find a large set of stable coalitions, E_j^r denotes the expected payoff if j (or any other country) rejects the MPR proposed by i and $\bar{q} = 0$ applies. Hence, we call a proposed MPR "acceptable" if it stabilizes a coalition where each country j receives at least E_j^r. Obviously an equilibrium proposal must be acceptable. We require that countries have mutually consistent expectations in the sense that the sum of the expected payoffs cannot exceed the sum of payoffs under the stable coalition $S^* \in \mathcal{S}$ that gives the highest global payoff of all coalitions in $\mathcal{S}$. Formally, mutually consistent expectations imply the following.

DEFINITION 5 (mutually consistent expectations): If expectations about payoffs under $\bar{q} = 0$ are mutually consistent, then $\sum_{i \in N} E_i^r \leq \sum_{i \in N} V_i(S^*)$ with $\sum_{i \in N} V_i(S^*) \geq \sum_{i \in N} V_i(S)$ for all $S \in \mathcal{S}$.

In the remainder of the analysis we assume that the grand coalition is unstable under $\bar{q} = 0$. Else an MPR has no force and the problem is not very interesting. Hence, $\sum_{i \in N} E_i^r < V_N(N)$.

We know from PROPOSITION 1 that the grand coalition will be internally stable and therefore stable under $\bar{q} = q_N^{\oslash}$. Also we know that the grand coalition is efficient. We have the following result.

RESULT 10 The proposal $\bar{q} = q_N^{\oslash}$ is acceptable for all under an appropriate sharing rule.

Proof: By assumption $N \notin \mathcal{S}$. Because $V_N(N) > \sum_{i \in N} E_i^r$ payoffs in the grand coalition can be arranged such that $V_i(N) \geq E_i^r$ for all $i \in N$. And no country would reject the proposal. ⧫

The next question then is whether any country can get a higher payoff than in the grand coalition. For this it is important to note that individual payoffs in the grand coalition depend on outside option payoffs –note that the Claim Rights Condition (3) must be met. The outside option payoffs will, in turn, depend on the MPR. Hence, the country that proposes the MPR will determine which countries are pivotal. This will impact the distribution of payoffs. Clearly the proposing country prefers to be non-pivotal as pivotal countries' payoffs are reduced to benchmark payoffs. If a country i is selected as proposer, it will try to set an MPR that stabilizes the grand coalition such that i is non-pivotal while countries $j > i$ are pivotal. This minimizes others' outside option payoff subject to i being non-pivotal. This implies that it could be optimal for the proposing country i to propose $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$ rather than $\bar{q} = q_N^{\oslash}$. Clearly if i is close to $|N|$ most countries will be non-pivotal, the sum of outside option payoffs is larger and this strategy will eventually undermine the internal stability of N. Still in this case it may be optimal to propose $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$, provided that this proposal would be acceptable. To fix ideas, we first examine the "smallest" country, country 1.

RESULT 11 If country 1 is the proposer, it proposes

$$\bar{q} = \begin{cases} q_N^{\oslash} - q_1^{\oslash} & \text{if acceptable} \\ q_N^{\oslash} & \text{otherwise} \end{cases}$$

and the grand coalition emerges.

Proof. Acceptability of $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$ implies $V_N(N) \geq \sum_{j=N_{-1}} E_j^r + V_1(N_{-1})$.

(i) If it holds, notice that all countries other than 1 are pivotal players and their outside option payoff is $V_j(\oslash)$, for all $j \neq 1$. Furthermore, by superadditivity we have $V_N(N) \geq V_{N-1}(N_{-1}) + V_1(N_{-1})$ and $V_{N_{-1}} \geq \sum_{j \in N_{-1}} V_j(\oslash)$. Hence condition (3) is satisfied and N is internally stable under optimal sharing. As N is externally stable by definition, N is stable. In addition, by positive spillovers, no other proposal will give a larger payoff to country 1 as it receives at least the outside option payoff $V_1(N_{-1})$.

(ii) If the proposal $q_N^{\oslash} - q_1^{\oslash}$ is unacceptable, it will be dominated by proposing $q_N^{\oslash}$ which is acceptable by RESULT 10 and stable by PROPOSITION 1. Furthermore $q_N^{\oslash}$ also dominates any other acceptable proposal that leads to coalitions smaller than the grand coalition since by superadditivity payoffs can always be arranged such that $V_1(N) \geq V_1(S^*)$. ♦

RESULT 11 can be generalized. For a randomly selected proposer we have the following result.

PROPOSITION 2 If country i is the proposer, it proposes

$$\bar{q} = \begin{cases} q_N^{\oslash} - q_i^{\oslash} & \text{if acceptable} \\ q_N^{\oslash} & \text{otherwise} \end{cases}$$

If $q_N^{\oslash} - q_i^{\oslash}$ is acceptable, the grand coalition emerges if and only if $V_N(N) \geq \sum_{j=i+1}^{n} V_j(\oslash) + \sum_{j=1}^{i} V_j(N_{-j})$. Otherwise coalition N_{-i} emerges.

If $q_N^{\oslash}$ is proposed, the grand coalition always emerges.

Proof. To determine whether $q_N^{\oslash} - q_i^{\oslash}$ is acceptable we have to distinguish two cases: the grand coalition is either (*i*) stable or (*ii*) unstable.

(*i*) If $V_N(N) \geq \sum_{j=i+1}^{n} V_j(\oslash) + \sum_{j=1}^{i} V_j(N_{-j})$, the grand coalition is stable given $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$. By positive spillovers, if acceptable, no other proposal will give a larger payoff to country i as it receives at least the outside option payoff $V_i(N_{-i})$. Acceptability implies $V_N(N) \geq \sum_{j=i+1}^{n} E_j^r + \sum_{j=1}^{i} V_j(N_{-j})$ because pivotal countries would reject $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$ if they will not receive at least E_j^r under the grand coalition. If the proposal $q_N^{\oslash} - q_i^{\oslash}$ is unacceptable, $q_N^{\oslash}$ is proposed and part (*ii*) of the proof of RESULT 11 applies. ♦

(*ii*) If the grand coalition is unstable given $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$, then by proposing $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$ country *i* can still secure $V_i(N_{-i})$, if the proposal is acceptable. The further course of play will then be $\sigma_i = 0$ at stage 2 and others' best response is $\sigma_j = 1$ for all $j \neq i$. Hence, coalition N_{-i} is formed. N_{-i} is stable as all its members are pivotal under $\bar{q} = q_N^{\oslash} - q_i^{\oslash}$. In this case acceptability requires $V_{N_{-i}}(N_{-i}) \geq \sum_{j \in N_{-i}} E_j^r$. If the proposal $q_N^{\oslash} - q_i^{\oslash}$ is unacceptable, $q_N^{\oslash}$ is proposed and part (*ii*) of the proof of RESULT 11 applies.

Typically, in a public goods game with a sufficiently large number of countries coalition S^* would be "small" compared to N or N_{-i} and it would provide significantly less than the efficient level of abatement. Therefore, implementation of an MPR is always an equilibrium. In some cases the MPR will not require full participation. Even though in that case the proposing country *i* becomes non-pivotal, members of N_{-i} have no incentive to decline *i*'s proposal and country *i* can exploit a 'first-mover advantage'. The grand coalition might emerge nevertheless. Only if the proposer is a sufficiently "large" country, the grand coalition may not be an equilibrium outcome. But notice that the 'first mover advantage' is subject to the acceptability of the proposal. A proposal that allows free-riding of a large country is likely to be unacceptable. In that case the equilibrium MPR requires full participation and the grand coalition emerges.

6.4 Policy Coordination and IEAs

As IEAs are wide-spread and important for environmental policy making we turn now to discuss the significance of our theoretical results for environmental policy coordination. Also we provide a more in-depth review of previous contributions on MPRs in the literature. Even though, as we show, MPRs may have a decisive role for the stability of IEAs, only a few previous theoretical contributions exist in the literature with an explicit focus on MPRs. Closest to our research are models with perfect information. To these we turn first. Then we broaden the scope and discuss MPRs under uncertainty and incomplete information about payoff structures.

Rutz (2001) analyzes the role of MPRs in the coalition formation game that has become canonical for the study of IEAs (Hoel, 1992; Carraro and Siniscalco, 1993; Barrett, 1994a). In this game a coalition forms at stage 1 and, at stage 2, the coalition and the non-signatories play a transboundary pollution game. Rutz considers identical countries and shows that the equilibrium number of signatories is equal to a number required by an exogenously given MPR.

Rubio and Casino (2005) introduce a stock pollutant into the game. The partition function is generated by a differential game. They consider the effect of MPRs and arrive at the same conclusion: once an MPR is established, the size of a stable coalition is the number of countries required by the MPR.

Empirical evidence suggests that IEAs are negotiated to establish a minimum abatement level (instead of optimal levels). Courtois and Haeringer (2008) analyze this case for identical players. In this setting an MPR is characterized by the number of participating countries. Similar to other studies they obtain the result that the grand coalition can be stabilized. They also contrast their result to the empirical observation that most IEAs have adopted MPRs which do not require full participation. Two possible explanations are provided. First, a threshold close to full participation might be too demanding and involves a risk that ratification fails. Second, because incentives to free-ride increase with coalition size, countries might prefer a threshold below the grand coalition to preserve an individual option to free-ride.

These studies examine exogenous MPRs. Carraro et al. (2009) have extended the model to analyze the endogenous choice of an MPR. The MPR is unanimously agreed in the first stage of the game. Once the MPR is established, the standard IEA formation game follows. Carraro et al. (2009) arrive at the result that there exists (among other equilibria) an equilibrium MPR that requires full participation such that the grand coalition is stable.

Our model is an extension of Carraro et al. (2009). While the basic set-up of our game is similar, we allow for heterogeneous players. This is an important step towards practical applicability of the theoretical analysis of MPRs. Introducing heterogeneous players poses three challenges for the analysis. First, if players differ with respect to benefits and costs of abatement, the design of transfer schemes (e.g. tradable permits) is an important determinant of the stability of coalitions. The benefits from cooperation can be shared in different ways. A sharing rule (or transfer scheme) that satisfies the Claim Rights Condition will support stability whenever it is feasible. Second, with heterogeneous players, the equilibria of the game cannot be described by the number of players anymore. The identity of players matters. Third, the different characteristics of players allow for the use of different types of MPRs. An MPR may require a minimum number of countries, but it may also require some other aggregate characteristics. In our analysis we choose for the equilibrium abatement level of countries in the non-cooperative equilibrium of the transboundary pollution game. This captures the "size" of the different countries. Addressing these three challenges together is a genuine novelty in the analysis of MPRs.

We now turn to a more detailed discussion of our results and link them to international environmental policy making.

First notice that, due to superadditivity, an increase in coalition size will always increase the gains from cooperation. With a sufficiently strict MPR it is more likely to stabilize larger coalitions than in the absence of an MPR (RESULT 8). An immediate implication is that a social planner would set an MPR sufficiently strict to stabilize the grand coalition. Hence, the result derived by Rutz (2001) generalizes to heterogeneous countries.

Comparing our findings to the results obtained by Carraro et al. (2009) there is a noticeable difference. We find, in contrast to the result of Carraro et al. (2009), that the equilibrium MPR is not always requiring full participation. The MPR proposed in some cases allows the proposing country to free-ride on the coalition consisting of all other countries. Still the grand coalition will emerge if the country that proposes the MPR is sufficiently small as compared to other countries. The grand coalition also emerges if the proposing country sets an MPR that requires full participation as a proposal that allows free-riding would be unacceptable. With identical countries a grand coalition emerges in an equilibrium, as found by Carraro et al. (2009).

Generally, we find that MPRs can play a significant role in establishing successful coalitions that overcome the free-rider problem in the provision of public goods, at least to large extent. In many cases an efficient grand coalition emerges. In some cases a single large player free-rides. Still in a setting with many players the largest part of the gains from cooperation can be reaped.

Furthermore, our model underlines the importance of agenda-setting. We model the first stage of the game as a simple bargaining game with a take-it-or-leave-it offer. The country that can make a proposal, or set the agenda, can exploit some bargaining power if is able to establish an MPR that does not require participation of all countries ($\bar{q} = q_N^{\oslash} - q_i^{\oslash}$). In that case a country's equilibrium proposal makes that country non-pivotal for the grand coalition. This establishes a larger claim and, hence, a larger payoff under any sharing rule that satisfies the Claim Rights Condition compared to an MPR where the proposing country is pivotal to the agreement. The grand coalition can only emerge if coalition gains are large enough to compensate all countries for their outside option payoff. This requires that each pivotal country receives at least $V_j(\oslash)$ and each non-pivotal country at least $V_j(N_{-j})$.

One interesting implication of our model is that if free-riding occurs in equilibrium ($V_N(N) < \sum_{j=i+1}^{n} V_j(\oslash) + \sum_{j=1}^{i} V_j(N_{-j})$), it will be the proposing (large country) that free-rides. This holds despite of the fact that the equilibrium proposal of a sufficiently large country ($\bar{q} = q_N^{\oslash} - q_i^{\oslash}$) also makes all smaller countries non-pivotal and increases their claims. This can be explained as follows. If condition (3) cannot be met for the grand coalition, the smaller non-pivotal countries expect the large non-pivotal country to free-ride at stage 2 of the game. Then all other non-pivotal countries have no better option than to join the agreement.

If, however, a proposal of the big country that would allow a free-ride turns out to be non-acceptable, then an MPR that requires full cooperation is proposed ($\bar{q} = q_N^{\oslash}$). The grand coalition is the resulting equilibrium for that case.

It may be interesting to examine Russia's position during the ratification process of the Kyoto-Protocol in the light of our model. In our model each country prefers being non-pivotal rather than pivotal for an agreement. However, the empirical observation that Russia produced additional "hot air" seems to indicate that Russia could take advantage of being pivotal for the Kyoto-Protocol (cf. Dagoumas et al., 2006). This apparent difference between model prediction and evidence highlights another important implication for environmental policy coordination. Notice that the Kyoto ratification process was a sequential game while our model analyzes simultaneous ratification. Sequential accession implies that a single country will become pivotal at some stage and can bargain with the signatories. Hence, presumably Russia could exploit some bargaining power after others had ratified. However, our model of simultaneous ratification suggests that Russia, as pivotal country, did not have a credible threat to not ratify the Kyoto-Protocol indicating that Russia's bargaining power may have been overestimated. This sheds new light on the discussion about the apparent advantage of Russia in the Kyoto negotiation process.

A rather restrictive assumption of our model is the assumption of complete information. This implies that each player is informed about choice options (strategy spaces) and payoffs of all other players. However, the long-term environmental impacts that an IEA addresses and the technological abatement options are generally uncertain. This leads to uncertain payoffs –an issue that hampers, presumably, the formation of a global climate agreement. In addition coalition formation is a political process and there may be uncertainties about policy preferences as well.

Black et al. (1993) were the first to provide an analysis of the role of MPRs for IEAs under uncertainty. They include incomplete information in their model assuming that individual countries know their cost function but do not know their benefits from the agreement. Black et al. (1993) use this approach in order to assess the optimality of MPRs depending on different abatement costs as well as the number of participating countries. Countries are assumed to be symmetric and the binary choice about coalition formation is made simultaneously, or at least without knowledge about the decision of the other countries (Black et al., 1993, p. 284). Therefore, countries are uncertain about whether a coalition will be formed or not. According to the underlying assumptions of the model, coalition formation is only possible under the condition that an MPR is incorporated into the treaty. The motivation to sign an agreement "is the contribution that added commitment makes to the likelihood that the treaty is effected" (Black et al., 1993, footnote 9). Under incomplete information about the payoffs the grand coalition might not be efficient (individual marginal abatement costs may exceed the sum of expected marginal benefits). Therefore, in contrast to our model, a social planer would eventually choose a threshold below the grand coalition.

Harstad (2006) models uncertainty about the costs and benefits of the provision of a public good and discusses incentives for cooperation of heterogeneous countries to jointly provide the public good. Flexible participation (open membership) is compared with rigid cooperation (full membership) and minimum participation rules. The decision about the agreement on the MPR is endogenized assuming majority voting on the threshold defined by the MPR. (Harstad, 2006, proposition 5) shows that the voting game may not have a Condorcet winner and there may not be a stable equilibrium MPR.

The MPRs of most IEAs require less than full participation. The models of Black et al. (1993) and Harstad (2006) explain this by incomplete information and uncertainty. In our model less than full participation is explained by the bargaining power of the proposing country.

