Political Economy and Economic Impacts of Climate Policy

A Quantitative Analysis of International Emissions Trading

and Environmental Taxation

Von der

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– Fakultät II für Informatik, Wirtschafts- und Rechtswissenschaften –

genehmigte

DISSERTATION

zur Erlangung des Grades eines

Doktors der Wirtschaftswissenschaften (Dr. rer. pol.)

vorgelegt von

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geboren am 12. September 1977 in Erlangen

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Einreichung der Dissertation: 27. September 2008

Tag der Disputation: 26. März 2009

Kurzzusammenfassung

Die vorliegende Dissertation analysiert die politische Ökonomie und die ökonomischen Auswirkungen der Klimapolitik. Die Arbeit zeigt, dass die Ausgestaltung marktbasierter Instrumente des Klimaschutzes durch das Verhalten von politischen Entscheidungsträgern begründet werden kann, die ihre politische Unterstützung maximieren. So kann die Berücksichtigung von Präferenzen sektoraler Interessengruppen in klimapolitischen Entscheidungen ökonomische Ineffizienzen verursachen, die sich etwa in einer sektoralen Differenzierung von Umweltsteuern oder einer asymmetrischen Ausstattung von Teilbereichen der Volkswirtschaft mit handelbaren Emissionsrechten äußern. Die Ausgestaltung klimapolitischer Instrumente spielt ihrerseits eine entscheidende Rolle für die ökonomischen Effekte der Klimapolitik. Die Dissertation zeigt, dass der ökonomische Nutzen einer internationalen Verknüpfung von Emissionshandelssystemen in Industrieländern von der sektoralen Abdeckung der Systeme sowie der Stringenz der Zuteilung von Emissionsrechten abhängt. Die Ermöglichung regional flexibler Emissionsreduktionen, etwa durch den Zugang zu Vermeidungsoptionen in Entwicklungsländern, verbessert zudem die Aussichten für eine kosteneffiziente und ambitionierte zukünftige Klimapolitik substantiell.

Abstract

This thesis presents a political economy analysis and an economic impact assessment of climate change policy. It shows that the design of market-based instruments of climate policy can be explained by the behavior of environmental regulators who maximize their political support. The consideration of preferences of sectoral interest groups in regulatory decisions can induce economic inefficiencies in terms of a sectoral differentiation of environmental taxes or an asymmetric allocation of tradable emissions permits to parts of the economy. In turn, the design of climate policy instruments plays a decisive role for the associated economic impacts. The thesis shows that the economic benefits of linking domestic emissions trading schemes of industrialized nations depend on the sectoral scope of these schemes and the stringency of allowance allocation. Establishing regional flexibility of emissions reductions, e.g. via the access to carbon abatement options in developing countries, further improves the prospects for a cost-efficient and ambitious implementation of future climate policy.

Acknowledgements

This dissertation was accomplished during my occupation as a research fellow at the Centre for European Economic Research (ZEW), Mannheim. I would like to express my appreciation to a number of persons without whom this thesis would not have been possible. First of all I am grateful to Christoph Böhringer, who introduced me to the quantitative economic analysis of climate change policy and provided invaluable scientific advice and guidance for the dissertation. I would like to particularly thank Heinz Welsch for the supervision of the dissertation and his valuable suggestions, as well as Andreas Löschel, head of the ZEW department "Environmental and Resource Economics, Environmental Management" for his scientific support and the facilitation of a dynamic working environment. Many colleagues at the ZEW have supported the thesis with helpful comments and suggestions: Tim Hoffmann, Victoria Alexeeva-Talebi, Astrid Dannenberg, Henrike Koschel, Andreas Lange, Tim Mennel, Ulf Moslener, Ulrich Oberndorfer, Bodo Sturm, Carsten Vogt and Andreas Ziegler. Parts of this dissertation were completed during a research visit at the Graduate School of Business, Columbia University, New York. I would therefore like to thank Geoffrey Heal for his scientific advice and the opportunity to participate in an inspiring international research environment.

I am grateful for comments and suggestions of participants at annual congresses of the European Economic Association, the Verein für Socialpolitik, the European and International Association of Environmental and Resource Economists, the International Association for Energy Economics, the European Public Choice Society, the Monte Verità Conference on Sustainable Resource Use and Economic Dynamics and the Spring Meeting of Young Economists. In particular, I would like to thank the participants of the workshops of the Ph.D. network on International Climate Policy and the Research Committee "Environmental and Resource Economics" of the Verein für Socialpolitik for helpful discussions and interesting encounters. Financial support from the European Commission, the German Federal Ministry of Education and Research, the German Federal Environment Agency, the German Academic Exchange Service and the Deutsche Bundesbank is gratefully acknowledged.

Finally, I would like to thank my parents, my sister and Esther who were always at my side with so much support and advice.

Contents

List of Tables

List of Figures

1 Introduction

The change of the global climate has become a growing concern worldwide. In its 2007 assessment report, the Intergovernmental Panel on Climate Change (IPCC) reemphasized the urgency of political action by stating that "continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century" (IPCC, 2007). Fossil fuel combustion and land use change are the primary causes of global warming, both leading to increased atmospheric concentrations of greenhouse gases such as carbon dioxide, methane and nitrous oxide. The projected consequences of climate change include rising sea levels due to thermal expansion of the oceans, melting of glaciers and the polar ice sheets, as well as increases in extreme weather events and changes in ecological and physical systems. Against this background, the Stern Review recently suggested that strong and early action to combat global warming would yield benefits in terms of prevented damages that considerably outweigh the associated economic costs (Stern, 2007).

The public response to global warming originates from the United Nations Framework Convention on Climate Change, which recognized the climate system as a shared resource on an international level (UNFCCC, 1992). Five years later, concrete climate change policy was agreed upon in the Kyoto Protocol, committing industrialized countries to quantitative reductions of greenhouse gas emissions between 2008 and 2012 (UNFCCC, 1997). For these commitments to be fulfilled economically, the agreement allows for three flexible mechanisms: international emissions trading among governments as well as project-based emissions reductions, either in Annex B regions via Joint Implementation (JI) or in developing countries via the Clean Development Mechanism (CDM). At the national level, many industrialized nations implemented market-based instruments of climate policy in order to achieve their targets under the Kyoto Protocol, most importantly taxes on emissions and energy use or domestic emissions trading schemes. At the European level, the EU Emissions Trading Scheme (EU ETS) is operating since the year 2005 and facilitates the international trade of carbon emissions allowances among energy-intensive installations (EU, 2003).