6.5 Conclusion

In this study we show that the model of endogenous choice of minimum participation rules (MPRs) for international environmental agreements (IEAs) suggested by Carraro et al. (2009) can be generalized to heterogeneous countries. We find that MPRs are an effective tool to stimulate participation in IEAs. The grand coalition, full participation, can be established in cases where the country that puts a proposal for an MPR on the bargaining table is small. If a large country makes a proposal the grand coalition results if the free-rider proposal is unacceptable to at least one other country. In some cases, however, free-riding can result in equilibrium. We also find that proposing non-pivotal countries can exploit negotiating power and take advantage of countries that are pivotal to the agreement. This implies that non-pivotal large countries bear a particular responsibility in the negotiation process of a new climate agreement.

Even though our findings shed new light on the formation of IEAs with an MPR, some open questions remain. Our model could be extended in various directions. An important issue is to gain a better understanding of the dynamics of coalition formation, in particular an understanding of the negotiation process (cf. Caparros et al., 2004) and of the role of renegotiations (cf. Weikard and Dellink, 2008). As discussed in the previous section uncertainties are an important determinant of IEA formation. Uncertainties may unravel over time. When renegotiations are considered, learning becomes an important issue (Ulph, 2004; Kolstad, 2007). Furthermore, signing –and ratifying– an agreement just means that countries declare their intention to contribute to the public good. It is an additional step to incorporate the treaty into national law. Clearly, the important issue here is enforcement. Barrett (2009) argues that the lack of an enforcement mechanism is a decisive failure of Kyoto-Protocol. McEvoy and Stranlund (2009) incorporate enforcement into the standard IEA formation game.

Models of IEA formation have been looking at these aspects one by one –a comprehensive model of IEA formation that combines MPRs, renegotiations and enforcement is still missing.

Chapter 7

Environmental Policy and the European Automotive Industry*

7.1 Introduction

Based on the assumption of citizens maximizing personal utility, an externality arises when private marginal costs for the use of fossil fuels are smaller than social marginal costs. The decision on consumption of fossil fuels as an input factor for transport is based on an individual preferences and the externality generated on the social level is not taken into account when individuals focus their consumption decision on given prices. Since climate change has global impacts, the individual decision to use fossil fuels can generate global damage. As the problem described holds for all citizens who consume the non-renewable energy source generating externalities, a social dilemma is present. Following IPCC (2007) and Stern (2007), we treat climate change as a global public bad. Private transport (due to the fact that the use of fossil fuels has a positive impact on carbon dioxide (CO_2) concentration in the atmosphere) contributes to this global public bad.

This chapter aims to derive a solution for the policy proposed by the EU to regulate the automotive industry by combining the sustainability approach with two normative criteria, consumer sovereignty, on the one hand, and a high degree of competition, on the other hand. As these two criteria seem to have played a minor role when developing the directive for the automotive sector, the outcome's result may be inefficient, and a certain degree of disorder is possible.[1] The chapter is structured as follows. Section 1 starts by explaining the rationality behind delegating global environmental problems to be the responsibility of the European Union. In a proceeding step we look at the rules applied

*This chapter is mainly based on Dettmer and Wangler (2010). We are indebted to Andreas Freytag, Christoph Vietze and Sebastian Voll for helpful comments on an earlier version of this work.

[1]The line of argument is based on the voting procedures that influence decision making at the European level until today. Under the Treaty of Lisbon a reform of the voting procedures is foreseen. However, the new voting procedure does not enter into force before 2014 and therefore the problems discussed in the chapter so far still have political relevance.

on environmental policy in order to understand the decision making process. The directive coming from the European commission intended to regulate the automotive industry is discussed in the next step. In Section 2 we define three criteria which we consider minimum requirements for the policy measure aimed to solve the problem in question. In section 3 the supply and demand for automobiles is analyzed with a focus on specialization patterns of automotive manufacturers. In order to evaluate the impact of the Commission's proposal on consumer preferences, environmental aspects are taken into account. In section 4 we try to find the optimal policy instrument that is able to internalize the externalities generated by private transport. We come to the result that market-based instruments, namely certificates or a Pigouvian tax, seem to be adequate. As both instruments can be applied on the supply and demand side, we also take political economy considerations into account. In a next step international problems are evaluated. The last section is our conclusion.

7.2 Environmental policy in the European Union

7.2.1 Decision making on the European Level

Environmental policy is a political topic that increasingly attracts political attention and is, therefore, imbedded in the political agenda of policy-makers. Environmental initiatives from the European Commission, especially, have increased a development which began with the signing of the Treaty of Maastricht (Leveque, 1996a, p. 9). One reason for this can be found in the rules at the European level (compare also footnote 1). In the case of environmental regulation, a qualified majority is applied to ratify a proposal coming from the European Commission. Two major exceptions limit the power of the European Commission with regard to the "fabric of environmental regulation" (Leveque, 1996a, p. 9). On the one hand, there is the principle of subsidiarity[2] and, on the other hand, article 130 of the Maastricht Treaty. The following three cases define exceptions with respect to the qualified majority:

- Provisions primarily of fiscal nature.
- Measures concerning town and country planning, land use and management of water resources.
- Measures significantly affect a member state's choice between different energy sources and the general structure of its general supply.

[2] As stated in article 3b of the Maastricht Treaty, the community will only take action if the objectives of the proposed action cannot be sufficiently achieved in the member states. Subsidiarity, in general, means that political action should be undertaken at the lowest level of decision making that can be assumed to be able to make decisions on a specific problem efficiently.

In the case the European Commission puts forward a proposal concerning market-based instruments, e.g. harmonization of the carbon tax, unanimity rule is applied and decision making requires the agreement of all members of the community. For regulations which are neither limited due to the principle of subsidiarity nor subject to the three categories listed, the decision is made with a qualified majority. Thus, the European Commission has a certain power with respect to industrial regulation targeting environmental policy. All directives from the European Commission can enter the national level, if the European Council decides with a qualified majority. At the national level the legal political process has to be used to transform the directive into national law (Leveque, 1996b). These considerations have to be taken into account when evaluating the Commission's proposal on regulation of the automotive industry.

7.2.2 European Regulation of the Automotive Industry

The European Commission established a framework to improve fuel efficiency to reduce CO_2 emission from passenger cars by environmental regulation (COM, 2007a). The framework builds upon three main pillars:

1. Voluntary commitments by automobile manufacturers associations:
   A cornerstone of this strategy is the voluntary commitment of the associations of European (ACEA), Japanese (JAMA), and Korean (KAMA) automobile manufacturers. As negotiated in 1998, the ACEA committed to reduce the average CO_2-emission of newly registered cars to 140 gram/km by 2008.[3]

2. Guidelines on labeling and the supply of information to consumers:
   While the EU relies in part on the commitments of the automobile manufacturers, consumers need to be informed about the importance of fuel efficiency of passenger cars.

3. Tax measures that favor vehicles with light fuel requirements:
   According to the strategy (COM, 2007a, p. 3), fiscal measures such as national taxes should establish a direct relationship between tax level and CO_2 performance to increase incentives for consumers to buy cars fulfilling the requirements of low fuel consumption and CO_2-emission.

Moreover, the Commission published a proposal for reducing CO_2-emission from private automobiles that set allowable emissions according to the mass of the vehicle. The core of the strategy is the so-called limit-value-curve relating the vehicle mass to a CO_2-emission limit (COM, 2007a, Article 4/annex I), which is the average CO_2-emission

[3] The Japan and Korean automobile manufacturers associations made a commitment to the level of 140 gram/km by 2009.

level, 130 gram/km, that should be achieved by manufacturers of newly-registered cars on the European market. The draft of the new directive states that a CO_2-emission increase is allowed in accordance with the vehicle mass. The permitted specific CO_2-emission shall be determined using the following formula:

$$CO_{2e}missions = 130 + 0.0457(M - 1289) \tag{7.1}$$

where M is the vehicle mass in kilograms and the mass of 1289 kilograms reflects the current sales-weighted average (COM, 2007b, p. 5). While the slope-parameter of the formula seems arbitrary and remains without any justification, the limit-value-curve is such that a disproportionate reduction of CO_2-emission is requested. The slope parameter is below the actual slope parameter of CO_2 emission –weight of the car– relation. With regard to the parameter 0.0457, it should be obvious that manufacturers of heavier vehicles must achieve a higher percentage reduction in emission than manufacturers of lighter vehicles. It is required that the goal be achieved by 2012. Additionally, article 7 of the proposal states that penalty payments will be claimed for newly-registered automobiles which exceed the average emission target (COM, 2007a, p. 21).[4] It is foreseen that the fines start in 2012 with €20 for each additional gram of CO_2. It is scheduled that from 2013 until 2015 the specific fines increase to €35, to €60, and finally to €95 (COM, 2007a, p. 21).

While the Commission's proposal is aimed at reducing CO_2-emissions from passenger cars, the regulation with regard to penalty payments is a considerable incentive for manufacturers to develop fuel-saving technologies. It is reasonable to argue that consumers will bear the cost imposed on automobile manufacturers resulting from the fines or from the technological upgrade needed to avoid them, with payment incorporated in the price structure of automobile manufacturers (with a relatively high CO_2-emission level). A first impression is that the Commission's proposal to reduce CO_2-emission from passenger cars will fail to be an optimal strategy in achieving environmental protection. It will also fail to set efficient incentives for automobile manufacturers to develop fuel-saving technologies.

7.3 Sustainability vs. Consumer Sovereignty and Competition

7.3.1 Environmental Problems and the Constitutional Setting

Complex models are able to predict possible developments in the climate using long-term forecasts Nordhaus (1994b); Nordhaus and Boyer (2003). It seems to be clear that doing nothing will be very risky and can destabilize the whole ecosystem. The most

[4]Moreover, "excess emission is the number of grams per kilometer by which the manufacturer's average specific emissions exceeded its specific emissions target." (COM, 2007b, p. 21).

important approach to coping with environmental problems is the normative argument of sustainability.[5] As we treat climate change as a global public bad (IPCC, 2007; Stern, 2007), we argue that a first best solution for the internalization of the externality will require international policy coordination. However, the problems related to negotiations on a follow-up agreement to the Kyoto-Protocol, which took place in December 2009 in Copenhagen,[6] show that international policy coordination is difficult. From this perspective, it is understandable that the European Union starts its own initiatives.

In thinking about policy measures aimed at reducing the problems related to global warming, it is challenging to find the appropriate political instruments. The major concern is that climate change arguments (or more generally the criteria of sustainability) can easily be used to justify policy measures which contradict basic economic principles guaranteeing the functioning of a liberal market order (Gerken and Renner, 1996). As our aim is to derive policy recommendations, we now define two criteria which can be considered as minimum requirements that have to be fulfilled. The policy measures on CO_2 emission reduction for private transport, proposed in the directive of the European Commission, should be in line with our minimum requirements in order to be considered desirable.

7.3.2 Minimum Criteria Imposed on Policy Measures

The following discussion outlines the motivation behind a call for two minimum requirements for policy measures by focusing on potential conflicts between sustainability, non-discrimination between competitors, open market access and consumer sovereignty. Since the EU directive is formulated in such a way that all automobile manufacturers are treated the same, it seems that different specialization patterns, as well as the variety of consumer preferences or needs of citizens, are overlooked. By defining an average emission goal for each automotive manufacturer it seems that each firm will generate the same average emissions per produced car in the long run. Therefore, the variety of preferences with respect to product characteristics (such as speed, size or functionality) will be distorted and consumer sovereignty does not play a major role anymore. As emissions are linked to the utilization of the product (e.g. measured in km per year), it cannot be said that a car which generates high emissions per definition also does so in reality.[7] The preferences with regard to a passenger car may differ for a family and a single member household. As a result, higher costs are imposed on social groups which

[5] The United Nations Commission on Sustainable Development has defined sustainable development in its Brundtland report as a “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Hauff, 1987, p. 46).

[6] A short overview is given by (Macintosh, 2010) and Nicoll et al. (2010).

[7] It might be that so-called “sports cars” are only driven on Sundays and therefore the burden they will impose on the environment is rather low compared to small cars which are used every day for a distance which could easily be covered by public transport.

might not have been the initial target group of the resulting cost increases.[8] Based on the main criticism of the first directive from the Commission, we derive the first criterion that should be fulfilled:

CRITERION 1 High degree of consumer sovereignty under the condition that the externality will be internalized.[9]

The second point is related to competition between automobile manufacturers. As stated above, specialization patterns are desirable from an economic perspective. The actual proposal coming from the commission carries the potential threat that automotive manufacturers which specialize in higher class or more expensive cars have disadvantages compared to those automotive manufacturers that produce a greater variety of automobiles. Mergers between automotive producers seem to be likely, forcing even more concentration on the market for passenger cars. It is also possible that car producers enter into different manufacturing segments or areas(e. g. producers of big cars offer also small cars) which will increase competition within the segments of cars. Nevertheless, there is also the risk that such a development leads to disinvestment, in the sense that investment in a market entry strategy for new types of passenger cars could have been better invested in new technologies reducing CO_2 emissions. Hence, the second condition considers competition and different specialization patterns explicitly:

CRITERION 2a Minimization of distortions with respect to competition at the European level.

Even though it is possible to develop a concept for regulation in a way that the distortions in competition at the EU level are minimized, it is likely that such a reform goes hand in hand with entry barriers for potential foreign competitors. Due to the export orientation of European automobile manufacturers, lobbying in favor of entry barriers is not very likely in the short run. However, the question is whether the regulation will increase international demand for cars produced in Europe or whether it reduces comparative advantages. If the former is the case, regulation increases competitiveness of European car producers. If the latter is the case, then with respect to the loss of international market shares entry barriers become likely. Therefore the third criterion is

[8]Of course, this will enter the political debate afterwards, such that the state has to think about compensation of social groups. Anyway, it seems clear that the initial idea of regulating passenger cars will require further state intervention.

[9]Vanberg (2000), p. 89: "Consumer sovereignty means that the economic process should be organized-or be framed by rules-in such a way that producers are made most responsive to consumer wants. In other words, consumer sovereignty describes the ideal of an economic process in which consumer wants are the principal controlling variable".

defined as follows:

CRITERION 2b Minimization of distortions with respect to competition at the international level.

The criteria are a first step in constructing a theory of what should be done to reduce CO_2 emissions generated by private transport. So far, nothing has been said on the implementation of policy measures. The European Commission has focused on the supply side. Nevertheless, an alternative would be to implement policy measures on the demand side. What follows is a positive analysis of market structures in order to evaluate policy measures with regard to demand or supply sides from a normative perspective.

7.4 Supply and Demand Patterns in the Automotive Industry

This section puts the European automotive industry into perspective. The first part sheds some light on the supply side, while the second part concentrates on automotive demand in the home market. Consumer preferences play an important role in the international market for automobiles. One of the major challenges for automobile manufacturers is the rising importance of environmental issues, as set out by the Kyoto-Protocol, which will be considered in the chapter as well.

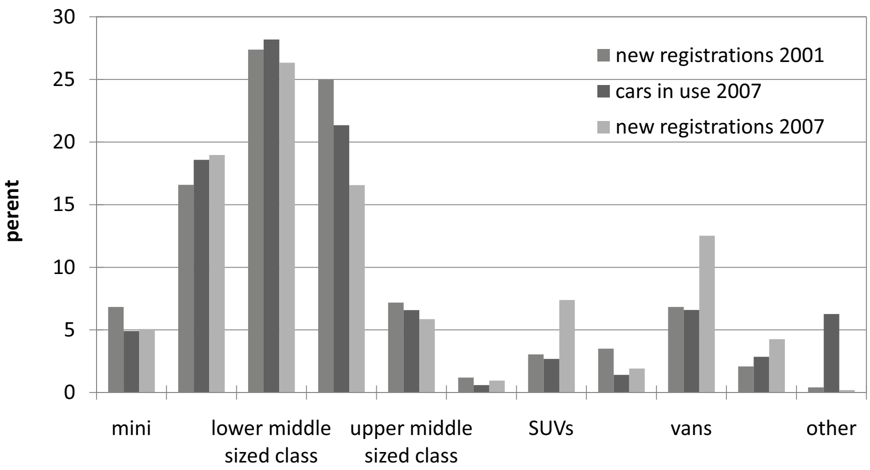
7.4.1 Automotive Supply and Demand

Automobile production is highly concentrated in the EU-15. Germany alone accounts for nearly half of total value-added production COM (2004).[10] Many studies conclude that European enlargement has been beneficial to the automotive industry (Radosevic and Rozeik, 2005; COM, 2004). One third of world production of passenger cars is located in Europe, and Germany alone accounts for one third of the European automotive production (VDA 2008). Due to high export activities, automotive producers face a variety of consumer preferences in different countries. The trade structure of important European automotive producing countries (Germany, England, Italy, France and Spain) is shown in table E.1 (App. E, p. 216). The majority of automotive trade occurs within the European Union, intra EU-25 trade accounts for around 70 percent on average. According to Heitger et al. (1999), the Grubel-Lloyd-Indicator, measuring the share of intra-industry trade in total trade, was around 80 for German bilateral automotive

[10] According to the data of the German Federal Statistical Office, from 2007, the manufacturing of transport equipment contributes about 17 percent to total manufacturing employment as well as to value-added production in 2006 (Destatis, 2007a,b).

trade with France, Italy and the United Kingdom in the year 1996.[11] Thus, consumer preferences and economies of scale and scope explain the specialization pattern of the European automotive industry, as trade in differentiated (automotive) products occurs (in terms of quality). Based on the "love of variety" approach, consumer preferences play an important role in the automotive market when exporting differentiated products to international markets.[12]

FIGURE 7.1: Registration of passenger cars vs. cars in use in Germany



Quelle: KBA (2008c,a).

In Germany, nearly 70 per cent of cars registered since 1990 have been those classified as compact cars and (lower-middle and) middle-sized cars (figure 7.1). While demand for mini cars has declined, sports utility vehicles (SUVs) and vans gained market share in new registrations in 2007. However, comparing the structure of the registered car fleet over time may be more valuable in terms of assessing fundamental changes in demand. In 2007, demand for compact cars (in terms of new registrations) increased in terms of market share compared to the car fleet as a whole (figure 7.1). In contrast, registration of passenger cars in the middle-sized car segment declined. Rather, there has been a shift in demand for passenger cars from the middle-sized type to passenger cars of the compact-type on the one hand, and vans and SUVs on the other hand. This change in

[11]See Grubel and Lloyd (1975) and Fontagné and Freudenberg (1997) for methodological issues on intra-industry trade.

[12]See Dixit and Stiglitz (1977), Krugman (1979, 1980) and Dixit and Norman (1980).

automotive demand has important implications for the overall CO_2-emission level of the car fleet on European markets.

7.4.2 Environmental Perspective

The transport sector, electricity generation notwithstanding, is one of the largest sources of greenhouse gas emission in Europe. In 2005, it was responsible for about 20 percent of CO_2-emission in the European Union (EEA, 2004, p. 64). Moreover, the use of passenger cars accounts for about 12 percent of overall European CO_2-emission (COM, 2007c, p. 2). Road traffic is one of the few sectors in which emissions have increased (26 percent from 1990 to 2005) (EEA, 2004, p. 65), despite the fact that emissions from the average new car sold on the EU-15 Market in 2004 were 163$g\ CO_2/km$, 12.4 percent below the 1995 starting point of 186$g\ CO_2/km$ (COM, 2007c, p. 7). The proposed directive by the Commission has been more or less motivated by the failure to achieve an average CO_2-emission level of 140$g\ CO_2/km$ by 2008, based on a voluntary commitment of the European Automobile Manufacturers Association.

By looking at table E.2 (App. E, p. 217) it can be seen that German brands have an above average market share in nearly all passenger car segments, except the mini-, compact- and mini-van segments, where German brands account for around 40 percent on average. These segments reveal a relatively higher consumer demand for French, Italian and Japanese brands of passenger cars compared to other passenger car segments. In contrast, the middle-sized-, upper-middle-sized-, premium- and roadster segments, which are dominated by German brands, have the highest CO_2-emission on average (middle-sized, 174.9$g\ CO_2/km$; upper-middle, 201.0$g\ CO_2/km$; premium, 250.4$g\ CO_2/km$; roadster, 232.5$g\ CO_2/km$) . Cars in these segments have a relatively low share of total passenger registration (except the middle-sized passenger car segment with 17 percent). According to the first part of table E.2, it is interesting to note that German brands perform on average better in terms of CO_2-emission levels within segments (lower-middle, 155.4$g\ CO_2/km$; upper-middle, 199.4$g\ CO_2/km$; premium-vans, 172.5$g\ CO_2/km$; and roadster, 224.2$g\ CO_2/km$) in which they are specialized (in terms of relatively high market share) compared to their foreign counterparts which is an indication of technological advantage.[13]

Despite the fact that Japanese brands are demanded in all segments to a greater (mini, mini-van and SUVs) or lesser extent (lower- and upper-middle-sized cars), in segments with a relatively low average CO_2-emission level (mini-class, 124.8$g\ CO_2/km$; and compact-class, 143.7$g\ CO_2/km$) Japanese brands perform still better (mini-class, 109$g\ CO_2/km$; compact-class, 134.4$g\ CO_2/km$) than the European brands, respectively

[13] These segments account for around 40 percent of total passenger car registrations in 2007.

(mini-class: 125.7$g\ CO_2/km$, compact-class: 144.3$g\ CO_2/km$) (last part of table E.2).[14] As a result, German brands compete in markets where Japanese brands are less competitive and vice versa.

The change in automotive demand shown by figure 7.1 will be affected by the CO_2-emission level set by the Commission as it plays an increasing role in the consumer's choice of passenger car type. If smaller passenger cars are demanded by an increasing share of consumers, this will have an impact on the specialization pattern of automotive manufacturers. While French, Italian and Japanese automotive manufacturers are mainly present in the smaller car segments, German manufacturers are more specialized in production of cars in the higher classes.

According to the limit-value-curve proposed by the Commission, manufacturers that specialize in car segments with higher emissions on average have to achieve higher percentage reductions in CO_2-emissions relative to the weight of the car, compared to manufacturers of lighter vehicles. It is also proposed by the Commission that penalty payments result for each gram of CO_2 exceeding the required average level of the car fleet. Frondel et al. (2008) state that the abatement cost that emerge from the penalty structure shown in section 7.2 are substantial. They calculated CO_2 abatement costs of about €200 per ton in the case that the automobile is driven $100,000$ kilometers. As a benchmark, Böhringer and Löschel (2002) estimated average abatement costs within the ETS of about €30 per ton CO_2.[15]

It seems reasonable to assume that the per kilometer CO_2 emission limit will have effects on the differentiated market segments of the automobile industry in such a way that the competitive position of manufacturers will change relative to the current situation. While the penalty payments are inducements to make technological innovations to further reduce CO_2 emissions from passenger cars, it seems questionable whether the incentives will be directed into the right areas. As shown by the analysis in table E.2, German automotive manufacturers are among the best performing brands in terms of CO_2 emission in the particular passenger car segments (within those segments emissions on average are higher compared to other segments). Due to the specialization pattern it is not surprising that the German automotive industry lobbies against the Commission's proposal. In order to internalize the externality, alternative policy options exist and will be discussed in the next section. As it is of considerable interest to explain why the Commission proposal is directed at regulating the automotive industry, political instruments will be evaluated based on the minimum criteria mentioned in the last section.

[14]Passenger car segments in which there is less demand for German brands (mini, compact and SUVs) account for around 30 percent of total passenger car registration in 2007.

[15]This comparison is somewhere misleading as Frondel et al. (2008b) used an example of an automotive producer rather than calculating the average abatement cost for the automotive industry as a whole.

7.5 Search for an Optimal Political Instrument

This section aims to show an upcoming conflict when economic policy is used to tackle environmental problems.[16] The reason for this can be found in the lack of political consistency. We start with a description of policy instruments which we consider to have the potential to solve the environmental problems related to emission reduction in private transport. Previous results have shown that the automotive industry is important from an industrial perspective and therefore has considerable lobbying power. Different aspects related to this are discussed from a closed economy perspective. We extend this discussion to include international considerations. We then bring the different aspects together and come up with policy recommendations at the end of the section.

7.5.1 Environmental Instruments

Three different policy instruments will be discussed: emission trading with certificates, the Pigouvian tax and negative rules. We restrict our discussion to these three instruments as other political instruments do not seem to be helpful to internalize the CO_2 emissions generated by private transport.[17] Regulation in the form of command and control policy, as in the Commission's proposal, is considered to be inferior compared to market-based policies (cf. Buchanan and Tullock, 1975).

One classic approach to externalities is the so-called Pigouvian tax (Pigou, 1920, pp. 129). Pigou's idea was to tax negative externalities and subsidize positive externalities.[18] Of course from a static perspective and under the assumption of complete information, a Pareto efficient result is possible. One major criticism of this approach is that the optimal tax is not known. Even though the Pigouvian tax has limitations, it is, nevertheless, in many cases considered to be an effective market-based instrument.

[16] One of the first contributions which shows the weak performance of such an approach comes from Kydland and Prescott (1977).

[17] Beside the instruments proposed above, subsidies still remain an alternative, but will not be further discussed, because they are not relevant for emission reduction in private transport. Accountability for the social damage, as per the constitutional principles of Eucken (1955), is also an alternative which seems not to be very convincing if it is to be implemented at the international level. Praxis has shown that use of moral suasion to address the problem in question does not lead to the desired outcome, from the perspective of the EU. Ecologic labeling is also an alternative which seems to be promising for the internalization of externalities but does not seem to be helpful in the case of the automotive industry. From an international perspective this alternative can also be abused with regard to protectionism (Gerken and Renner, 1996, pp. 83).

[18] Coase (1960) criticized Pigou's approach (1924) using an example of environmental damage caused by railways. Coase gives an example what kind of policy implementation would result from using the Pigouvian approach, which he criticizes in the following sentence: "[...] Pigou does not seem to have noticed that his analysis is dealing with an entirely different question. The analysis as such is correct. But it is quite illegitimate for Pigou to draw the particular conclusions he does. The question at issue is not whether it is desirable to run an additional train or a faster train or to install smoke-preventing devices; the question at issue is whether it is desirable to have a system in which the railway has to compensate those who suffer damage from the fires which it causes or one in which the railway does not have to compensate them" (Coase, 1960, p. 141).

With some slight modifications it is also an applicable model (Baumol and Oates, 1971). Criticism of the approach came from, among others, Coase (1960).

Coase (1960) demonstrates that private negotiations under the assumption that transaction costs are neglectable and property rights are adequately defined, will lead to a Pareto optimal outcome. According to Coase (1960), two major problems lead to market failure: inadequately defined property rights and the existence of transaction costs. One lesson to be drawn for political intervention is the need to create markets by defining property rights and, additionally, providing an infrastructure that reduces transaction costs.

The third alternative instrument proposed to internalise the externality comes from Hayek (1978). Property rights should be defined in such a way that the owner of the right is allowed to do whatever he wants with his own property as long as there is no interference with the protected sphere of the non-owners. The type of rules Hayek (1978) proposes to tackle such problems are negative rules. The evolutionary approach on the selection of rules and the constitutional order has the advantage that it leaves enough room for private decisions and space for autonomous innovative creativity of firms. It is the consumer's decision whether a product (or technique) is acceptable or not.

The limitations of this approach are as follows: a framework which is based on negative rules needs to be stable, problems occur in those cases where rules have to be adjusted to the actual changing knowledge (Wegner, 1998, p. 221). Thus, we think that negative rules are not the optimal instrument to reduce CO_2 emissions generated by private transport. Certificates are also not without problems. For trade with certificates, the overall quantity or volume of the tradable certificates has to be defined. It can be seen as an advantage that this instrument is flexible in the way it can be adjusted quickly to the actual knowledge; nevertheless it is also likely that the overall quantity of certificates might be too big or too small with respect to an optimum. To summarize, we consider the definition of property rights and trade with certificates to be a first best solution to our problem. The Pigouvian tax is a kind of second best solution. Hayeks approach does not seem to be the optimal one for addressing the problem of CO_2 emissions generated by private transport.

7.5.2 Political Economy Perspective

The previous discussion has highlighted the pros and cons of environmental instruments. The European Commission opts for regulating the supply side. The interaction between state activities, on the one hand, and private markets, on the other, is a critical issue and may impose additional problems. In the case of Europe, decisions on environmental regulation by the European Council are made with a qualified majority vote. The sustainability approach serves as a key to initiate regulations at national levels. In cases where regulations are poorly defined, they can conflict with the liberal market order. Due to a lack of knowledge, policy measures originally intended to increase welfare may rather lead to an overall decline in welfare. This threat seems to be present in the regulation on the automotive industry.

We give emphasis on this argument by constructing a kind of "worst case scenario" using basic political economy arguments. A developed directive which aims to tackle a specific problem is the starting point. Sustainability is the only normative criterion which is applied. A decision on the topic in question is made by a simple majority vote. As the burdens of the regulative intervention will be regionally clustered, the industry in question starts with lobbying activities. If they are successful, governments will start to cooperate with the industry to reduce the burdens of the directive coming from the EU. In turn, policy can enter a kind of intervention process Mises (1929).[19]

Interaction between state and industry may increase and the regulation, which was initially intended to generate structural change towards an environmental friendly technology, may be a hinderance as the process of creative destruction described by Schumpeter (1987b,a)[20] is not driven by market forces (Wegner, 1998, p. 225). The major costs imposed on citizens can be summarized as follows: (i) higher consumption costs, (ii) costs for the adjustment of production processes, (iii) costs of lobbying activities,[21] (iv) an additional loss of consumer sovereignty, (v) additional costs due to distortions, and (vi) costs if a conflict with open market access occurs.

It is clear that the benefits with respect to climate protection remain an asset. On the other hand, the benefit of regional protection is also highly questionable, because European policy cannot tackle the problem of climate change alone, it being a global problem. Of course these arguments cannot be taken as an excuse for doing nothing about climate change, but the example shows how necessary it is to follow a clear, defined rule-based approach which puts enough emphasis on the protection and functioning of the market. Looking at the topic from an international perspective supports an even more skeptical view.

7.5.3 International Political Economy Perspective

With respect to climate change, it is important to mention relevant issues related to international markets and prices. If reduced demand for fossil fuels, as a result of energy

[19]Due to the local concentration of certain industries and the incentive for politicians to maximize votes Schumpeter (1987a) the political power of industries is at least explained in certain regions. Additionally, due to the regulation, it is also possible that the devaluation of private capital will increase capital costs for the automotive industry. As a result, necessary investments into future technologies will not be undertaken

[20]Creative destruction means that the dynamics of a market order will always generate winners and losers. Due to technological innovations which destroy or displace old ways, new opportunities arise such that creative destruction can be seen as one of the major driving forces behind growth leading to an increase in welfare.

[21]For a discussion about the costs of lobbying see Krueger (1974).

efficiency improvements, also decreased international prices, the positive impact of the EU on the world climate would be redundant if total demand remained constant Sinn (2008).[22] Further it has to be taken into account that an increase of wealth in other countries would raise automotive demand and consumption of petrol even further. Beside this criticism, it is unclear whether the so-called "rebound effect" is so strong that European policy will be without any positive global impact. Due to increasing demand for fossil fuels, industries have to adapt to changing consumption patterns anyway. Further, it has been stated that the high carbon tax in Germany is one of the main reason why German technology with respect to car production is relatively more efficient (according to table E.2) than in countries with lower carbon taxes (Kunert et al., 2002, p. 440). This shows that demand has some effects on supply of a product and positive spillovers can be assumed when the technology is exported (compare also Freytag and Wangler, 2008). Therefore, if policy instruments are applied appropriately, welfare gains can be expected. In contrast to this, if European standards are wrongly designed and go hand in hand with decreasing comparative advantages of the automotive industry, then it becomes likely that European car producers lobby in favor of import barriers. The "voluntary" commitments of JAMA and KAMA to agree on Europeans regulation can also be interpreted as meaning the fear of losing market access is present. But then, what is the consequence of the directive for car producers outside Japan and Korea? It seems that not fulfilling the requirements very likely has the potential for a response with import restrictions (e.g. for car producers in emerging economies).

The results which can be derived so far can be summarized as follows. Taking the global nature of climate change into account, more emphasis on global policy coordination seems to be desirable. If international cooperation fails, it is difficult to determine the net impact of policy measures intended to have a global impact. The resulting partial equilibrium may set wrong incentives at the global level and the resulting general equilibrium might differ. In the worst case, the investment will yield low positive spillovers and there is a risk that high standards at the European level will be used to implement import barriers on car producers outside of Europe.