Both the Kyoto Protocol and the EU ETS are currently undergoing important developments. The 2007 United Nations Climate Change Conference resulted in the adoption of the so-called "Bali Roadmap", which shall pave the way for a negotiation process towards a new and more ambitious international climate policy treaty beyond the year 2012. In addition to the access of industrialized countries to abatement options in developing regions via the CDM under the Kyoto Protocol, a more stringent post-Kyoto agreement is expected to consider new abatement options such as reduced deforestation in tropical rainforest regions. Also the EU ETS is envisaged to tighten carbon constraints for EU Member States. Likewise, the future emissions reduction targets are expected to be fulfilled with greater regional flexibility by linking the EU ETS internationally to emerging emissions trading schemes in third countries.

As compared to the policy instrument of tradable permits introduced more recently, environmental taxes on energy or emissions have already played an increasing role in market-based climate policies of OECD countries over the last decades (OECD, 2007). Against the background of rising unemployment rates in the industrialized world, environmental tax reforms commonly increased levies on energy use while recycling the additional tax revenues through a reduction of employers' social security contributions. A prominent example is Germany's reform which was implemented between 1999 and 2003. The introduction of environmental tax reforms thus generally aimed at achieving a "double dividend", i.e. simultaneously improving environmental quality by decreasing emissions and fostering economic development by increasing employment.

Conceptual and methodological approach

This thesis provides a political economy analysis and an economic impact assessment of climate change policy. While the former dimension aims at explaining the rationale and determinants of the actual implementation of environmental policy, the latter focuses on the economic consequences induced by alternative policy designs and gives recommendations for an economically desirable policy design. In particular, this dissertation assesses the role of interest groups for the implementation of environmental taxes and emissions trading schemes, as well as the economic implications of future designs and novel market-based instruments of climate policy. The two dimensions of this thesis are conceptually interlinked: Anticipated or actual economic impacts of climate policy may generate an organization of interests with the goal of influencing the policy design in a favorable direction, and induced changes in the design of climate policy translate into an adjustment of the corresponding economic impacts.

Standard economic theory suggests that a sound introduction of market-based instruments of environmental policy – such as uniform emissions taxes or (auctioned) tradable emissions allowances – can generate cost-efficient emissions reductions by equalizing marginal abatement costs across polluters. However, the actual implementation of market-based instruments generally deviates from its first-best design: The free allocation of allowances in the initial phase of the EU ETS has been criticized for its generous and differential treatment of regulated industries, as well as its incomplete sectoral coverage. In this vein, a number of previous studies on the economic impacts of EU ETS regulation indicate considerable efficiency losses through segmented emissions markets and a loose allocation of permits (see e.g. Böhringer et al., 2005 or Kallbekken, 2005). As regards environmental taxation, most commonly tax rates are differentiated across polluters and discriminate in favor of energy-intensive industries, including the extreme case of full tax exemptions. However, macroeconomic simulation studies find little economic rationale for discriminating environmental taxes strongly in favor of energy-intensive industries, even when accounting for potential efficiency reasons such as tax interactions, leakage or international market power (Böhringer and Rutherford, 2002).

The lack of an economic efficiency rationale for the observed implementation of environmental taxes and emissions trading schemes provides the motivation for a political-economy analysis of climate policy. Here, the term *Political Economy* denotes the analysis of political processes through which public economic decisions are made and aims to identify key determinants of actual policy decisions. In the context of climate policy and the associated competition between environmental and economic preferences, interest groups play a central role for explaining the design of policy instruments. While traditional positive theories of environmental policy analyzed how efficient policy measures affected interest groups in order to explain their formation and behavior, more recent approaches take the opposite perspective: they analyze how competing interests of economic agents in the form of lobby groups determine an (inefficient) implementation of climate policy by supporting their preferred designs (Oates and Portney, 2003). This thesis will follow the latter approach by analyzing the role of interest groups for the design of environmental taxation and international emissions trading.

Due to the public-good nature of climate protection, the most important obstacle to the implementation of ambitious climate policy has traditionally been the associated mitigation costs. As a prominent example, the protracted negotiations of the Kyoto Protocol eventually allowed business-as-usual emissions and imposed negligible compliance costs of regulation (Böhringer and Vogt, 2003). Thus, viable and environmentally effective strategies for future climate policy will have to be economically acceptable at the same time. Numerical model evaluations of emissions reduction policies indicate that the associated mitigation costs can be substantially reduced through the international trade of permits and the associated regional flexibility in emissions abatement. In general, these studies show that central determinants of the magnitude of compliance costs include the number of regions participating in the emissions market, regional abatement cost characteristics and the extent to which permit importers can achieve their abatement targets through emissions trading (see e.g. Weyant and Hill, 1999 for an evaluation of the Kyoto Protocol). This thesis builds on these fundamental insights by analyzing the economic impacts of designs of future climate policy with a focus on its most prominent instrument: international emissions trading.

In order to conduct the conceptually twofold analysis, three methodological approaches will be employed. First, economic theory constitutes the backbone of the analysis by providing insights into the fundamental mechanisms at work and setting the stage for a concrete assessment of the political economy and the economic impacts of climate policy. Second, numerical economic simulation models incorporate real-world data and complexities to quantify the economic impacts of climate policy on partial markets or the macroeconomic level from an *ex ante* perspective. The economic impacts of climate policy such as international emissions trading are analyzed with numerical simulation models covering the interactions between energy, environment and the economy (see Weyant and Hill, 1999 for an overview). These models typically differ with respect to their technological richness and market coverage. While partial economic models feature, e.g., a detailed representation of the energy system or the marginal cost structure of emissions abatement, they abstract from interactions with the remaining parts of the economy. Economy-wide models such as Computable General Equilibrium (CGE) models feature a more aggregate treatment of the energy system, but are able to capture important feedback effects of climate policy on non-energy or emissions markets via price reactions in factors and intermediate goods. Third, econometric analysis aims to explain the implementation of climate policy from an *ex post* perspective. It thereby facilitates the empirical identification of key political-economy determinants of climate policy decisions, as well as their interplay with other relevant factors of instrument design.

Structure of the dissertation

This dissertation comprises a selection of essays on the political economy and the economic impacts of climate change policy. Each chapter provides a stand-alone analysis featuring an introduction to the research question of interest, the contribution to the existing literature and the methodological approach. The majority of essays was written in collaboration with co-authors and simultaneously prepared for submission to academic journals. Against this background, a schematic overview of the thesis (including employed methodologies, co-authors, and status of submission) is provided in Table 1 subsequent to the introduction.

The dissertation is structured along two thematic parts. Following this introduction, Part I presents a political-economy analysis of climate change policy and consists of three chapters: Chapter 2 assesses the role of interest groups for environmental tax differentiation across industries on theoretical and empirical grounds. Propositions from a political-support model of differentiated environmental taxes are tested with an econometric analysis of the German ecological tax reform. Chapter 3 investigates the political-economy determinants of allowance allocation in the EU ETS. Theoretical predictions from a political-support model of the role of interest groups for the allocation of emissions allowances are verified by an empirical analysis of the first trading phase of the EU ETS at the firm level. Chapter 4 assesses the political economy of environmental policy advice by conducting a meta-analysis of model-based simulation studies on the double-dividend hypothesis. It investigates the implications of commissioning and the role of central model assumptions for the outcome of publications.