7.5.4 Competition, Consumer Sovereignty and Policy Measures

For the following discussion two different approaches have to be distinguished: market-based approaches applied on the supply side and internalization of the externality through market-based approaches applied on the demand side. So far, these two approaches seem to be the most satisfactory in reducing CO_2 emissions by passenger cars. If the question is whether the policy instruments should be applied on the supply side

[22]Of course, this view is far too easy because there is no evidence to assume that the so-called "rebound effect" will be translated 1:1 to a price decrease.

or on the demand side, we opt in favor of a demand side approach.[23] Regulation seems to be inferior to market-based approaches and therefore non-optimal for CO_2 emissions reduction in passenger cars. What has to be kept in mind is that in the case of non-market-based approaches like regulations, a qualified majority is the voting standard in the European Council. For market-based approaches such as taxes, the unanimity rule is applied.[24] This leads us to derive the first result:

RESULT 1 In cases where different useful instruments are available to reach the same target; application of the same voting rule would reduce distortions.

We justify this result because of the political economy considerations.[25] Industrial regulations are a sensible topic but in the case of CO_2 emissions generated by passenger cars may be problematic. To underline our arguments we rank the policy measures from first best to fourth best. A ranking of the four alternatives based on the previous discussion and our two criteria looks as follows:

- First best (demand side (a)): Tradable certificates,
- Second best (demand side (b)): Pigouvian tax,
- Third best (supply side (aa)): Segment specific emission targets (small, medium, big) implemented by using tradable certificates,[26]
- Fourth best (supply side (ab)): Segment specific emission targets (small, medium, big) implemented by using penalty payments,
- Fifth best (supply side (ba)): Same emission targets on all automobile manufacturers implemented by using tradable certificates,
- Sixth best (supply side (bb)): Same emission targets on all automobile manufacturers implemented by using penalty payments.

The directive coming from the European commission might result in a different, less efficient order. We hypothesize that this inefficient result would be due to the two different voting mechanisms. The different voting rules for taxes and regulations might generate a kind of bias in favour of non-market-based instruments. The distinction

[23]The main argument is that a demand side approach leaves the decision on adequate technology to the automotive industry.

[24]For a more detailed discussion on the features of the majority rule and unanimity rule see Buchanan and Tullock (1962).

[25]Because consumers have to bear the costs of the externality anyway a tax would be transparent and the state as such would be safe from lobbying activities by the automotive industry.

[26]We think that segment specific regulations would lead to less distortion related to different specialization patterns of automotive manufacturers.

between the first best and second best options can be questioned. Even though, theoretically, emission trading with certificates is considered as first best, it does not seem too unrealistic that it is possible to calculate the externality which results from each liter of fossil fuels consumed (compare also Baumol and Oates, 1971). For the problem at hand it might be that the definition of property rights and the installation of a tradable certificate system makes implementation difficult and that the tax solution has some advantages (with respect to effectiveness and applicability) (Raux and Marlot, 2005). This leads to the second result of the chapter:

RESULT 2 Market-based instruments (taxes or certificates) are adequate in the case that private mobility shall contribute to CO_2 emission reduction.[27]

The instruments we propose seem to be the best to cope with emissions generated by private transport and come close to the criteria we have defined:

1. High degree of consumer sovereignty under the condition that the externality will be internalized,
2. Minimization of distortions with respect to competition at the European level,
3. Minimization of distortions with respect to competition at the international level.

It is difficult to take for granted that the best result will also turn out to be the best alternative for the European Commission, if the same voting rule were to be applied for regulations and taxes. Under the Treaty of Lisbon it is foreseen that in 2014 a double majority will be needed for most of the decision.[28] However, even though one can expect less discrimination between regulation and market-based instruments, the political process tends to favor regulation over market-based instruments, in general (Kirchgässner and Schneider, 2003). One possibility could be that the Commission buys accord from the automobile industry by offering additional rents (cf. FAZ, 2008). Nevertheless, it will be more difficult to impose regulations if other options have to be taken more seriously, and it becomes more difficult to use regulation as an instrument to intervene in private markets if their only justification is that they are "easier" to install. Without rules on limiting the regulative power of the European Union, the initial notion of a "strong state" at the national level (Eucken, 1955) may be undermined by arguing for a sustainability approach. Obviously, this is not optimal and in some cases it may even be problematic.

[27]If a carbon tax was implemented then it is likely that the price level will not be set at the optimal stage. Nevertheless, our proposition is that in comparing the supply and demand side approach, the demand side approach is superior. On the demand side, because all citizens using and owning a car would be affected, the transaction costs argument is convincing, and in favour of a carbon tax.

[28]Double majority means that 55 percent of the member states have to agree upon the issue, and those states in agreement have to represents at least 65 percent of all people within the European Union.

7.6 Conclusion

This study focuses on the European Commission's proposal to reduce CO_2 emissions from passenger cars by finding an optimal policy instrument to internalize an externality. While automotive demand shifts to smaller passenger car segments under the proposal, to a relatively high extent, the study also looks at specialization patterns of automotive manufacturers. It turns out that different specialization patterns exist. The Commission's proposal for regulation can lead to market distortions in competition. One further finding is that sustainability is a quite powerful normative criterion if it is applied by policy-makers to justify political intervention in market processes. We try to show that the political process violates the basic principles of consumer sovereignty and competition. We have focused on those points where we think there is a weak link and therefore potential threat to the functioning of competitive private markets. We have highlighted potential problems related to different voting rules applied in the cases of regulation and taxation aimed at internalizing externalities. While a qualified majority applies in the case of environmental regulations, regulation of the industry can be applied on lower decision making costs than this would be the case for market-based instruments. This approach can be criticized, because in the medium and long term regulation carries the potential threat of further state interventions and further inefficiencies.

Chapter 8

Summary and Final Conclusions

This thesis is devoted to the “Political Economy of Climate Policy”. Its aim is to deepen the understanding of interest groups and their influence on public economic decision-making in the context of climate change policy. The topic, as such, is broad. In order to gain some insights it was necessary to approach the research question using different methods, such as econometrics, laboratory experiments and theoretical modeling.

The different topics are more or less related to each other. They can be grouped into three main subject areas: structural change in the energy sector (chapter 2-4), policy coordination (chapter 4-6) and industry regulation (chapter 7). Chapter 4 relates structural change in the energy sector to international policy coordination. In the following the chapter results are discussed and some final conclusions are drawn.

8.1 Structural Change in the Energy Sector

In chapter 2 we were able to show that diffusion of green technologies, even though inefficient, was able to achieve some pre-defined political targets. The instrument used to foster diffusion of green technologies (GTs) is a form of command and control policy. However, industries producing GTs seem to compete with each other and also face international competition. From this point of view, there are incentives to be innovative (as shown in chapter 3) and the prices for the technology can be expected to reflect somehow the related production costs. It seems that producers of green electricity gain most from the steady feed-in tariffs as price reductions in GTs increase the related revenues to green electricity production.

From an economic point of view structural change in the energy sector towards climate friendly technologies is confronted with two major problems. First, from the perspective of welfare economics (in case of a closed economy), diffusion of GTs is related to losses in gross domestic product (GDP). Second, inefficiencies are supposed to be high as feed-in tariffs are relatively stable and diffusion of GTs does not focus on the cheapest GT available.

The first criticism can be countered with the argument that there is a need for carbon dioxide (CO_2) neutral backstop technologies (also in developing countries). This requires a transition in the energy system which can be fostered by policy-makers. Other energy technologies generate long lasting externalities which are not integrated into energy prices. Green technologies might become substitutes in the near future what somehow justifies policies aimed to foster diffusion of GTs. However, the question about the optimal "transition path" is difficult to answer. Based on the current information, it would be optimal to raise standards for conventional energy technologies to a level that requires the internalizing of all the related externalities. This would require a more strict application of the emission trading scheme. Additionally, market access for GTs has to carry a guaranteed remuneration that is calculated on the basis of electricity prices and the related positive externalities. This can be seen as a first best solution. For a more precise answer additional insights are needed.

The second point is not so difficult to evaluate. The proposition can be labeled as second best. If it is the aim to foster diffusion of GTs, then it seems convincing to invest in the cheapest alternatives available. However, this argument might overlook positive externalities (like the creation of knowledge) that are related to certain technologies. This has to be taken into account. The theory of transition management underlines the need for a certain technology base to facilitate structural change. From this point of view, in early stages of structural change it seems to be important to establish different technologies to reduce the risk of technological lock-in. This, of course, can theoretically be done by establishing different feed-in tariffs. Nevertheless, at a certain stage, it is important to invest in those technologies which are able to produce green electricity at the lowest price. The target to produce about 30 percent of electricity with GTs by 2020 seems to require a reform of the related feed-in system. In this context, it is important to keep in mind that as long as there is competition among GT industries one can expect efficient prices related to the supply of GTs. Hence, any reform has to focus on the demand side (the producers of green electricity).

One possible way to increase efficiency is to switch from (pure) command and control to a charges and standards approach (Baumol and Oates, 1971, 1988) without pre-selecting different GTs. It would be sufficient to define a standard (e.g. 15 percent of electricity produced with GTs in 2012) and regulate this standard over one single feed-in tariff. The overall price (in this case the single feed-in tariff) that has to be paid depends on the pre-defined diffusion path. If the growth rate of GTs is too low to reach the pre-defined standard within the pre-defined time, the feed-in tariff has to be increased.[1] If diffusion is at a level that is too high, the feed-in tariff has to be reduced. Other

[1]Nevertheless, the feed-in tariff for the contracts signed at the given point in time have to be kept stable for a pre-defined period (e.g. 10 or 15 years).

approaches (like the application of tradable certificates) are also promising, but would require more fundamental reforms.

However, such reform would reduce demand for particular GTs. One lesson that can be drawn from the previous chapters is that technology specific interest groups try to prevent any reform that is against their economic interests. This makes policy reforms difficult. Without reforms the technology specific rents can also be expected to increase which might consolidate technological lock-in. An early reform is supposed to face lower opposition from interest groups. Focusing on the regulation of the feed-in tariff (what determines the diffusion level of GTs) has the major advantage that efficiency increases and decision makers become more independent of industry specific interests.

8.2 Policy Coordination

In chapter 4 diffusion of GTs in Germany is related to international policy coordination. One important aspect resulting from the analysis is that structural change at the national level may also positively affect climate change policy at international levels. One interesting finding is that the free-riding positions of some countries (regarding investment in backstop technologies) might increase the incentives for other countries to invest even more into diffusion of GTs. This contradicts the general wisdom that the free-riding positions of some countries always reduces incentives to invest in global public goods. The country specific interest in high emission reduction targets might even have a positive impact on the efficiency of future international environmental agreements (IEAs). The long-term time horizon, in combination with external constraints (in the form of IEAs), might further increase the pressure on previous free-riding countries to implement high environmental standards of their own.

Chapter 5 looks at the impact of policy coordination over time. One of the findings is that milestones (as a proxy for an IEA) may be helpful in approaching long-term targets. This is especially the case if investment in the public good does not generate additional payoffs. However, if public good contributions positively affect payoffs, milestones are not efficiency enhancing. One example could be the investment in geo-engineering, as described in the introductory chapter 1. In this case policy coordination aimed at fostering investment in knowledge creation seems to be redundant. This is in line with game theory predictions (Schelling, 1996).

The impact of minimum participation rules on stabilizing IEAs is examined in Chapter 6, it already having been pointed out in Chapter 4 that minimum participation rules (MPRs) have the advantage that IEAs can be established even though some countries free-ride on the agreement. Also, in the case of heterogeneous countries, welfare is maximized when the MPR requires participation of all countries. However, as the decision on the MPR is endogenized, it turns out that the participation of all countries is not necessary for there to be an equilibrium. Another result is that being the agenda-setter allows a country to be non-pivotal with regard to the agreement, which positively affects negotiating power.

The chapters discussing climate change from an international perspective emphasize the importance of IEAs in increasing the efficiency of national climate change policies. Institutions integrated in IEAs can help overcome free-riding problems. However, incentives to free-ride are still high because of missing sanctioning mechanisms. Some propositions point out that trade barriers integrated into IEAs could work as a sanctioning mechanism (e.g. Barrett, 1997). There are substantial concerns with such an approach. Some arguments are discussed in Barrett (2009). The research in the field of "International Political Economy" highlights further problems related to trade sanctions (for an overview see Helpman, 1997; Gawande and Krishna, 2003). Chapter 4 was able to show that free-riding may become beneficial for non-free-riding countries. One necessary condition is that non-free-riding countries can rely on liberalized markets. The result from chapter 4 and 6 raise hope that an IEA can be effective even without application of an international sanctioning mechanism. However, the results from chapter 5 imply punishment. This seems to indicate that punishment is important. There is further the result that an efficient IEA requires the cooperation of (almost) all countries. More research is needed to come to a better understanding of the role that institutions can play in increasing the opportunity costs of free-riding.

8.3 Industry Regulation

In chapter 7 different aspects of industry regulation are considered as part of the analysis. First, the way in which the application of different voting rules for different policy instruments can cause a bias in the choice of the instruments is described. At the European level there is a bias towards command and control policies. This is a result of the fact that the simple majority rule is applied for command and control, whereas the unanimity rule is used for market-based instruments. The second lesson that can be drawn from the discussion in chapter 7 is that policy should favor market-based approaches over command and control in order to be more independent of the pressure of vested interest groups. Command and control policies carry the threat of decreasing the international competitiveness of certain export goods which might then result in demands for protection. This problem can be reduced by using market-based instruments for environmental protection.

8.4 Concluding Remarks

The contribution of this thesis is small compared to the extent of the problem at hand. The related spillover effects requires an approach to the problem from an international perspective. However, implications on the micro level are equally important. The predicted climate problems carry the associated threat of encouraging decision makers to apply discretionary policies with high inefficiencies. Research in the field can help prevent short-term oriented policy reactions. There is the possibility of applying market-based approaches in order to foster structural change. Appropriately designed policy instruments allow for an efficient transition, thus reducing the related costs. The increasing relevance of climate change policy shows the importance of giving adequate advice to policy makers, and of increasing their awareness of the costs related to wrongly designed policies. More research is needed to further understand the “Political Economy of Climate Policy”.

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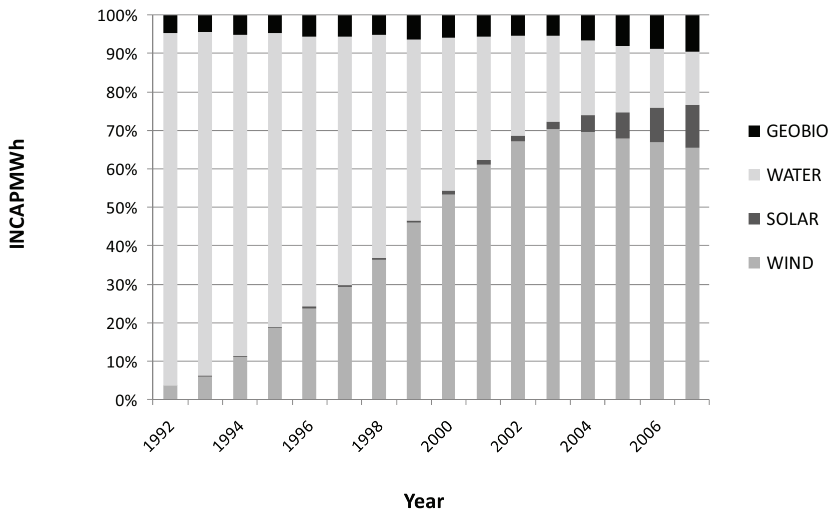
Appendix A.

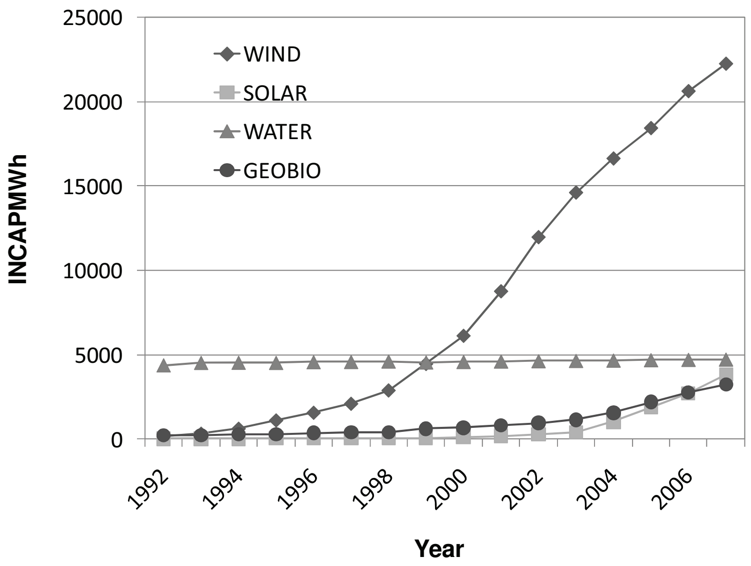
A.1 Diffusion of GTs

FIGURE A.1: Relative diffusion of the different GTs (measured in MW)



Data source BMU (2008).

FIGURE A.2: Diffusion of GTs given by installed capacity (measured in MW)



Data source BMU (2008).

TABLE A.1: Overview of the installed capacity of GTs

Year	WATER MW	WIND MW	SOLAR MW	BIO MW	GEO MW	TOTAL MW
1990	4403	56	2	190	0.0	4651
1991	4403	98	3	190	0.0	4504
1992	4374	167	6	227	0.0	4774
1993	4520	310	9	227	0.0	4839
1994	4529	605	12	276	0.0	5422
1995	4521	1094	16	276	0.0	5631
1996	4563	1547	24	358	0.0	6492
1997	4578	2082	36	400	0.0	7096
1998	4601	2875	45	409	0.0	7930
1999	4547	4444	58	604	0.0	9653
2000	4572	6112	100	664	0.0	11448
2001	4600	8754	178	790	0.0	14322
2002	4620	11965	258	952	0.0	17795
2003	4640	14609	408	1137	0.0	20794
2004	4660	16629	1018	1550	0.2	23857
2005	4680	18428	1881	2192	0.2	27181
2006	4700	20622	2711	2740	0.2	30773
2007	4720	22247	3811	3238	2.4	34018

Source: Data source BMU (2008).

TABLE A.2: Feed-in tariffs for the SEG/EEG

GT j	Size	StrEG 1990-1999[1]	2000	EEG 2002 cents/KWh	2003	EEG Am. 2004E	Annual 2002 ff.	Reduction 2005ff.
	<500 KW			7.67		9.67	0%	
HYDRO	500 KW - 5 MW	6.5		6.65		6.65		1%
	5 - 150 MW	0.0		0.0		3.7-7.67[2]	NA	
Landfill Gas,	< 500 KW	6.5		7.67		7.67-9.67	0%	
Sewage Gas,	500 KW - 5- MW			6.65		6.65-8.65		1.5%
Coal Mine	> 5 MW[8]	0.0		0.0		6.65-8.65	NA	
Methane								
	<150 KW	7.1	10.23	10.1	10.0	11.5-17.5		
BIO	<500 KW					9.9-15.9	1%	1.5%
	< 5MW		9.21	9.1	9.01	8.9-12.9		
	> 5MW	0.0	8.7	8.6	8.51	8.4		
	< 5 MW					15.0		
GEO	< 10 MW	NA		8.95		14.0	0%	1%[3]
	< 20 MW					8.95		
	>20 MW			7.16		7.16		
	< 5 Years		9.1	9.0	8.87	0.0 or 8.7[4]		
WIND	8.2						1.5%	2%
Onshore	> 5 Years		6.19	6.1	6.01	0.0 or 5.5-8.7[4]		
WIND	< 9 Years	NA	9.1	9.0	8.87	9.1[5]	1.5%	2%[7]
offshore	> 9 Years		6.19	6.1	6.01	6.19[6]		
SOLAR	stand-alone	8.2	50.62	48.1	45.7	45.7	5%	5%
	building-integr.					54.0-62.4		

[1] The indicative numbers are based on actual values from 1998.
[2] Applies to refurbishment of already existing hydropower plants dependent on the size.
[3] Degression starts in 2010.
[4] For projects on poor wind sites (< 60% of average wind resource), no compensation will be payed.
[5] Will be applied for 12 years on offshore projects commissioned prior 2010.
[6] Applies on other offshore projects than in [5].
[7] Degression is starting in 2008.
[8] Is only for coal-bed methane.
Own illustration following (Wüstenhagen and Bilharz, 2006, p. 1686).

A.2 Theoretical Model (Complete Competition)

There is still the assumption that demand is supported by monetary transfers from the government and therefore total demand for GTs is given by

$$p_j - pid_j = 1 - Q_j, \quad (A.1)$$
$$= 1 + pid_j - Q_j. \quad (A.2)$$

Residual demand is given by

$$p_j = 1 + pid_j - (N-1)q_j - q_j. \quad (A.3)$$

Firms maximize profits at $p_j = MC_j$ with

$$c_j = [1 + pid_j - (N-1)q_j] - q_j. \quad (A.4)$$

Taking (A.4) into account the quantity of output produced by one single firm is given by

$$q_j^c = \frac{1 - c_j + pid_j}{(N)}. \tag{A.5}$$

Multiplying q_j with N leads to the total output (Q_j^*) which is

$$Q_j^c = (1 - c_j + pid_j). \tag{A.6}$$

Using (A.6) for the market demand gives p^* which is

$$p_j^c = c_j, \tag{A.7}$$

and profit π_j^c is equal to zero (the notation ^{c} stands for equilibrium under competition).

Governments

TPI transfers

TPI transfers lead to the optimal outcome without any state failure. It is assumed that welfare W (compare equation A.8) generated by the GT industry j comes from the GEP surplus ($GEP_j = 1/2 * Q_j^c * (1 + pid_j - p_j^c)$) minus the support plus the positive effect (b_j) expected from GTs times Q_j^c. The optimal solution can be found by choosing the support pid_j able to maximize welfare. This leads to an optimal support pid_j^c and an optimal welfare level W_j^c. It follows

$$\max_{pid_j} \qquad W_j(pid_j) = GEP_j - (pid_j - b_j)Q_j^c. \tag{A.8}$$

The partial derivative from (A.8) with respect to pid_j leads to

$$\frac{\partial W_j}{\partial pid_j} = b_j - pid_j. \tag{A.9}$$

Therefore, the optimal support pid_j^c is given by the solution for the first order condition which is given by

$$pid_j^{c\_TPI} = b_j. \tag{A.10}$$

Substituting $pid\_j^{c_TPI}$ into the equations for price and total output, the corresponding welfare level can be calculated. This leads to

$$p_j^{c\_TPI} = c_j \tag{A.11}$$

$$Q_j^{c\_TPI} = 1 - c_j + b_j \tag{A.12}$$

$$W_j^{c\_TPI} = \frac{1}{2}(1 - c_j + b_j)^2. \tag{A.13}$$

ETR transfers

Political support for the GT industry j (V_j) comes from *three different sources*: First, as the output coming from the GT sector increases, jobs are created which also leads to greater support for the incumbent government. Second, electricity prices (as a function of pid_jQ_j) enter negatively into the political support function. Third, GEPs which install

GTs or buy assets on GTs are aware of the $FITs$ that are positively related to pid_j. If pid_j increases political support also increases.

This allows us to model the welfare of the incumbent government by G.

$$\begin{aligned}\max_{pid_j} G^c(pid_j) &= \alpha W_j^c(pid_j) + (1-\alpha)V_j^c \\ &= \alpha W_j^c(pid_j) + (1-\alpha)[Q^c - \\ &\quad pid_j Q^c + pid_j(FIT_j)]\end{aligned} \tag{A.14}$$

with $0 < \alpha \leq 1$. Maximizing equation A.14 relative to pid_j leads to

$$pid_j^{c\_ETR} = \frac{-\alpha b_j + (\alpha-1)c_j + (\alpha-1)}{(\alpha-2)}, \tag{A.15}$$

with the result that

$$pid_j^{c\_TPI} - pid_j^{c\_ETR} = \frac{(\alpha-1)(2b_j - 1 - c_j)}{(\alpha-2)}. \tag{A.16}$$

Compared to the equilibrium which arises under Cournot competition, the number of firms operating in the market does not play a role anymore. This leads to the result that the optimal support has to be adjusted to the market structure. If there is a change in market structure towards complete competition (e.g. if the learning curve becomes less significant), the optimal pid_j for the GT industry j is given by the positive externality b_j.

Appendix B.

B.1 Empirical Data

Patents (*PAT*) and all patents Germany (*APAT*), source DEPATIS net

Table B.1 contains the list of patent classes from which the patent counts are extracted. The "renewable energy sector-specific technologies" of interest are electricity production with wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO) and biomass (BIO). The original table is from Johnstone et al. (2010).[1] The patent data comes from the German Patent office.[2] The vector of *PAT* contains patents that have been granted in Germany (including the "Neue Bundesländer") using the *date of application*.[3] The data does not contain double counting and only those patents with priority for Germany are taken into account with the intention to exclude foreign inventors. Information captured with *PAT* is on the national level and sector-specific (WIND, SOLAR, WATER, GEO, BIO).
Information captured with *APAT* is also on the national level but is not sector-specific. *APAT* stands for the count of all patents applied for in Germany.

German R&D expenditures(*RuD*), source IEA

The data on sector-specific public expenditures on *R&D* in the different GT industries comes from the International Energy Agency.[4] R&D refers to expenditures of the federal government. The resources can be given to private as well as to public entities. The data is in million Euro on exchange rates from 2006.[5] Information captured with *RuD* is on the national level and is sector-specific (WIND, SOLAR, WATER, GEO, BIO).

German installed capacity of sector-specific technology INCAP, source BUND

INCAP is used as a proxy for the size of the market for different GTs. The data contains

[1] Note that the list is extended with patent classes for WATER as the law for renewable energy which is analyzed for Germany also changed the institutional framework for energy produced with water. On the other hand WASTE is excluded from the list because it is difficult to separate non-renewable waste from renewable waste.

[2] For further information see http://depatisnet.dpma.de/DepatisNet/depatisnet?window=-1&space=menu&content=index&action=recherche&session=c23b66f230d535e054a0e96346f598d6b4b3c-0c1ada0&stamp=34353.

[3] Even though information about patents until 2007 is available, the analysis is restricted to 2005. The information about the last two years is dropped to get rid of the problem that there is a long time lag between the application for a patent and patent granting. Once the patent is granted, the patent protection goes back to the application date. Therefore, it is plausible to assume that the data from 2006 and 2007 contains a lack of information (Popp, 2005b, p. 5).

[4] For further information see http://www.iea.org/.

[5] The data for Germany at the national level does not contain information about the expenditures of regional governments.

information about the installed capacity measured in megawatt-hours (MWh). It measures the overall installed capacity of the sector-specific technology per year. The data comes from the Ministry for the Environment in Germany.[6] Information captured with $INCAP$ is on the national level and is sector-specific (WIND, SOLAR, WATER, GEO, BIO).

Electricity price index ($CPIE$), electricity consumption (ELC), source GSO and IEA

The electricity price index comes from the German Statistical Office. $CPIE$ is inflation corrected and the year 2004 is set to 100. Consumption taxes are not taken into account. Information about ELC comes from the International Energy Agency. ELC is measured in kilowatt hours per capita. Information captured with $CPIE$ and ELC is on the national level and is not sector-specific.

[6]Compare BMU (2007b).

B.2 List of IPC Codes

TABLE B.1: IPC codes for renewable energy technologies*

WIND	Class	Sub-Classes
Wind motors with rotation axis substantially in wind direction	F03D	1/00-06
Wind motors with rotation axis substantially at right angle to wind direction	F03D	3/00-06
Other wind motors	F03D	5/00-06
Controlling wind motors	F03D	7/00-06
Adaptations of wind motors for special use	F03D	9/00-02
Details, component parts, or accessories not provided for in, or of interest, apart from the other groups of this subclass	F03D	11/00-04
Electric propulsion with power supply from force of nature, e.g. sun, wind	B60L	8/00
Effecting propulsion by wind motors driving water-engaging propulsive elements	B63H	13/00
SOLAR		
Devices for producing mechanical power from solar energy	F03G	6/00-08
Use of solar heat, e.g. solar heat collectors	F24J	2/00-54
Machine plant or systems using particular sources of energy - sun	F25B	27/00B
Drying solid materials or objects by processes involving the application of heat by radiation -e.g. sun	F26B	3/28
Semiconductor devices sensitive to infra-red radiation - including a panel or array of photoelectric cells, e.g. solar cells	H01L	31/042
Generators in which light radiation is directly converted into electrical energy	H02N	6/00
Aspects of roofing for the collection of energy - i.e. solar panels	E04D	13/18
Electric propulsion with power supply from forces of nature, e.g. sun, wind	B60L	8/00
WATER/OCEAN		
Engines of impulse type, i.e. turbines with jets of high-velocity liquid impinging on bladed or like rotors, e.g. Pelton wheels	F03B	1/00-04
Machines or engines of reaction type; Parts or details peculiar thereto	F03B	3/00-18
Water wheels	F03B	7/00
Adaptations of machines or engines for special use; Combinations of machines or engines with driving or driven apparatus	F03B	13/00-10
Controlling	F03B	15/00-22
Adaptations of machines or engines for special use; combinations of machines wave or tide energy	F03B	13/12-24
Mechanical-power producing mechanisms - ocean thermal energy conversion	F03G	7/05
Mechanical-power producing mechanisms - using pressure differentials or thermal differences	F03G	7/04
Water wheels	F03B	7/00
GEOTHERMAL		
Other production or use of heat, not derived from combustion - using natural or geothermal heat	F24J	3/00-08
Devices for producing mechanical power from geothermal energy	F03G	4/00-06
Electric motors using thermal effects	H02N	10/00
BIOMASS		
Solid fuels based on materials of non-mineral origin - animal or vegetable	C10L	5/42-44
Engines operating on gaseous fuels from solid fuel - e.g. wood	F02B	43/08
Liquid carbonaceous fuels - organic compounds	C10L	1/14
Anion exchange - use of materials, cellulose or wood	B01J	41/16

*From the original table WASTE has been excluded and WATER has been added.

Own presentation, following Johnstone et al. (2010)

B.3 Further Estimations

TABLE B.2: Estimation result 1c, different Estimation Models with time dummies included

estimation method	**OLS FD** (random effects)	**AR(1) FD** (random effects)	**OLS FD** (random effects)	**AR(1) FD** (random effects)	**AR(1) FD** (fixed effects)	**neg.Bin.** (fixed effects)
Independent Variable	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}	PAT_{t-1}
$INCAP$	0.0071795* (0.0029073)	0.0073236* (0.0030653)	−−	−−	−−	−−
$\Delta INCAP$	−−	−−	0.031745** (0.0087984)	0.0318642** (0.0088353)	0.0288904** (0.0097047)	0.0001964** (0.0000473)
RuD_{t-1}	1.198481** (0.3905481)	1.249239** (0.3896302)	1.152284** (0.3653252)	1.163613** (0.3649809)	1.260779** (0.4376515)	0.0074726* (0.003264)
$CPIE_{t-2}$	−0.1348853 (0.440692)	−0.1289086 (0.4434311)	−0.0893127 (0.4143496)	−0.087851 (0.4144228)	−0.0916542 (0.4400515)	0.0032765 (0.0066363)
ΔELC_{t-2}	−0.0087178 (0.0170297)	−0.0086222 (0.0166748)	−0.0112142 (0.0160142)	−0.0112018 (0.0159367)	−0.010779 (0.0169107)	0.0004999 (0.0003443)
$APAT_{t-2}$	0.0008593 (0.0017597)	0.0008798 (0.0017789)	0.0003491 (0.0016241)	0.0003511 (0.0016253)	0.0003264 (0.0017243)	0.0000378* (0.000015)
β_0	−0.740014 (4.033444)	−0.7279031 (4.13823)	1.679 (3.553627)	1.69379 (3.563932)	1.935938 (3.760159)	1.816683 (1.473224)
time dummies	YES	YES	YES	YES	YES	YES
R-sq	0.3732	0.3730	0.4467	0.4467	0.4198	–
Wald chi2	–	–	–	–	–	110.76
Baltagi-Wu LBI	–	2.1771212	–	2.1013374	–	–
Nr. of observations:	60	60	60	60	55	65
Nr. of groups:	5	5	5	5	5	5