Part II presents an economic impact assessment of climate change policy and consists of three chapters: Chapter 5 analyzes the economic impacts of linking the EU ETS to emerging schemes beyond Europe in the presence of a post-Kyoto agreement. Based on a numerical multi-country, two-sector partial equilibrium model of the world carbon market economic impacts are quantitatively assessed. Chapter 6 assesses the macroeconomic and international trade implications of supra-European emissions trading schemes employing a large-scale computable general equilibrium model of the global economy. It derives the aggregate welfare impacts of linking the EU ETS as well as economy-wide and sectoral trade-based competitiveness effects. Chapter 7 investigates the economic impacts of integrating reduced tropical deforestation in international emissions trading by linking a numerical equilibrium model of the global carbon market with a dynamic equilibrium model of the forestry sector.

As the closing section of this thesis, chapter 8 summarizes its central findings and concludes.

Table 1: Schematic overview of the dissertation

Part	Chapter	Methodology	Co-authors	Corresponding author	Status
***I.** Political Economy of Climate Policy*	**2.** The Political Economy of Environmental Tax Differentiation: Theory and Empirical Evidence	Theoretical model, Regression analysis	Andreas Lange (University of Maryland), Christoph Böhringer (University of Oldenburg)	Niels Anger	Submitted to: *Journal of Public Economics*
	3. Public Interest vs. Interest Groups: Allowance Allocation in the EU Emissions Trading Scheme	Theoretical model, Regression analysis	Christoph Böhringer (University of Oldenburg), Ulrich Oberndorfer (Centre for European Economic Research)	–	Submitted to: *Scandinavian Journal of Economics*
	4. Paying the Piper and Calling the Tune? A Meta-Analysis of Simulating the Double-Dividend Hypothesis	Regression analysis	Christoph Böhringer (University of Oldenburg), Andreas Löschel (Centre for European Economic Research)	Niels Anger	Submitted to: *Ecological Economics*
***II.** Economic Impacts of Climate Policy*	**5.** Emissions Trading Beyond Europe: Linking Schemes in a Post-Kyoto World	Theoretical background, Numerical model simulations	–	Niels Anger	Published in: *Energy Economics*
	6. Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis	Theoretical background, Numerical model simulations	Victoria Alexeeva-Talebi (Centre for European Economic Research)	Niels Anger	Submitted to: *Applied Economics*
	7. Reducing Deforestation and Trading Emissions: Economic Implications for the post-Kyoto Carbon Market	Numerical model simulations	Jayant Sathaye (Lawrence Berkeley National Laboratory)	Niels Anger	Submitted to: *The Energy Journal*

Part I

Political Economy of Climate Policy

2 The Political Economy of Environmental Tax Differentiation: Theory and Empirical Evidence[1]

Over the last decade, environmental taxes on energy or emissions have played a growing role in environmental policies of OECD countries. As a common feature of environmental tax schemes, tax rates are differentiated across polluters: taxation typically discriminates in favor of energy-intensive industries including – as an extreme case – complete tax exemptions (OECD, 2007).

While simple textbook economics suggests uniform tax rates to internalize an environmental externality, market imperfections or distortions are potential reasons why sectorally differentiated taxes can be desirable under efficiency considerations. Environmental tax differentiation may, for example, attenuate the inefficiencies induced by labor market rigidities or initial tax distortions (Richter and Schneider, 2003). Another well-known argument for environmental tax differentiation is the phenomenon of leakage, i.e. increased transboundary pollution from non-abating countries in the case of unilateral emission abatement (Felder and Rutherford, 1993). Here, a differentiation of tax rates across domestic sectors can reduce leakage and increase efficiency of (global) emission reduction (Hoel, 1996). Accounting for market power of large open economies, differentiated environmental taxes may also be enacted to change terms-of-trade against trading partners (Krutilla, 1991; Anderson, 1992; Rauscher, 1994).

Quantitative evidence to back these theoretical arguments, however, is rather scant. Drawing on simulations with a computable general equilibrium model based on empirical data, Böhringer and Rutherford (2002) conclude “that there is little economic rationale for the common policy practice of discriminating strongly in favor of heavy industries, even when accounting for interacting taxes, leakage, and international market power.“ In the same vein, Babiker et al. (2000) and Kallbekken (2005) identify large efficiency costs from differentiating emission regulation across sectors. The lack of a strong rationale for sectorally differentiated environmental taxes based on pure efficiency considerations provides the

[1] This chapter is based on the paper: Anger, N., Böhringer, C., and A. Lange (2006): “Differentiation of Green Taxes: A Political-Economy Analysis for Germany”, *ZEW Discussion Paper* 06-003, Mannheim. The manuscript is currently submitted to the *Journal of Public Economics*. As the corresponding author of the

motivation for our political-economy analysis. We investigate the role of interest groups for environmental tax differentiation both from a theoretical and empirical point of view.

Positive theories on the role of interest groups in policy formation employ various models to study political determinants of environmental policy. Oates and Portney (2003) provide an overview of alternative modeling approaches: rent-seeking models describe how interest groups compete for group-specific rents (Tullock, 1980), specifically in the context of environmental instrument choice (Dijkstra, 1998). Probabilistic-voting models assume that lobby groups influence policy makers through the potential, yet uncertain votes of their members (Coughlin, 1992). Models of information transfer refer to the exchange of truthful information between interest groups and policy makers, upon which politicians base their decisions (Grossman and Helpman, 2001; Naevdal and Brazee, 2000; Potters and van Winden, 1992).

Previous research on political-economy determinants of environmental taxation includes Frederiksson (1997) and Aidt (1997, 1998) who investigate the implications of international competition and revenue recycling for the design of environmental tax reforms.[2] Cremer et al. (2004) adopt a voting model to analyze how political support for environmental taxes depends on the revenue rebating scheme. Polk and Schmutzler (2005) present a theoretical model where two interest groups can lobby for a general tax rate or sector-specific favors.

In this paper, we adopt the common-agency approach by Grossman and Helpman (1994) to explain environmental tax differentiation by lobbying activities when the environmental target is fixed and tax revenues are used to lower labor costs. We focus on analyzing the impact of lobbying on tax differentiation. That is, we take the decision on how to recycle tax revenues as well as the environmental emission target as given.[3] We demonstrate that, ceteris paribus, a sector with larger lobby power faces lower environmental tax rates than sectors with smaller lobby power. However, the effectiveness of lobbying depends on the ease of emission abatement in industrial sectors: if interest groups have little influence on regulatory decisions, sectors with relatively inelastic emission demand face higher tax rates (corresponding to the standard Ramsey formula). In contrast, if regulatory decisions are sufficiently prone to

manuscript, I contributed to all sections of the chapter except of section 2.1, with a focus on the empirical analysis in section 2.2.