Significance: $^{**} \leq 1\%, ^{*} \leq 5\%, ^{+} \leq 10\%$

TABLE B.3: Estimation result 1b, Alternative Estimations

estimation method	**neg.Bin.** (fixed effects)	**neg.Bin.** (fixed effects)	**OLS** (fixed effects)	**OLS FD** (fixed effects)	**OLS FD** (fixed effects)	**AR(1) FD** (fixed effects)	**AR(1) FD** (fixed effects)
Independent Variable	−− PAT_{t-1}	−− PAT_{t-1}	$RELPAT_{t-1}$ −−	$RELPAT_{t-1}$ −−	$RELPAT_{t-1}$ −−	$RELPAT_{t-1}$ −−	$RELPAT_{t-1}$ −−
$INCAP$	0.000039^{**} ($6.82e-06$)	−−	−−	−−	−−	−−	$2.93e-07^{*}$ (1.21e-07)
$\Delta INCAP$	−−	0.0001845^{**} (0.0000509)	$5.73e-07^{**}$ (8.85e-08)	$5.08e-07^{**}$ (1.60e-07)	$4.78e-07^{**}$ (1.60e-07)	$5.47e-07^{**}$ ($1.71e-07$)	−−
RuD_{t-1}	0.0075649^{**} (0.0029366)	0.0064701^{+} (0.0036583)	$9.34e-06^{+}$ ($4.81e-06$)	0.0000238^{**} (6.00e-06)	0.0000234^{**} (6.56e-06)	0.0000392^{**} (8.32e-06)	0.0000412^{**} (8.70e-06)
$CPIE_{t-3}$	0.0142486^{**} (0.0035858)	0.0064506 (0.0040973)	−−	−−	0.0000209^{+} (0.0000105)	0.0000242^{*} (0.0000109)	0.0000341^{**} (0.0000119)
ΔELC_{t-3}	0.0000463 (0.0002292)	−0.000047 (0.0002831)	−−	−−	$3.41e-07$ (4.22e-07)	3.88e-07 (4.30e-07)	$6.88e-07$ (4.75e-07)
$CPIE_{t-2}$	−−	−−	$1.20e-06$ ($3.36e-06$)	$1.66e-06$ (6.72e-06)	−−	−−	−−
ΔELC_{t-2}	−−	−−	$1.69e-07$ ($3.96e-07$)	$-1.91e-07$ ($2.59e-07$)	−−	−−	−−
$APAT_{t-2}$	0.0000536^{**} ($9.13e-06$)	0.0000384^{**} (0.0000122)	−−	−−	−−	−−	−−
β_0	0.5222763 (1.103971)	1.265181 (1.119384)	0.001037^{**} (0.0003837)	0.0000292 (0.0000398)	0.0000926^{+} (0.0000539)	0.0000624 (0.0000514)	0.0000178 (0.0000623)
time dummies	*No*	*No*	*No*	*No*	*No*	*No*	*No*
R-sq	–	–	0.4747	0.3572	0.3635	0.4268	0.3125
Wald chi2(5)	112.05	66.43	–	–	–	–	–
Nr. of observations:	60	60	65	60	55	50	50
Nr. of groups:	5	5	5	5	5	5	5

Significance: $^{**} \leq 1\%, ^{*} \leq 5\%, ^{+} \leq 10\%$

B.4 Correlation Matrices for Different Econometric Models

TABLE B.4: Correlation matrices

Correlation matrix 1

	PAT	$INCAP$	$CPIE$	ELC	$APAT$	RuD
PAT	1.0000					
$INCAP$	0.1745	1.0000				
$CPIE$	-0.2146	-0.2630	1.0000			
ELC	0.1380	0.3558	-0.5783	1.0000		
$APAT$	0.2214	0.2927	-0.9467	0.5699	1.0000	
RuD	0.7675	-0.2187	0.1156	-0.0693	-0.1271	1.0000

Correlation matrix 2

	PAT_{t-1}	$INCAP$	$CPIE_{t-2}$	ΔELC_{t-2}	$APAT_{t-2}$	RuD_{t-1}
PAT_{t-1}	1.0000					
$INCAP$	0.2117	1.0000				
$CPIE_{t-2}$	-0.1603	-0.3318	1.0000			
ΔELC_{t-2}	0.1095	0.1854	-0.6231	1.0000		
$APAT_{t-2}$	0.1653	0.3237	-0.9462	0.6053	1.0000	
RuD_{t-1}	0.8098	-0.2125	0.1162	0.1162	-0.1407	1.0000

Correlation matrix 3

	PAT_{t-1}	$\Delta INCAP$	$CPIE_{t-2}$	ΔELC_{t-2}	$APAT_{t-2}$	RuD_{t-1}
PAT_{t-1}	1.0000					
$\Delta INCAP$	0.4073	1.0000				
$CPIE_{t-2}$	-0.1603	-0.3310	1.0000			
ΔELC_{t-2}	0.1095	0.2000	-0.6231	1.0000		
$APAT_{t-2}$	0.1653	0.3216	-0.9462	0.6053	1.0000	
RuD_{t-1}	0.8098	0.8098	0.1162	-0.0919	-0.1407	1.0000

Correlation matrix 4

	PAT_{t-1}	$\Delta INCAP$	$CPIE_{t-3}$	ΔELC_{t-3}	$APAT_{t-2}$	RuD_{t-1}
PAT_{t-1}	1.0000					
$\Delta INCAP$	0.4111	1.0000				
$CPIE_{t-3}$	-0.1156	-0.2951	1.0000			
ΔELC_{t-3}	0.0852	0.1595	-0.5938	1.0000		
$APAT_{t-2}$	0.1421	0.3066	-0.9249	0.6332	1.0000	
RuD_{t-1}	0.8386	0.0508	0.1017	-0.0340	-0.1205	1.0000

Correlation matrix 5

	ΔPAT_{t-1}	$\Delta INCAP$	$\Delta CPIE_{t-2}$	$\Delta(\Delta ELC_{t-2})$	$\Delta APAT_{t-2}$	ΔRuD_{t-1}
ΔPAT_{t-1}	1.0000					
$\Delta INCAP$	0.1970	1.0000				
$\Delta CPIE_{t-2}$	-0.1590	-0.0075	1.0000			
$\Delta(\Delta ELC_{t-2})$	-0.0468	-0.0468	-0.0468	1.0000		
$\Delta APAT_{t-2}$	-0.0468	-0.0468	-0.2671	-0.1773	1.0000	
ΔRuD_{t-1}	0.3274	-0.0615	-0.0748	0.0071	-0.0110	1.0000

Correlation matrix 6

	ΔPAT_{t-1}	$\Delta(\Delta INCAP)$	$\Delta CPIE_{t-2}$	$\Delta(\Delta ELC_{t-2})$	$\Delta APAT_{t-2}$	ΔRuD_{t-1}
ΔPAT_{t-1}	1.0000					
$\Delta(\Delta INCAP)$	0.4517	1.0000				
$\Delta CPIE_{t-2}$	-0.1590	-0.1672	1.0000			
$\Delta(\Delta ELC_{t-2})$	-0.0468	0.0150	-0.2191	1.0000		
$\Delta APAT_{t-2}$	-0.2191	-0.0208	-0.2671	-0.1773	1.0000	
ΔRuD_{t-1}	0.3274	0.3274	0.3274	0.0071	0.0071	1.0000

Appendix C.

C.1 Different Scenarios

TABLE C.1: Scenarios 3-5

	Description	Modifications on the model	Expectations
Scenario 3	F decides to support firms located in F directly to produce GTs	Case (a): $\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^H_{pr_j}) - c_{l_j} \leq 0.$ No additional exports.	Case (3a): The first mover advantage does not lead to exports.
		Case (3b): $\pi^e_{H_j} = q^e_{H_j}(A^e - q^e_{H_j} - q^e_{F_j} - c^H_{pr_j}) - c_{l_j} > 0.$ If the GT industry is so competitive that it was already exporting GTs to F without any subsidies → In this case it can continue to export, if it is still able to compete with the GT industries$_j$ located in F.	Case (b): Decreasing exports of GTs compared to the case without local content clause.
Scenario 4	H competes with the GT industry located in another country (country I) in a "third" market in F. In this case F is not able to produce GTs but is forced to buy them (e. g. because of high international environmental standards).	There is competition between H and I. The underlying game depends on which cost curve H and I are operating. They can play Stackelberg, or if they have the same marginal costs, the market has the characteristic of a duopoly with simultaneous market entrance.	Increasing exports of GTs.
Scenario 5	There is also the possibility that a firm located in H is making a direct contract with politicians in L	Case (5a): $\pi^e_{H_j} = \hat{q}^e_{H_j}\hat{p}_j - c^H_{pr_j}\hat{q}^e_{H_j} - c_{l_j} > 0.$ $\hat{q}_{H_j}$ stands for "agreed quantity of GTs" which the GT industries$_j$ located in H can sell at the agreed price $\hat{p}_j$.	Case (a) F buys the technology from the GT industries$_j$ located in H. In this case the GT industry would sell a *package* of GTs to F → Increasing exports of GTs.
		Case (5b): $\pi^e_{H_j} = \hat{q}^e_{H_j}\hat{p}_j - c^H_{pr_j}\hat{q}^e_{H_j} - c_{l_j} - ttr > 0.$ ttr stands for "technology transfer".	Case (b): The contract is combined with a local content clause → Increasing exports of GTs, but less than in case (a).

C.2 Stackelberg Game

In our framework, the GT industry j in H benefits from pid_{F_j} and enters the foreign market as a Stackelberg leader. The Stackelberg game can be solved as follows: the GT industry in H and F are assumed to maximize profits. For F the profit function is given by equation 4.1.

The profit maximization problem leads to

$$\begin{aligned}\frac{\partial \pi^e_{F_j}}{\partial q^e_{F_j}} &= A^e - q^e_{H_j} - 2q^e_{F_j} - c^{pr}_{F_j} + pid^e_{F_j} = 0 \\ q_{F_j} &= R_F(q_{H_j}) = \frac{A - q_{H_j} - c^{pr}_{F_j} + pid_{F_j}}{2}. \end{aligned} \tag{C.1}$$

$R_F(q^e_{H_j})$ represents the response function for F. H maximizes its expected profits with respect to $q^e_{H_j}$ by taking equation C.1 into account. It follows

$$\begin{aligned}\frac{\partial \pi^e_{H_j}}{\partial q^e_{H_j}} &= A^e - 2q^e_{H_j} - \frac{1}{2}A^e + q^e_{H_j} + \frac{1}{2}c^{pr}_{F_j} - \frac{1}{2}pid^e_{F_j} - c^{pr}_{H_j} + pid^e_{F_j} \\ q^{e*}_{H_j} &= \frac{A^e + c^{pr}_{F_j} - 2c^{pr}_{H_j} + pid^e_{F_j}}{2}. \end{aligned} \tag{C.2}$$

Finally we can solve the maximization problem for the industry $_j$ in F. The solution for F is given by

$$q^{e*}_{F_j} = \frac{A^e - c^{pr}_{F_j} + pid^e_{F_j}}{4}. \tag{C.3}$$

If we substitute the values for $q^{e*}_{F_j}$ and $q^{e*}_{H_j}$ into equation 4.1 we obtain

$$\begin{aligned}\pi^e_{H_j} &= \left[\frac{A^e + 3(c^{pr}_{H_j} - pid^e_{F_j})}{4} - c^{pr}_{H_j} + pid^e_{F_j}\right]\left[\frac{A^e - c^{pr}_{H_j} + pid^e_{F_j}}{2}\right] - c_{l_j} \\ \pi^e_{H_j} &= \frac{1}{8}(A^e - c^{pr}_{H_j} + pid^e_{F_j})^2 - c_{l_j}. \end{aligned} \tag{C.4}$$

The *expected* contribution to the national GDP of H through exports of GTs is simply denoted as y^e_H. This leads to

$$y^e_{H_j} = \pi^e_{H_j} = \frac{1}{8}(A^e - c^{pr}_{H_j} + pid^e_{F_j})^2 - c_{l_j}. \tag{C.5}$$

In contrast to the costs which go in hand with policy induced demand for GTs at the national level, y^e_H enters positively into the GDP of H.[1]

[1] This is true as long as $A^e + pid^e_{F_j} > c^{pr}_{H_j}$ and $c_{l_j} < (A^e - c^{pr}_{H_j} + pid^e_{F_j})^2$.

C.3 Econometric Model

Empirical Data

Patents ($PATENT^{HF}$), source EPO: Table B.1 on page 200 contains the list of patent classes from which the dataset is extracted. The "renewable energy industry specific technologies" of interest are for electricity production with wind (WIND), solar (SOLAR), water & ocean (WATER), geothermal (GEO) and biomass (BIO). The original table on patent classes comes from Johnstone et al. (2010).[2] The dataset contains patents which are *granted* in at the EPO, JPO and APO with priority in Germany (including the "Neue Bundesländer").[3] The dataset includes patents and utility patents. The data we use comes from a freely available dataset of the European Patent (DOC-DB).[4] Information captured with $PATENT^{HF}$ therefore is industry specific (WIND, SOLAR, WATER, GEO, BIO) and country/ territorial specific (EP, JPO and APO).

Patent counts about patents applied in region r ($APATENT^{F}$), source OECD: The variable $APATENT^{F}$ contains information about the overall number of patents applied in the specific territory (EPO, JPO, APO). This variable captures all patents applied for at the EPO, JPO and APO with the inventor's country of residence and fractional counts. The patent counts are based on the earliest priority date. The data mainly derives from EPO Worldwide Statistical Patent Database (April 2007).[5] Information captured with $APATENT^{F}$ is country/ territorial specific (EP, JPO and APO).

German R&D expenditures(RuD^{H}), source IEA: The data about industry specific expenditures concerning public expenditures on research and development related to R&D in the different GT industries comes from the international energy agency.[6] The data for Germany is in million Euro on exchange rates from 2006.[7] Information captured with RuD^{H} is at the German level and industry specific (WIND, SOLAR, WATER, GEO, BIO).

German installed capacity of industry specific technology $INCAP^{H}$, source BUND: $INCAP^{H}$ is used as a proxy for the induced demand implemented by institutional changes because of laws such as the EEG. The data contains information about the installed capacity measured in megawatt-hours (MWh). It measures the overall installed capacity of the industry specific technology per year. The data comes from the Ministry of Environment.[8]
Information captured with $INCAP^{H}$ is at the German level and industry specific (WIND, SOLAR, WATER, GEO, BIO).

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[2]Note that the list is extended in the case of patent classes for Water, because the law for renewable energy which is analyzed for Germany also changed the institutional framework for energy produced with water. On the other hand, we excluded WASTE, because we focus on GTs and therefore WASTE is not really considered as a renewable energy source.

[3]Note that the date for the patents that are granted goes back to the date when inventors applied for the patent. Even though information about patents until 2006 is available, the analysis is restricted to from 1992 to 2002. The information about the last three years is dropped to get rid of the problem that granted patents always go back to the priority date. Therefore, it is plausible to assume that the data from 2004 and 2006 contains a lack of information (Popp, 2005b, p. 5).

[4]For further information look at http://www.epo.org/patents/patent-information/free.html.

[5]For more detailed information see Organization for Economic Co-Operation and Development (OECD), Patent Database, June 2007.

[6]For further information look at http://www.iea.org/.

[7]The data for Germany at the national level does not contain information about the expenditures of regional governments.

[8]Compare BMU (2007b).

Energy price index ($CPIE^F$), electricity consumption (ELC^F) and installed capacity of renewable energies in the foreign country ($INCAP^F$), source IEA: $CPIE^F$ is a consumer price index for energy. $CPIE^F$ is country specific. Year 2000 is set to 100, taxes are included in the calculation. ELC^F measures the electricity consumption in KWh per capita ELC^F is country specific. $INCAP^F$ measures the overall installed capacity of renewable energies in the foreign country. Information captured with $CPIE^F$, ELC^F and $INCAP^F$ is country/ territorial specific (EP, JPO and APO).

C.4 Alternative Estimations

In table C.2, we use a fixed effects Poisson-model, which more or less replicates our results (compare table 4.1, page 107). Using a first differences model (OLS) as shown in table C.3 still shows significant results for $INCAP^H_{2000-2002}$ in JPO and APO.

TABLE C.2: Fixed effects Poisson regression

$PATENT^{HF}$	EPO	JPO	APO
$lagRuD^H_{1992-1999}$	−0.003891 (0.0050035)	−0.0053209 (0.0070105)	−0.0027717 (0.0059082)
$lagRuD^H_{2000-2002}$	−0.0218788*** (0.0076388)	−0.0205298* (0.0113637)	−0.0242853** (0.0096594)
$INCAP^H_{1992-1999}$	0.0001682*** (0.0000476)	0.0003202*** (0.000074)	0.0002738*** (0.0000645)
$INCAP^H_{2000-2002}$	0.0000832*** (0.0000172)	.0002117*** (0.0000279)	0.0001901*** (0.0000242)
$lagINCAP^F$	$4.78e-06$ (0.0000164)	0.0005027* (0.0003115)	−0.000037 (0.0000375)
$lagAPATENT^F$	−0.0001206 (0.000266)	−0.0001457 (0.000173)	0.0007427** (0.000334)
$lagCPIE^F_{1992-1999}$	0.0190602 (0.025742)	−0.003186 (0.0246747)	−0.0009674 (0.0269702)
$lagCPIE^F_{2000-2002}$	0.023799 (0.02162)	−0.0020967 (0.0249417)	0.0032361 (0.0220473)
$lagELC^F$	−0.0035969 (0.003572)	−0.0058992** (0.0024022)	0.0023531*** (0.0005705)
Wald chi2	411.06		
Nr. of observations:	165		

Significance: $^{***} \leq 1\%,^{**} \leq 5\%,^{*} \leq 10\%$

TABLE C.3: OLS fixed effects first differences model

$PATENT^{HF}$	EPO	JPO	APO
$lag1RuD^{H}_{1992-1999}$	−0.2735567	−0.0252574	−0.053742
	(0.1733541)	(0.0849316)	(0.1719576)
$lag1RuD^{H}_{2000-2002}$	−0.2446132	−0.0247744	−0.1965391
	(0.2085309)	(0.1635901)	(0.2077007)
$INCAP^{H}_{1992-1999}$	0.0001368	0.0021967	0.0017532
	(0.0013486)	(0.0013473)	(0.0013839)
$INCAP^{H}_{2000-2002}$	−0.0007135	0.0012767**	0.0013259**
	(0.0005851)	(0.0005684)	(0.0013259)
$lagINCAP^{F}$	0.0009494	0.0024222	0.0013545
	(0.0106794)	(0.0238106)	(0.0095546)
$lagAPATENT^{F}$	0.0060522	−0.0036444	0.0060825
	(0.0559459)	(0.0571749)	(0.0470171)
$lagCPIE^{F}_{1992-1999}$	−0.538605	0.0867416	−0.0706172
	(10.112697)	(0.7568268)	(0.5441484)
$lagCPIE^{F}_{2000-2002}$	−0.3647433	0.1282116	0.0190248
	(10.356288)	(10.207714)	(0.8598966)
$lagELC^{F}$	0.0091146	−0.0480379	0.0228105
	(0.0829318)	(0.2854876)	(0.1428906)
β_0	−8.647436		
	(88.44358)		
R-sq:	0.3082		
F(27,108)	1.89		
Nr. of observations:	150		

Significance: $^{***} \leq 1\%$, $^{**} \leq 5\%$, $^{*} \leq 10\%$

C.5 Correlation Matrices

TABLE C.4: Correlation matrix 1 for the model with a one year lime lag for *RuD*

	A	B	C	D	E	F	G	H	I	J
A: $PATENT^{HF}_{EU,JAPAN,USA}$	1.0000									
B: $lag1RuD^{H}_{1992-1999_{EU}}$	0.3672	1.0000								
C: $lag1RuD^{H}_{2000-2002_{EU}}$	0.3896	-0.0662	1.0000							
D: $INCAP^{H}_{1992-1999_{EU}}$	-0.0242	0.0860	-0.0598	1.0000						
E: $INCAP^{H}_{2000-2002_{EU}}$	0.3678	-0.0142	0.2504	-0.0548	1.0000					
F: $lagELC^{F}_{EU}$	0.2345	-0.1872	0.2733	-0.1485	0.2095	1.0000				
G: $lagCPIE^{F}_{1992-1999_{EU}}$	0.1077	0.5518	-0.1186	0.5036	0.0147	-0.2615	1.0000			
H: $lagCPIE^{F}_{2000-2002_{EU}}$	0.2786	-0.0998	0.6637	-0.0901	0.4320	0.4127	-0.1787	1.0000		
I: $lagINCAP^{F}_{EU}$	0.2001	-0.1931	0.2953	-0.1650	0.1874	0.9697	-0.2863	0.4453	1.0000	
J: $lagAPATENT^{F}_{EU}$	0.2361	-0.1617	0.1995	-0.1028	0.1864	0.9403	-0.1805	0.3010	0.8616	1.0000
K: $lag1RuD^{H}_{1992-1999_{JAPAN}}$	0.0422	-0.0996	-0.0662	-0.0900	-0.0607	-0.1872	-0.1783	-0.0998	-0.1931	-0.1617
L: $lag1RuD^{H}_{2000-2002_{JAPAN}}$	0.0257	-0.0662	-0.0441	-0.0598	-0.0404	0.2733	-0.1186	-0.0664	0.2953	0.1995
M: $INCAP^{H}_{1992-1999_{JAPAN}}$	-0.1398	-0.0900	-0.0598	-0.0813	-0.0548	-0.1485	-0.1611	-0.0901	-0.1650	-0.1028
N: $INCAP^{H}_{2000-2002_{JAPAN}}$	0.1228	-0.0607	-0.0404	-0.0548	-0.0370	0.2095	-0.1086	-0.0608	0.1874	0.1864
O: $lagELC^{F}_{JAPAN}$	0.2180	-0.1711	0.2053	-0.1011	0.1716	0.9126	-0.1851	0.3078	0.8517	0.9767
P: $lagCPIE^{F}_{1992-1999_{JAPAN}}$	-0.1835	-0.1784	-0.1187	-0.1611	-0.1087	-0.2888	-0.3194	-0.1787	-0.3075	-0.2187
Q: $lagCPIE^{F}_{2000-2002_{JAPAN}}$	-0.0544	-0.0998	-0.0664	-0.0901	-0.0608	0.4120	-0.1787	-0.1000	0.4433	0.3010
R: $lagINCAP^{F}_{JAPAN}$	0.2178	-0.1814	0.2363	-0.1184	0.1847	0.9608	-0.2195	0.3562	0.9205	0.9771
S: $lagAPATENT^{F}_{JAPAN}$	0.2571	-0.1869	0.2798	-0.1626	0.2275	0.9764	-0.2680	0.4199	0.9425	0.9149
T: $lag1RuD^{H}_{1992-1999_{USA}}$	0.1728	-0.0996	-0.0662	-0.0900	-0.0607	-0.1872	-0.1783	-0.0998	-0.1931	-0.1617
U: $lag1RuD^{H}_{2000-2002_{USA}}$	0.1031	-0.0662	-0.0441	-0.0598	-0.0404	0.2733	-0.1186	-0.0664	0.2953	0.1995
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.1169	-0.0900	-0.0598	-0.0813	-0.0548	-0.1485	-0.1611	-0.0901	-0.1650	-0.1028
W: $INCAP^{H}_{2000-2002_{USA}}$	0.2145	-0.0607	-0.0404	-0.0548	-0.0370	0.2095	-0.1086	-0.0608	0.1874	0.1864
X: $lagELC^{F}_{USA}$	0.2551	-0.1625	0.2090	-0.1104	0.1816	0.8836	-0.1897	0.3101	0.8129	0.9425
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.0891	-0.1784	-0.1187	-0.1612	-0.1087	-0.2722	-0.3195	-0.1788	-0.2945	-0.1953
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	0.0258	-0.0997	-0.0664	-0.0901	-0.0608	0.4121	-0.1786	-0.1000	0.4429	0.3012
AA: $lagINCAP^{F}_{USA}$	0.0624	-0.0069	-0.0717	0.0056	0.0626	-0.0133	0.0860	-0.1108	-0.0567	0.2059
BB: $lagAPATENT^{F}_{USA}$	0.2409	-0.1714	0.2249	-0.1269	0.1892	0.9651	-0.2070	0.3379	0.9047	0.9724

	K	L	M	N	O	P	Q	R	S	T
K: $lag1RuD^{H}_{1992-1999_{JAPAN}}$	1.0000									
L: $lag1RuD^{H}_{2000-2002_{JAPAN}}$	-0.0662	1.0000								
M: $INCAP^{H}_{1992-1999_{JAPAN}}$	-0.0662	-0.0598	1.0000							
N: $INCAP^{H}_{2000-2002_{JAPAN}}$	0.0860	0.2504	-0.0548	1.0000						
O: $lagELC^{F}_{JAPAN}$	-0.0142	0.2053	-0.1011	0.1716	1.0000					
P: $lagCPIE^{F}_{1992-1999_{JAPAN}}$	-0.171	-0.1187	0.5050	0.0028	-0.2226	1.0000				
Q: $lagCPIE^{F}_{2000-2002_{JAPAN}}$	0.5610	0.6636	-0.0901	0.4359	0.3081	-0.1787	1.0000			
R: $lagINCAP^{F}_{JAPAN}$	-0.0998	0.2363	-0.1184	0.1847	0.9827	-0.2537	0.3558	1.0000		
S: $lagAPATENT^{F}_{JAPAN}$	-0.1814	0.2798	-0.1626	0.2275	0.9024	-0.2938	0.4206	0.9373	1.0000	
T: $lag1RuD^{H}_{1992-1999_{USA}}$	-0.1869	-0.0662	-0.0900	-0.0607	-0.1711	-0.1784	-0.0998	-0.1814	-0.1869	1.0000
U: $lag1RuD^{H}_{2000-2002_{USA}}$	-0.0996	-0.0441	-0.0598	-0.0404	0.2053	-0.1187	-0.0664	0.2363	0.2798	-0.0662
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.0662	-0.0598	-0.0813	-0.0548	-0.1011	-0.1611	-0.0901	-0.1184	-0.1626	0.0860
W: $INCAP^{H}_{2000-2002_{USA}}$	-0.0900	-0.0404	-0.0548	-0.0370	0.1716	-0.1087	-0.0608	0.1847	0.2275	-0.0142
X: $lagELC^{F}_{USA}$	-0.1625	-0.0607	-0.1104	0.1816	0.9581	-0.2247	0.3116	0.9351	0.9231	-0.1625
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.1784	-0.1187	-0.1612	-0.1087	-0.1989	-0.3196	-0.1788	-0.2323	-0.2778	0.5556
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	-0.0997	-0.0664	-0.0901	-0.0608	0.3073	-0.1787	-0.1000	0.3556	0.4198	-0.0997
AA: $lagINCAP^{F}_{USA}$	-0.0069	-0.0717	0.0056	0.0626	0.2872	0.0647	-0.1073	0.1727	0.0669	-0.0069
BB: $lagAPATENT^{F}_{USA}$	-0.1714	0.2249	-0.1269	0.1892	0.9593	-0.2413	0.3375	0.9643	0.9503	-0.1714

	U	V	W	X	Y	Z	AA	BB
U: $lag1RuD^{H}_{2000-2002_{USA}}$	1.0000							
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.0598	1.0000						
W: $INCAP^{H}_{2000-2002_{USA}}$	0.2504	-0.0548	1.0000					
X: $lagELC^{F}_{USA}$	0.2090	-0.1104	0.1816	1.0000				
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.1187	0.5042	0.0098	-0.2035	1.0000			
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	0.6631	-0.0901	0.4402	0.3094	-0.1787	1.0000		
AA: $lagINCAP^{F}_{USA}$	-0.0717	0.0056	0.0626	0.3339	0.0757	-0.1077	1.0000	
BB: $lagAPATENT^{F}_{USA}$	0.2249	-0.1269	0.1892	0.9270	-0.2197	0.3369	0.1183	1.0000

TABLE C.5: Correlation matrix 1 for the model with a two year lime lag for *RuD*

	A	B	C	D	E	F	G	H	I	J
A: $PATENT^{HF}_{EU,JAPAN,USA}$	1.0000									
B: $lag2RuD^{H}_{1992-1999_{EU}}$	0.4386	1.0000								
C: $lag2RuD^{H}_{2000-2002_{EU}}$	0.2749	-0.0570	1.0000							
D: $INCAP^{H}_{1992-1999_{EU}}$	-0.0221	0.0923	-0.0486	1.0000						
E: $INCAP^{H}_{2000-2002_{EU}}$	0.3709	0.0460	0.1404	-0.0573	1.0000					
F: $lagELC^{F}_{EU}$	0.2224	-0.1583	0.2304	-0.1644	0.2022	1.0000				
G: $lagCPIE^{F}_{1992-1999_{EU}}$	0.1070	0.5202	-0.0945	0.5127	0.0187	-0.2770	1.0000			
H: $lagCPIE^{F}_{2000-2002_{EU}}$	0.2770	-0.0011	0.5183	-0.0945	0.4288	0.4081	-0.1837	1.0000		
I: $lagINCAP^{F}_{EU}$	0.1840	-0.1680	0.2740	-0.1844	0.1785	0.9641	-0.3066	0.4453	1.0000	
J: $lagAPATENT^{F}_{EU}$	0.2300	-0.1321	0.1557	-0.1199	0.1835	0.9428	-0.1931	0.2961	0.8357	1.0000
K: $lag2RuD^{H}_{1992-1999_{JAPAN}}$	0.0477	-0.1106	-0.0570	-0.0943	-0.0672	-0.1583	-0.1834	-0.1109	-0.1680	-0.1321
L: $lag2RuD^{H}_{2000-2002_{JAPAN}}$	-0.0101	-0.0570	-0.0294	-0.0486	-0.0347	0.2304	-0.0945	-0.0572	0.2740	0.1557
M: $INCAP^{H}_{1992-1999_{JAPAN}}$	-0.1360	-0.0943	-0.0486	-0.0804	-0.0573	-0.1644	-0.1563	-0.0945	-0.1844	-0.1199
N: $INCAP^{H}_{2000-2002_{JAPAN}}$	0.1203	-0.0672	-0.0347	-0.0573	-0.0408	0.2022	-0.1114	-0.0673	0.1785	0.1835
O: $lagELC^{F}_{JAPAN}$	0.2109	-0.1267	0.1432	-0.1211	0.1687	0.9175	-0.2035	0.3102	0.8295	0.9674
P: $lagCPIE^{F}_{1992-1999_{JAPAN}}$	-0.1801	-0.1834	-0.0946	-0.1563	-0.1114	-0.3005	-0.3039	-0.1838	-0.3233	-0.2257
Q: $lagCPIE^{F}_{2000-2002_{JAPAN}}$	-0.0648	-0.1109	-0.0572	-0.0945	-0.0673	0.4074	-0.1837	-0.1111	0.4431	0.2961
R: $lagINCAP^{F}_{JAPAN}$	0.2081	-0.1516	0.1990	-0.1401	0.1819	0.9708	-0.2430	0.3634	0.9140	0.9671
S: $lagAPATENT^{F}_{JAPAN}$	0.2476	-0.1415	0.1903	-0.1812	0.2221	0.9720	-0.2850	0.4166	0.9313	0.9077
T: $lag2RuD^{H}_{1992-1999_{USA}}$	0.1987	-0.1106	-0.0570	-0.0943	-0.0672	-0.1583	-0.1834	-0.1109	-0.1680	-0.1321
U: $lag2RuD^{H}_{2000-2002_{USA}}$	0.0375	-0.0570	-0.0294	-0.0486	-0.0347	0.2304	-0.0945	-0.0572	0.2740	0.1557
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.1200	-0.0943	-0.0486	-0.0804	-0.0573	-0.1644	-0.1563	-0.0945	-0.1844	-0.1199
W: $INCAP^{H}_{2000-2002_{USA}}$	0.2141	-0.0672	-0.0347	-0.0573	-0.0408	0.2022	-0.1114	-0.0673	0.1785	0.1835
X: $lagELC^{F}_{USA}$	0.2563	-0.1029	0.0870	-0.1320	0.1798	0.8747	-0.2078	0.3108	0.7747	0.9164
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.0884	-0.1834	-0.0946	-0.1563	-0.1114	-0.2862	-0.3040	-0.1838	-0.3130	-0.2056
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	0.0176	-0.1108	-0.0571	-0.0945	-0.0673	0.4076	-0.1837	-0.1111	0.4426	0.2963
AA: $lagINCAP^{F}_{USA}$	0.0045	0.1268	-0.2400	0.0232	0.0292	-0.4151	0.1714	-0.2443	-0.4970	-0.2725
BB: $lagAPATENT^{F}_{USA}$	0.2304	-0.1351	0.1703	-0.1421	0.1814	0.9594	-0.2172	0.3291	0.8845	0.9732