[2] Abstracting from political economy considerations, Lange and Requate (2000) and Gersbach and Requate (2004) provide additional results on efficiency implications of alternative revenue-recycling schemes.

[3] The astute reader might wonder about the optimality of taxing emissions and rebating the revenues. Differently from the literature on optimal taxatation, we do not intend to study or compare different possible means of taxation (e.g. taxes on inputs, outputs, or profits, etc.). We therefore model the determinants of tax differentiation

influence by interest groups, sectors with relatively inelastic emissions demand and sufficiently strong lobby power will face lower tax rates. As a consequence, sectors with highly inelastic emission demand have large incentives to organize themselves in order to increase their lobby power.

In order to test our theoretical predictions, we employ a cross-sectional regression analysis of the German environmental tax reform which was implemented between 1999 and 2003. This tax reform increased taxes on energy use while recycling the additional tax revenues through a reduction of employer's social security contributions, i.e. labor costs. A central feature of Germany's environmental tax reform, which can be generalized to environmental tax reforms in other OECD countries (OECD, 2007), is tax differentiation in favor of energy-intensive firms. The empirical assessment is based on the number of lobby representatives in the respective sectors. It backs our theoretical propositions: environmental tax rates are discriminated in favor of industrial sectors represented by more powerful lobbies. Moreover, we find that the impact of lobbying depends on sector-specific energy demand elasticities. Besides the activities of lobby groups, market concentration and the exposure of industries to international trade flows are identified as important determinants of the environmental tax design.

To our best knowledge, the empirical analysis constitutes the first quantitative assessment of the role of interest groups in environmental tax differentiation. Previous empirical studies have analyzed the role of lobbying in other environmental policy areas using alternative channels of lobby power. Fredriksson et al. (2004) assess the effect of corruption and industry size on energy efficiency: they find that higher costs for lobby group coordination (i.e. larger sector size) increase energy policy stringency, while greater corruptibility of policy makers reduces it. Hanoteau (2003) shows that industrial lobbying can influence the allocation of emission allowances, measuring the level of rent-seeking efforts by contributions from Political Action Committees. Similarly, a study by Burkey and Durden (1998) on the design of the Clean Air Act Amendment of 1990 confirms that financial contributions significantly influenced the voting patterns of politicians.

The remainder of this paper is organized as follows. In section 2.1, we describe our common-agency framework and derive differentiated environmental taxes under political-economy considerations. In section 2.2, we present our empirical analysis on determinants of differentiated environmental taxes for the case of Germany. In section 2.3, we conclude.

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within the set of taxation schemes which was applied in the German environmental tax reform: taxes on

2.1 A political-economy model of differentiated environmental taxes

We develop a *common-agency* model of a small open economy in order to investigate political-economy motivations for environmental tax differentiation between sectors. Our model is in the tradition of Aidt (1998) and Grossman and Helpman (1994): lobbying of some sectors affects the policy choice of the government (the regulator) which is not only interested in overall welfare but also values political support by the different interest groups.

We consider an economy with $s = 1,...,n$ production sectors. Heterogeneous consumers (which we do not model explicitly) receive all the labor income and hold all the profit shares of the firms. In a sector *s*, competitive firms produce output by using labor l_s and energy (emissions) e_s. Energy is imported from the world market at unit costs $\bar{z}$. Output q_s of sector *s* is produced by means of a concave production function $f^s(e_s, l_s)$ and can be sold at world market price $\bar{p}_s$.[4] To simplify the exposition of our results, we assume that the production decisions on labor and energy are separable, i.e. $\partial^2 f^s / \partial e \partial l(e_s, l_s) = 0$.

The environmental tax reform is assumed to redistribute energy taxes via reductions in labor costs:[5] the regulator taxes emissions (energy use) at a rate τ_s such that firms face unit costs of energy (emissions) $z_s = \bar{z} + \tau_s$. As to the treatment of labor cost, we follow Bovenberg and van der Ploeg (1996) in assuming that labor supply is rationed by a (uniform) exogenous employees' wage $\bar{w}_e$, i.e. the net wage. The gross wage to be paid by the employers differs from the net wage because of taxes and social security contributions. We denote the gross wage prior to the tax reform by $\bar{w}_p$. The revenues from environmental taxes are earmarked to reduce the tax wedge between $\bar{w}_e$ and $\bar{w}_p$. The effective producer wage is therefore given by $w = \bar{w}_p - \sigma$ where σ will be endogenously determined by the tax yield.

We assume that the regulator taxes emissions in order to achieve an aggregate emission target:

$$\bar{E} = \sum_s e_s \,. \tag{1}$$

energy/emissions, rebates on labor.

[4] With this formulation, we implicitly assume a competitive world market such that we do not have to consider consumption choices and consumer surplus in the domestic market. More generally, a sector could face a downward sloping demand if no (perfect) substitutes are produced by producers abroad. Then, domestic policy could exploit the terms-of-trade. We abstract from these effects in our theoretical analysis in order to focus on the impact of lobby power on tax differentiation.

The emission tax yield is earmarked for reducing labor costs, i.e.:

$$\sigma\sum_s l_s = \sum_s \tau_s e_s \tag{2}$$

Profits at the sectoral level are:

$$\pi_s = \overline{p}_s f^s(e_s, l_s) - (\overline{z} + \tau_s)e_s - (\overline{w}_p - \sigma)l_s . \tag{3}$$

Social welfare is given by:

$$W = \overline{w}_e \sum_s l_s + \sum_s \pi_s + \psi[\sum_s \tau_s e_s + (\overline{w}_p - \overline{w}_e - \sigma)l_s] \tag{4}$$

where $\psi \geq 1$ denotes the marginal costs of public revenue. Since the aggregate emission target is fixed exogenously, we can neglect damages.[6]

Production decisions by competitive profit-maximizing firms are characterized by the usual first-order conditions:

$$\overline{p}_s f_e^s(e_s, l_s) = \overline{z} + \tau_s \qquad \overline{p}_s f_l^s(e_s, l_s) = \overline{w}_p - \sigma \tag{5}$$

Application of the envelope theorem yields:

$$\frac{d\pi_s}{d\tau_s} = -e_s \qquad \frac{d\pi_s}{d\sigma} = l_s \tag{6}$$

2.1.1 Political interests

The government chooses a tax scheme $TS = ((\tau_1, ..., \tau_n), \sigma)$ that achieves the emission target $\overline{E}$ (condition (1)) and uses the emission tax yield to reduce labor costs (condition (2)). In the design of the tax scheme, the government does not only consider social welfare but also contributions (political support) $C_s(TS)$ by lobby groups. We assume that there is a lobby group for each sector s representing (a fraction of) the firms or likewise profits in the respective sector. The weight by which contributions are valued on behalf of the government is denoted by λ. Thus, the government maximizes:

$$W(TS) + \lambda \sum_s C_s(TS) \tag{7}$$

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[5] The swap of energy taxes for labor costs is a general feature of green tax reforms (OECD, 2001; OECD, 2007).