	K	L	M	N	O	P	Q	R	S	T
K: $lag2RuD^{H}_{1992-1999_{JAPAN}}$	1.0000									
L: $lag2RuD^{H}_{2000-2002_{JAPAN}}$	-0.0570	1.0000								
M: $INCAP^{H}_{1992-1999_{JAPAN}}$	0.0923	-0.0486	1.0000							
N: $INCAP^{H}_{2000-2002_{JAPAN}}$	0.0460	0.1404	-0.0573	1.0000						
O: $lagELC^{F}_{JAPAN}$	-0.1267	0.1432	-0.1211	0.1687	1.0000					
P: $lagCPIE^{F}_{1992-1999_{JAPAN}}$	0.5276	-0.0946	0.5158	0.0080	-0.2348	1.0000				
Q: $lagCPIE^{F}_{2000-2002_{JAPAN}}$	0.0008	0.5133	-0.0945	0.4328	0.3105	-0.1838	1.0000			
R: $lagINCAP^{F}_{JAPAN}$	-0.1516	0.1990	-0.1401	0.1819	0.9758	-0.2711	0.3628	1.0000		
S: $lagAPATENT^{F}_{JAPAN}$	-0.1415	0.1903	-0.1812	0.2221	0.9012	-0.3068	0.4173	0.9383	1.0000	
T: $lag2RuD^{H}_{1992-1999_{USA}}$	-0.1106	-0.0570	-0.0943	-0.0672	-0.1267	-0.1834	-0.1109	-0.1516	-0.1415	1.0000
U: $lag2RuD^{H}_{2000-2002_{USA}}$	-0.0570	-0.0294	-0.0486	-0.0347	0.1432	-0.0946	-0.0572	0.1990	0.1903	-0.0570
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.0943	-0.0486	-0.0804	-0.0573	-0.1211	-0.1563	-0.0945	-0.1401	-0.1812	0.0923
W: $INCAP^{H}_{2000-2002_{USA}}$	-0.0672	-0.0347	-0.0573	-0.0408	0.1687	-0.1114	-0.0673	0.1819	0.2221	0.0460
X: $lagELC^{F}_{USA}$	-0.1029	0.0870	-0.1320	0.1798	0.9365	-0.2360	0.3127	0.9049	0.9252	-0.1029
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.1834	-0.0946	-0.1563	-0.1114	-0.2146	-0.3040	-0.1838	-0.2533	-0.2931	0.5227
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	-0.1108	-0.0571	-0.0945	-0.0673	0.3095	-0.1837	-0.1111	0.3627	0.4165	-0.0002
AA: $lagINCAP^{F}_{USA}$	0.1268	-0.2400	0.0232	0.0292	-0.1944	0.1703	-0.2395	-0.3341	-0.3042	0.1268
BB: $lagAPATENT^{F}_{USA}$	-0.1351	0.1703	-0.1421	0.1814	0.9649	-0.2471	0.3288	0.9633	0.9409	-0.1351

	U	V	W	X	Y	Z	AA	BB
U: $lag2RuD^{H}_{2000-2002_{USA}}$	1.0000							
V: $INCAP^{H}_{1992-1999_{USA}}$	-0.0486	1.0000						
W: $INCAP^{H}_{2000-2002_{USA}}$	0.1404	-0.0573	1.0000					
X: $lagELC^{F}_{USA}$	0.0870	-0.1320	0.1798	1.0000				
Y: $lagCPIE^{F}_{1992-1999_{USA}}$	-0.0946	0.5137	0.0143	-0.2190	1.0000			
Z: $lagCPIE^{F}_{2000-2002_{USA}}$	0.5161	-0.0945	0.4371	0.3100	-0.1837	1.0000		
AA: $lagINCAP^{F}_{USA}$	-0.2400	0.0232	0.0292	-0.0977	0.1678	-0.2401	1.0000	
BB: $lagAPATENT^{F}_{USA}$	0.1703	-0.1421	0.1814	0.9171	-0.2279	0.3281	-0.2771	1.0000

Appendix D.

D.1 Panel regressions

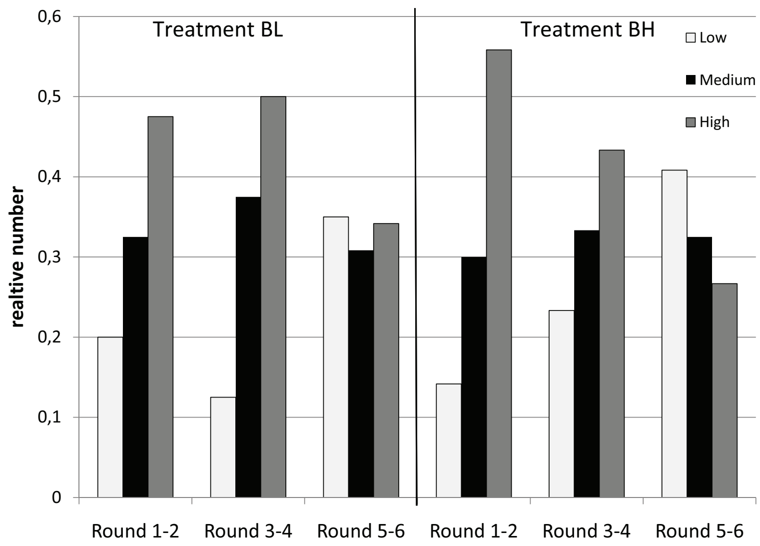
TABLE D.1: OLS Panelregression with clustered standard errors on group level for scenario *B*

	Run 1 contribution	Run 1 contribution	Run 2 contribution	Run 2 contribution	Both runs contribution
BH	-0.367	-0.206	-0.400	-0.262	-0.315
	(-0.66)	(-0.46)	(-1.94)	(-1.52)	(-1.40)
S_{BH}	-0.111	-0.187	-0.0389	0.0564	-0.0731
	(-0.22)	(-0.48)	(-0.20)	(0.33)	(-0.35)
S_{BL}	-0.0889	0.186	-0.133	-0.0141	-0.0639
	(-0.19)	(0.56)	(-0.21)	(-0.03)	(-0.21)
Lag contribution		0.371***		0.284***	0.294***
		(5.61)		(3.81)	(5.93)
Lag average contr.		0.213		0.263	0.0878
		(1.69)		(1.94)	(1.02)
Lag accumulated		-0.0142***		-0.0137***	-0.00495*
		(-4.52)		(-3.70)	(-2.13)
Restart					0.181
					(0.98)
cons	6.022***	3.509***	5.794***	3.466***	3.956***
	(22.54)	(3.89)	(31.86)	(3.99)	(7.03)
N	720	600	720	600	1320
$N_{Indiv.}$	120	120	120	120	120
R^2_O	0.00341	0.214	0.00324	0.189	0.115

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D.2 Contribution classes over rounds

FIGURE D.1: Contribution classes over treatments and rounds for *B*



D.3 Instructions (English translation for treatment BH)

Welcome and thank you for participating in this experiment! Please read these instructions carefully, they are identical for all participants. For arriving on time you receive a show-up fee of €2.50. In the experiment, you will earn additional money, depending on your decisions and the decisions of other participants. During the course of the experiment, all amounts are stated in ECU (experimental currency units). At the end of the experiment, all earned ECU will be converted into cash and privately paid out according to the following exchange rate:

$$1ECU = 0.10€$$

From now on, please do not talk to your neighbors, switch of your cell phone, and remove unnecessary things from your desk. It is important that you follow these rules, otherwise we have to exclude you from the experiment and any payment. In case you have a question, please raise your hand, and we will answer your question privately.

The experiment will last for 6 rounds, and you will have to make a decision in each round. You are randomly assigned to groups of 5 participants, which remain unchanged for all rounds. At the beginning of the experiment, each participant of the group is endowed with 65 ECU just once. Your task in each of the 6 rounds is to make a decision on how you will use the 65 ECU.

The decision problem

As already described, you are a member of a group of five participants, in which each member is endowed with 65 ECU at the beginning. In each of the six rounds, you have the possibility to contribute any integral number between 0 and a maximum of 10 ECU to a joint account. The amount you have not contributed you may keep. After each member has made a decision about his or her contribution to the joint account, the next round starts, except for the sixth and last round.

The total income of each member of the group after the sixth round is calculated as follows:

Income from the joint account = Sum of all contributions over six rounds x 0.4

plus the ECU not contributed during the six rounds:

Total Income = Income from the joint account + ECU not contributed

For example, if, after six rounds, the sum of contributions of all group members to the joint account is 150 ECU, you and any other group member will receive an income of 150 x 0.4 = 60 ECU from the joint account. Additionally, you and all other group members will receive the respective ECU that have not been contributed to the joint account. If, after six rounds, the sum of contributions of all group members to the joint account is 150 ECU and you have not contributed 35 ECU, you will receive 60 + 35 = 95 ECU.

Thresholds

The total income at the end of round 6 also depends on whether the sum of contributions to the joint account has reached certain thresholds after the critical rounds 2, 4, and 6. The threshold for the sum of contributions after the second round is 50 ECU, after the fourth round 100 ECU, and after the sixth round 150 ECU. If the sum of contributions after a critical round does not reach the respective threshold, you will lose your total income with a probability of 50%.

All necessary random draws are made successively after round 6 (for rounds 2, 4, and six). This means you make a decision about your contribution to the joint account six times but will be informed whether you lost your total income if a threshold has not been reached after one of the critical rounds after the end of round 6. The result of the random draws will then be displayed on your computer screen.

The probability of a total loss

If your group contributes less to the joint account than is required for the respective thresholds after each of the three critical rounds (2, 4, and 6), you will lose your total income with a probability of $1/2 + 1/2 * 1/2 + 1/2 * 1/2 * 1/2 =$875/1000$(= 87.5\%)$.

If your group contributes less to the joint account than is required for the respective thresholds after two of the three critical rounds (rounds 2 and 4, 4 and 6, 2 and 6), you will lose your total income with a probability of $1/2 + 1/2 * 1/2 =$75/100$(= 75\%)$.

If your group contributes less to the joint account than is required for the respective threshold after one of the three critical rounds (round 2, 4, or 6), you will lose your total income with a probability of $1/2(= 50\%)$.

In case your group has reached the respective thresholds after each of the three critical rounds (round 2, 4, and 6), you may keep your total income for good.

	None of the three thresholds reached	One of the three thresholds reached	Two of the three thresholds reached	All three thresholds reached
Probability of losing the total income	87,5%	75%	50%	0%

If the threshold has been reached after each of the critical rounds, you and your group members earn the income from the joint account (sum of contributions over six rounds x 0.4) plus the ECU that you have not contributed.

If the sum of contributions to the joint account is less than 150 ECU after round 6, even though the thresholds have been reached after the other two critical rounds before (i.e., one of the three thresholds), you and your group members will lose your total income with a probability of 1/2 (50%). With a probability of 1/2 (=50%), you will receive the income from the joint account (sum of all contributions over six rounds x 0.4) plus the ECU that you have not contributed. The probability of not losing the total income is reduced analogously if more than one threshold has not been reached. After each round you are told how much each member of the group has contributed to the joint account.

Randomized Events
If thresholds have not been reached, it will be randomly decided whether you lose your total income after round 6. One number out of 1 to 1000 is randomly drawn. A number between 1 and 500 translates into a negative result (you lose your total income), while a number between 501 and 1000 translates into a positive result (you do not lose your total income). The number of random draws depends on the number of thresholds that have not been reached. If necessary, we start with the threshold after round 2, followed by, if necessary, the threshold after round 4, and finally, if necessary, the threshold after round 6. After the six rounds, your total income, the results of potential random draws, and your payoff (in €) will be displayed on the screen. After have finished reading the instructions, please click **Continue**. You will then be asked to answer some control questions.

Please answer the following control questions. The experiment will only start after all participants have answered all questions correctly.

1. Each group member is endowed with 65 ECU. Assume that all five group members (including yourself) contributed 3 ECU to the joint account in each of the six rounds.

   (a) In which critical rounds is the threshold reached (please mark the correct answer)?
   Round 2 ☐ and or
   Round 4 ☐ and or
   Round 6 ☐ or
   None of the three rounds ☐

   (b) With which probability will you lose your total income?

   ……

2. Each group member is endowed with 65 ECU. After the second round, a total 4 ECU have been contributed to the joint account. In the third round, a total of 20 ECU and in the fourth round a total of 26 ECU are contributed to the joint account. After round 6, 165 ECU have been contributed to the joint account.

   (a) After which rounds is the threshold reached (please mark the correct answer)?

Round 2	☐ and or
Round 4	☐ and or
Round 6	☐ or
None of the three rounds	☐

   (b) With which probability will you lose your total income?

   ……

   (c) Assume all random draws are to your advantage. Which income do you receive from the joint account?

   ……

3. Each group member is endowed with 65 ECU. You contribute a constant amount to the joint account in each of the six rounds. The other four group members contribute the same amount to the joint account in each of the six rounds.

   (a) What is the total income you will receive after round 6 if you and your group members contribute 10 ECU to the joint account in every round?

   ……

   (b) With which probability will you lose your total income if you and your group members contribute 0 ECU to the joint account in every round?

   ……

4. A total of 155 ECU have been contributed to the joint account. After round 6, you have 10 ECU left.

   (a) With which probability will you lose your total income if only the threshold after round 6 has been reached?

   ……

   (b) With which probability will you lose your total income if only thresholds after rounds 2 and 6 have been reached?

   ……

   (c) What is your total income (in ECU), if all thresholds have been reached?

   ……

Surprise restart (Instructions):
We are repeating this experiment once. You are once more assigned to a group of five participants, which will remain unchanged for the six rounds. Because of the high number of participants, it is unlikely that you will be assigned to the same group of five participants with the same group members.

Appendix E.

E.1 Trade Structure

TABLE E.1: Automotive trade in 2007 for selected European countries

	Germany	United Kingdom	Italy	France	Spain
Motor Cars Exports					
	In % of total exports				
Intra+Extra EU-25	14.4	6.6	2.3	5.6	11.7
Intra EU-25	16.0	6.8	3.1	7.3	14.7
Extra EU-25	11.7	6.3	1.3	2.5	4.9
	Exports in % of total intra EU-25 trade				
Germany	–	9.8	23.7	16.6	13.9
United Kingdom	24.1	–	14.8	14.4	13.6
Italy	17.6	15.4	–	15.3	11.1
France	12.4	7.1	16.8	–	41.9
Spain	12.3	13.9	13.0	20.0	–
Rest EU-25	33.6	53.8	31.6	33.7	19.5
	Relative share of intra trade (exports) compared to extra trade				
Intra EU-25	70.6	59.3	76.3	83.8	87.2
	Relative share of extra trade (exports) compared to intra trade				
Extra EU-25	29.4	40.7	23.7	16.2	12.8
Motor Cars Imports					
	In % of total imports				
Intra+Extra EU-25	4.2	7.0	7.5	5.6	7.7
Intra EU-25	4.8	11.5	12.0	7.3	10.1
Extra EU-25	3.0	1.7	1.8	1.9	3.8
	Imports in % of intra EU-25 trade				
Germany	–	45.3	44.9	36.3	48.9
United Kingdom	5.6	–	6.3	3.6	7.7
Italy	6.4	3.0	–	4.6	5.6
France	17.2	9.8	12.5	–	24.3
Spain	11.1	12.6	11.1	32.9	–
Rest EU-25	59.7	29.3	25.2	22.6	13.6
	Relative share of intra trade (imports) compared to extra trade				
Intra EU-25	74.3	88.7	89.3	89.6	80.6
	Relative share of extra trade (imports) compared to intra trade				
Extra EU-25	25.7	11.3	10.7	10.4	19.4

Quelle: Eurostat08 (2008), own compilation and calculations.

E.2 Demand Structure

TABLE E.2: German consumer preferences in 2007 (demand) and comparative national advantages with a focus on greenhouse gas emissions

Class	Country	Demand in %	CO_2/km
Lower-middle	Total	26.3	157.4
	European	76.8	155.7
	German	65.9	155.4
	Japanese	3.0	171.9
Lowest average emissions lower-middle	German		155.4
Upper-middle	Total	5.9	201
	European	97.5	200.2
	German	88.4	199.4
	Japanese	0.4	233.3
Lowest average emissions upper-middle	German		199.4
Premium-vans	Total	5.7	176.9
	European	86.1	174.4
	German	79.8	172.5
	Japanese	6.8	183.3
Lowest average emissions premium-vans	German		172.5
Middle	Total	16.6	174.9
	European	83.2	173.5
	German	80.2	173.7
	Japanese	6.4	174.1
Lowest average emissions middle	Swedish		155.8
Premium	Total	1.0	250.4
	European	98.2	250
	German	96.0	250.2
	Japanese	1.4	261.2
Lowest average emissions premium	British		236.3
Mini-vans	Total	6.9	162.9
	European	85.3	161.8
	German	51.4	159.8
	Japanese	9.4	168.6
Lowest average emissions mini-vans	Czech		157.5
Mini	Total	5.1	124.8
	European	72.0	125.7
	German	40.4	127.0
	Japanese	10.3	109.0
Lowest average emissions	Japanese		109.0
Compact	Total	19.0	143.7
	European	69.0	144.3
	German	39.8	142.8
	Japanese	4.9	134.4
Lowest average emissions compact	Japanese		134.4
SUVs	Total	7.4	229.7
	European	37.3	244.9
	German	37.3	244.9
	Japanese	14.4	190.3
Lowest average emissions SUVs	Japanese		190.3

Quelle: KBA (2008b).