[6] The fixing of emission targets is widely spread in environmental policies adopting a precautionary approach in the absence of full information on damages caused by emissions (see e.g. the current practise in climate policy where industrialized countries committed themselves to fixed emission targets under the Kyoto Protocol).

Within each sector, lobbying represents a public good and a single firm has incentives to free-ride on the lobbying activities of other firms in the same sector. We assume that the degree to which a sector can overcome these free-riding problems is measured by the fraction $\kappa_s \in [0,1]$ of total profits π_s represented by the respective lobby group.[7] $\lambda\kappa_s$ therefore measures the lobbying power of the respective sector. We first derive the lobbying outcomes for any given $(\kappa_s)_s$, and then discuss the determinants of $\kappa_s \in [0,1]$ in more detail in section 2.3.[8]

Before the government decides upon the tax system *TS*, each lobby group offers a menu of contributions (political support), $C_s(TS)$ (as a function of the government's policy choice), in order to maximize profits in its sector (Bernheim and Whinston, 1986). In our analysis, we focus on the equilibrium which is given by each lobby group truthfully reporting their costs and benefits from the respective policy (see, e.g., Grossman and Helpman, 1994 or Aidt, 1998 for a proof of existence). Each contribution schedule $C_s(TS)$ is hence given by $\kappa_s\pi_s$ (less some constant).

The decision problem (7) of the government then corresponds to the maximization of:

$$G(TS) = W(TS) + \lambda \sum_s \kappa_s \pi_s(TS) \tag{8}$$

by choosing $(\tau_s)_s$ and σ subject to (1) and (2).

Denoting the Lagrange multipliers for (1) and (2) by μ_1 and μ_2, and aggregate labor demand by $L = \sum_s l_s$, we obtain the following first-order conditions (based on the firms' first-order conditions (5) and (6)):

$$0 = \frac{\partial G}{\partial \sigma} = \sum_s (\lambda\kappa_s + 1) l_s + \bar{w}_e \frac{\partial L}{\partial \sigma} + \psi(\bar{w}_p - \bar{w}_e)\frac{\partial L}{\partial \sigma} - (\psi - \mu_2)[\sigma \frac{\partial L}{\partial \sigma} + L] \tag{9}$$

and

$$0 = \frac{\partial G}{\partial \tau_s} = -(\lambda\kappa_s + 1)e_s - \mu_1 \frac{\partial e_s}{\partial \tau_s} + (\psi - \mu_2)[\tau_s \frac{\partial e_s}{\partial \tau_s} + e_s]. \tag{10}$$

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[7] $(\kappa_s)_s$ thereby depend on the organizational structure of the sector, e.g. its concentration which will be used as one explanatory variable in the empirical part in section 3.

[8] The sector's incentives to organize, i.e. to increase κ_s, clearly also depends on the sector's influence on the government's policy choice (i.e. the impact of κ_s on sectoral profits). In the following, we therefore first consider the policy choice as a function of $(\kappa_s)_s$ and then undertake comparative statics with respect to these parameters.

Conditions (9) and (10) determine the optimal differentiation of taxes. Condition (9) can be rewritten as:

$$\begin{aligned}\psi - \mu_2 - 1 &= \lambda \sum_s \kappa_s l_s / L + [\overline{w}_e + \psi(\overline{w}_p - \overline{w}_e) - (\psi - \mu_2)\sigma] \frac{\partial L}{\partial \sigma} / L \\ &= \lambda \sum_s \kappa_s \gamma_s + [\overline{w}_e + \psi(\overline{w}_p - \overline{w}_e) - (\psi - \mu_2)\sigma] \varepsilon / (\overline{w}_p - \sigma)\end{aligned} \tag{11}$$

Here, $\varepsilon = \frac{\partial L}{\partial \sigma} \frac{\overline{w}_p - \sigma}{L}$ denotes the price elasticity of aggregate labor demand, and $\gamma_s = l_s / L$ is the fraction of labor in sector s. Condition (10) is equivalent to:

$$\begin{aligned}0 &= -(\lambda \kappa_s + 1) + \mu_1 \eta_s / (\overline{z} + \tau_s) + (\psi - \mu_2)[1 - \eta_s \tau_s / (\overline{z} + \tau_s)] \\ \tau_s &= \frac{\mu_1 \eta_s + (\psi - \mu_2 - \lambda \kappa_s - 1)\overline{z}}{(\lambda \kappa_s + 1) - (\psi - \mu_2)(1 - \eta_s)} \\ &= -\overline{z} + \frac{\mu_1 + (\psi - \mu_2)\overline{z}}{(\psi - \mu_2) - (\psi - \mu_2 - \lambda \kappa_s - 1) / \eta_s}\end{aligned} \tag{12}$$

where $\eta_s = (-\frac{\partial e_s}{\partial \tau_s} / e_s)(\overline{z} + \tau_s)$ denotes the price elasticity of energy demand in sector s. We use the first-order conditions (11) and (12) to discuss the determinants of tax differentiation in our political-economy framework.

2.1.2 The determinants of tax differentiation

In order to obtain theoretical propositions for determinants of environmental tax differentiation (tested below in section 3.3), we derive comparative static results for optimal tax rates in the political economy equilibrium as given by (11) and (12). Condition (12) implies that:

$$\tau_s < \tau_{s'} \Leftrightarrow (\psi - \mu_2 - \lambda \kappa_s - 1) / \eta_s < (\psi - \mu_2 - \lambda \kappa_{s'} - 1) / \eta_{s'} \tag{13}$$

Ceteris paribus, for two sectors which only differ in their lobby power (measured by κ_s), the one with a stronger lobby power κ_s faces a smaller tax rate. The equilibrium tax rates also depend on the price elasticities of energy demand: sectors with less elastic energy demand face a higher tax if $\psi - \mu_2 - \lambda \kappa_s - 1 > 0$. Differences in energy demand elasticities have the opposite effect if $\psi - \mu_2 - \lambda \kappa_s - 1 < 0$. This suggests that – in equilibrium – there is an interaction effect between lobby power and the elasticity of energy demand regarding their impact on the tax rate: while sectors with weak lobby power would receive a higher (lower) tax rate if they have relatively inelastic (elastic) energy demand, for sectors with strong lobby power this effect could be reversed.

We can derive the following proposition:

Proposition 1: *(i) If two sectors have identical energy demand (emission) elasticity, the sector with stronger lobby power faces a lower tax rate. (ii) If two sectors have identical lobby power (κ_s), the sector with less elastic emissions is taxed more (less) if the impact of lobbying on regulatory decisions is sufficiently weak (strong), i.e. if λ is sufficiently small (large).*

While (i) follows immediately from (13), we show (ii) by studying the extreme cases in which (a) the regulator does not consider contributions ($\lambda = 0$), and (b) the regulator only considers lobby support but places no weight on social welfare ($\lambda \to \infty$).[9]

Case (a):

If there is no political power of interest groups ($\lambda = 0$) then :

$$\psi - \mu_2 - 1 = [\overline{w}_e + \psi(\overline{w}_p - \overline{w}_e) - (\psi - \mu_2)\sigma]\varepsilon / (\overline{w}_p - \sigma) \tag{11'}$$

$$\tau_s = -\overline{z} + \frac{\mu_1 + (\psi - \mu_2)\overline{z}}{(\psi - \mu_2) - (\psi - \mu_2 - 1)/\eta_s} \tag{12'}$$

Since $\psi - \mu_2 - 1 > 0$,[10] and $\overline{z} > 0$, the numerator of (12') is positive and condition (12') implies that, ceteris paribus, less elastic energy demand leads to higher tax rates: tax rates will be differentiated because of a "tax yield" effect which corresponds to a standard Ramsey-formula.

Case (b):

If the regulator maximizes lobby support ($\lambda \to \infty$) only, the first-order conditions can be rewritten as (using a normalization of μ_1 and μ_2):

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[9] Due to continuity, the qualitative relationships for $\lambda = 0$ extend to sufficiently small λ, while sufficiently large λ qualitatively correspond to $\lambda \to \infty$.

[10] This is trivial for the case where $\mu_2 < 0$. If $\mu_2 > 0$, condition (11') implies the positive sign of ($\psi - \mu_2 - 1 > 0$) as the wedge between wages received by employees and the costs of labor faced by employers is positive, i.e. $\overline{w}_p - \overline{w}_e > \sigma$.

$$-\mu_2(1+\sigma\varepsilon/(\overline{w}_p-\sigma))=\sum_s \kappa_s\gamma_s \qquad (11'')$$

$$\tau_s=-\overline{z}+\frac{\mu_1-\mu_2\overline{z}}{-\mu_2+(\mu_2+\kappa_s)/\eta_s}. \qquad (12'')$$

Condition (11'') implies that $0<-\mu_2<\sum_s \kappa_s\gamma_s$ (where the right-hand side represents a labor-weighted average of lobbying power). As a consequence, the numerator in condition (12'') is positive ($\overline{z}>0$). With this, (12'') implies that sectors with large κ_s (i.e. $\mu_2+\kappa_s>0$) will, ceteris paribus, face a smaller emissions tax if they have less elastic emission demands. This completes the proof.

The traditional relationship between taxes and elasticities can therefore be reversed in the presence of strong lobby power: while taxing sectors with less elastic emissions is beneficial in terms of generating tax yield it would induce high tax payments and therefore heavily reduced profits by those sectors. As lobbying is targeted towards the increase of profits, stronger lobbying will lead to a smaller tax.

Proposition 1 thereby implies that the impact of the emission elasticity on taxes crucially depends on how the government weighs lobby support: if regulatory decisions are barely affected by lobbying, sectors with less elastic emissions face a larger tax rate, confirming the traditional Ramsey formula prediction. If, however, the regulator can easily be influenced by lobbying, this relationship is reversed such that less elastic sectors then face lower tax rates.[11]

So far we assumed the lobby power κ_s to be exogenous. As one cannot observe the lobby power parameter κ_s directly, we now discuss potential determinants of lobby power. These are used to derive proxies for sectoral lobby power within our empirical analysis.

2.1.3 Explaining the lobby power of sectors

Environmental taxation is only one policy measure among many which can induce lobbying activities. We may therefore assume that sectors have already formed lobby groups prior to an environmental tax reform.

In general, organizing sectoral lobbying is more difficult for sectors with large numbers of firms (see, e.g., Olson 1965). For a given group size, however, larger degree of organization can be expected if a sector is dominated by only a few big firms, i.e., the degree of market concentration is high. The reasoning behind can be traced back to the public good character of the lobbying efforts: single firms have incentives to free ride on lobbying of other firms in the same sector.[12]

In addition to this general organizational structure of lobby groups, the lobby power on a specific policy issue is obviously driven by the potential of interest groups to influence government's policy on this policy issue. In the context of an environmental tax reform, we can expect the lobby power κ_s to be larger for those sectors where the increase of κ_s will substantially augment the profits of the sector or – likewise – decrease the expected burdens from the tax reform net of lobbying expenditures (as opposed to sectors where an increase in κ_s has a smaller effect).

Against this reasoning, we consider the effects of changes in lobby power κ_s on the equilibrium of our political economy model: as laid out in Appendix 2.4.2, the marginal effect of an increase in κ_s on equilibrium profits of a sector s net of lobby contributions, $\hat{\pi}_s(\kappa_s) = \pi_s(TS(\kappa_s)) - C_s(TS(\kappa_s))$, is given by:

$$\frac{d\hat{\pi}_s(\kappa_s)}{d\kappa_s} = (1-\kappa_s)\overline{E}\left[-\alpha_s \frac{d\tau_s(\kappa_s)}{d\kappa_s} + \gamma_s L / \overline{E} \frac{d\sigma(\kappa_s)}{d\kappa_s}\right] \qquad (14)$$

where $\alpha_s = e_s / \overline{E}$.

According to condition (14), lobby activities by a sector s work via two distinct channels: the tax rate effect and the tax revenue effect. Obviously, energy-intensive sectors face a stronger increase in tax-induced energy cost than labor-intensive sectors. On the one hand, the increase in energy cost is the higher, the larger the emissions (energy) share α_s is. On the other hand, the tax rebates via the reduction of labor cost are the more beneficial for a sector, the higher is the share of labor γ_s.

The extent to which lobbying by a specific sector is driven by the tax rate effect and the tax revenue effect will depend on general equilibrium mechanisms which are hardly tractable. In order to illustrate the incentives to form lobby groups while maintaining analytical tractability, we assume that labor demand is inelastic across all sectors, $\varepsilon = 0$, and unit costs

[11] In our subsequent empirical analysis, we therefore include an interaction term between lobby power and energy demand elasticity.

[12] In our empirical analysis, we use the number of representatives as well as an index for market concentration as proxies for this aspect of lobby power.

of energy are zero, $\bar{z} = 0$. From (11) it follows that $\psi - \mu_2 = 1 + \lambda \sum_s \kappa_s \gamma_s$, and together with (12) we obtain:

$$\tau_s = \frac{\mu_1}{1 + \lambda \sum_t \kappa_t \gamma_t - \lambda(\sum_t \kappa_t \gamma_t - \kappa_s)/\eta_s} \tag{15}$$

Since we want to indicate which sectors have the largest incentives to lobby, we focus on the derivatives $\frac{d\hat{\pi}_s(\kappa_s)}{d\kappa_s}$ in a situation where the lobby power is identical for all *t*, i.e. $\kappa_t = \bar{\kappa}$.[13] Condition (15) then implies that there is no tax differentiation, $\tau_s = \bar{\tau} = \frac{\mu_1}{1 + \lambda \sum_t \kappa_t \gamma_t}$, and we can show (see Appendix 2.4.2) that:

$$\begin{aligned} -\frac{d\tau_s(\kappa_s)}{d\kappa_s} &= \lambda \frac{\bar{\tau}^2}{\mu_1} \left[\frac{\gamma_s - \alpha_s}{\sum_t \eta_t \alpha_t} + \frac{1 - \gamma_s}{\eta_s} \right] \geq 0 \\ L / \bar{E} \frac{d\sigma(\kappa_s)}{d\kappa_s} &= \lambda \frac{\bar{\tau}^2}{\mu_1} \left[-\frac{\gamma_s - \alpha_s}{\sum_t \eta_t \alpha_t} + \gamma_s \sum_t \frac{\alpha_t}{\eta_t} - \frac{\alpha_s}{\eta_s} \right] \end{aligned} \tag{16}$$

We see that increased lobbying power of a sector will unambiguously decrease the tax rate while the effect on tax revenues and therefore tax rebates is not clear. Furthermore, we can use equations (14) and (16) to gain insights into the importance of forming lobby groups: if two sectors only differ with respect to their emission elasticity η_s, increased lobbying by the sector with the smaller elasticity decreases the sector's tax rate to a larger extent, but leads to a smaller increase (or larger decrease) of the tax yield compared to lobbying of a sector with a larger elasticity. When we look at the marginal effect of lobbying on profits, the tax rate effect dominates (since for two otherwise identical sectors $\gamma_s < 1/2$) such that the incentives of a sector to lobby are the larger, the less elastic its emissions demand is. To put it in intuitive terms: sectors with highly inelastic energy demand have a strong incentive to lobby because they might not have access to necessary abatement technologies and therefore would be burdened with substantial costs when facing a high tax.

Next, we compare two sectors which only differ in their labor demand (γ_s). In this case, a larger labor demand does not only imply a larger share of tax revenues, but also the impact of increased lobbying on tax revenues is larger ($L / \bar{E} \frac{d^2\sigma(\kappa_s)}{d\kappa_s d\gamma_s} = \lambda \frac{\bar{\tau}^2}{\mu_1} \left[\sum_t \frac{\alpha_t}{\eta_t} - \frac{1}{\sum_t \eta_t \alpha_t} \right] \geq 0$).

The implications of a larger labor demand on the tax effect ($-\frac{d^2\tau_s}{d\kappa_s d\gamma_s} = \lambda \frac{\overline{\tau}^2}{\mu_1}\left[\frac{1}{\sum_t \eta_t \alpha_t} - \frac{1}{\eta_s}\right]$ are less obvious: while the impact of a larger γ_s on the tax rate effect of lobbying is positive if $\eta_s > \sum_{t'} \eta_{t'} \alpha_{t'}$ it is negative if $\eta_s < \sum_{t'} \eta_{t'} \alpha_{t'}$. A larger labor force therefore translates into increased incentives to lobby if a sector has relatively elastic emissions demand (with tax and revenue effects working in the same direction). The impact of increased labor force on the incentives to lobby could be reversed, however, if a sector's emissions are highly inelastic.

Finally, we perform comparative statics with respect to the emissions share α_s: the more emissions a sector has, the more this sector benefits from a tax rate decrease. However, more emission-intensive sectors are less effective when lobbying for a reduction in the tax rate ($-d\tau_s / d\kappa_s > -d\tau_{s'} / d\kappa_{s'}$ if $\alpha_s < \alpha_{s'}$). The effect on the tax yield again depends on how the emissions elasticity of this sector compares to the average ($\eta_s < \sum_{t'} \eta_{t'} \alpha_{t'}$ or $\eta_s > \sum_{t'} \eta_{t'} \alpha_{t'}$). Thus, the overall effect of the emission share on the incentives of a sector to lobby is ambiguous.

Complementing Proposition 1, our theoretical analysis therefore yields the following insights into which sectors have more incentives to overcome the internal free-riding and therefore can be expected to have a larger lobbying power κ_s:[14]

Proposition 2: *(i) Lobbying is most beneficial for sectors with inelastic emissions (small η_s) such that we should expect the formation of lobby groups (large κ_s) as well as reduced tax rates particularly in those sectors. (ii) Although emission-intensive sectors (large α_s) would benefit most from a reduced tax rate, their incentives for lobbying are not necessarily larger since they are less effective in influencing the energy tax rate and the rebate from tax revenues in their favor. (iii) More labor intensive sectors (larger γ_s) have larger incentives to form lobby groups if their emission demand is relatively more elastic than an emission-weighted average of all sectors ($\eta_s > \sum_{t'} \eta_{t'} \alpha_{t'}$).*

[13] We use s, t, s', t' to index the different sectors.

[14] Note that we adopt the assumption of a fixed environmental target which is backed, e.g., by the actual regimes in international climate policy. Since the target is fixed, a lower burden for one sector results in increased burdens for others (as is the case for the national allocation plans in EU countries to comply with fixed emission-reduction targets under the Kyoto Protocol). However, regulators might compromise on the environmental goal in order to increase the approval for policy regulation. The emission level which results in such a setting, could then be taken as input in our model.

2.2 Regression analysis of the German environmental tax reform

In order to test our theoretical findings, we perform a regression analysis based on data for environmental taxes in Germany. Between 1999 and 2003, Germany implemented an environmental tax reform. The reform levied higher taxes on energy use while recycling the additional energy tax revenue through a reduction of employer's social security contributions.[15] As a central feature of the policy, which can be generalized to environmental tax reforms in other OECD countries (OECD, 2007), energy-intensive firms received substantial energy tax breaks. In our regression analysis, we aim at assessing determinants of environmental tax differentiation across sectors as identified in our theoretical analysis of section 2.1: industrial lobbying power, market concentration, energy intensities and demand elasticities, as well as sectoral labor demand.

2.2.1 Data and variables

The cross-sectional regression analysis covers all 42 manufacturing sectors of the German economy as provided by the official input-output classification (see Table 2 in Appendix 2.4.1, where all tables are listed).

Our sector-level data set for Germany has been compiled from various sources. Data on sectoral energy use, tax rates and net burdens are provided by Bach et al. (2001, 2003). Sectoral production and employment data are taken from official input-output tables, and sector-specific price elasticities of energy demand are based on Capros et al. (1999). Market concentration data is provided by the German Monopolies Commission (2004a, 2004b). Estimates for Armington elasticities are taken from an econometric analysis by Welsch (2007). Data on the number of lobby representatives of German industrial associations was collected by means of an extensive telephone survey.[16]

For reasons of consistency, we employ the following years of observation: energy use data is taken from 1998 which served as the reference year for the design of the environmental tax reform initiated by the German government in 1999. Net burdens (i.e. the overall reform burdens resulting from energy tax payments less reimbursements) as well as energy taxes

[15] For a detailed overview of Germany's environmental tax reform see Kohlhaas (2000).
[16] The survey has been conducted at the Centre for European Economic Research (ZEW) in Mannheim, Germany, during June and July, 2004. Contact details of associations were taken from a database of German industrial organizations (Hoppenstedt, 2003). For each of the 42 manufacturing sectors of the German economy

refer to 2003 as the terminal year of the environmental tax reform which included annual discrete increases of energy tax rates. Employees of German industrial associations are taken from 1995 reflecting the fact that the political debate about an environmental tax reform in Germany has already reached its climax in the mid-1990s. For the same reason, price elasticities of energy use as well as production and employment levels are taken from this period, and estimates of Armington elasticities are based on time-series data ending in 1990. Due to limited data availability, information on market concentration is based on the year 2001. The time lag between the observation years for taxes and central independent variables assures that potential endogeneity problems (environmental taxation may have an effect on independent variables, e.g., on energy demand) are attenuated (Kennedy, 2003).[17]

We test our theoretical predictions on the extent and the determinants of tax differentiation employing three energy tax components of the German reform as dependent variables: the average *effective* taxes on electricity, gas and fuel oil use (i.e. taxes including reductions). In addition, we study to which extent sectors succeeded in lowering their net burden from the tax reform. Taking into account tax payments as well as the redistribution via the reduction in labor costs, we use the net burden as a fourth dependent variable.[18]

As mentioned in section 2, no direct measure of lobbying power (κ_s) is available. We therefore use the number of lobby representatives of the major industrial association in each sector as a proxy measure for lobbying power (see Table 3 for a mapping between sectors and respective associations). The measure describes political influence via the representation of sectoral interest vis-à-vis the policymaker: political influence should be the more effective, the more representatives a lobby employs.[19]. Consistent with our theoretical analysis in section 2.1, we incorporate interaction terms of lobby power with other independent variables in order to analyze how the lobbying impacts depend on the magnitude of other factors.

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we covered the representative industrial associations, the majority of which are at the same time members of the Federation of German Industries (BDI).

[17] Note that the preferable approach to cope with endogeneity problems is an instrumental variable estimation, where an instrument variable (a new independent variable that is contemporaneously uncorrelated with the error term and preferably highly correlated with the original independent variable) substitutes the original independent variable. Our inferior lagged-variable approach is motivated by the lack of appropriate instrumental variables.

[18] The net burden results from total energy tax payments less reimbursements in terms of reduced social security contributions by employers.

[19] Differently from lobbying in other countries, say, in the U.S., campaign contributions are not a feasible measure of political influence in Germany. Instead, information transfer and person-to-person interactions traditionally play a more important role. The contributions of a sector are therefore related to its expenses for lobby representative such that we can use their number as a proxy for lobby power. An exemplary channel of political influence is information transfer between interest groups and policy makers (see Grossman and Helpman, 2001; Naevdal and Brazee, 2000; or Potters and van Winden, 1992).

As control variables we introduce market concentration and the exposure to international competition to account for the degree of interest organization and popular arguments against (unilateral) environmental taxation. As a standard measure for market concentration, we employ the average sectoral Herfindahl-Hirschman Index (HHI).[20] Exposure to international competition is captured by sector-specific Armington elasticities of substitution between imports and competing domestic goods.[21]

Furthermore, we control for central objectives and implementation features of the environmental tax reform by introducing the following regressors: energy intensities (energy use per production value), sectoral employment levels, and price elasticities of fuel demand. Intensities for electricity, gas, fuel oil, and overall energy are employed as independent variables because the environmental tax reform in Germany explicitly granted tax breaks to energy-intensive sectors. The incorporation of the sectoral employment level as an independent variable allows us to investigate labor market aspects of the reform. Price elasticities of fuel demand (distinguished by fuel types) are introduced in order to test the propositions of our theoretical model in section 2.1, where energy demand elasticities played a crucial role for the environmental tax design.

An overview of all regression variables is provided in Table 4. Summary statistics for the variables are given in Table 5.

2.2.2 Econometric approach

For our regression analysis we employ two alternative econometric approaches. First, coefficients for all three energy tax components within the German reform (electricity, gas and fuel oil tax) are first estimated by *ordinary least squares* (OLS) using White's robust standard errors. We adopt a log-linear multiple regression model, where Y_s denotes the dependent variable with s sectoral observations, X_{is} refer to the independent variables with associated coefficients β_i, α is a constant and ε_s is a disturbance term:

$$\ln Y_s = \alpha + \beta_1 \ln X_{1s} + \beta_2 \ln X_{2s} + ... + \beta_n \ln X_{ns} + \varepsilon_s \tag{17}$$

[20] The HHI is calculated by squaring the market share of each firm competing in the respective market/sector and summing up the resulting numbers.

[21] Note that our stylized theoretical analysis does not provide predictions for the effect of international competition on tax differentiation.

The slope coefficients β_i then measure the elasticity of *Y* with respect to X_i. For equations involving the net burden as dependent variable, the log-linear regression model cannot be applied since the observed net burden is negative for some sectors. We therefore specify a lin-log model, where only the independent variables are logarithmized such that β_i measures the ratio between an absolute change in *Y* and a relative change in X_i. In this case, coefficients have been standardized (yielding so-called *Beta coefficients*) to accommodate a more transparent interpretation.

A potential problem for the interpretation of the separate OLS regressions arises as the three energy tax components form part of a joint environmental tax reform: the associated three tax equations might consequently be connected via correlations between the respective disturbance terms. We therefore employ *Seemingly Unrelated Regression Estimation* (SURE, see Zellner, 1962) as an alternative econometric approach: suppose that there are *N* equations $Y_j = X_j\beta_j + \varepsilon_j$ where the subscript *j* refers to the *j*-th equation. These equations can jointly be written as:

$$\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} = \begin{bmatrix} X_1 & & & \\ & X_2 & & O \\ O & & \ddots & \\ & & & X_n \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_n \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_n \end{bmatrix} \tag{18}$$

Here, e.g. the *t*-th disturbance term in the *j*-th equation is correlated with the *t*-th disturbance term in the *k*-th equation. SURE then allows us to estimate the three individual energy tax equations as a set using a single regression, thereby accounting for contemporaneous correlation between the disturbance terms across equations (Kennedy, 2003). As with OLS, we adopt a log-linear regression specification for the SURE tax regression models. The single net burden regression is invariably estimated by OLS.

2.2.3 Determinants of environmental taxation

In our central regression specification, the average, effective taxes on electricity, gas, and fuel oil use as well as the net burden of the reform are explained at the sectoral level by six independent variables: energy intensities, employment level, price elasticities of energy demand, market concentration, exposure to international trade and lobbying power.

Estimation results for the coefficients of our central regression specification – together with the goodness of fit for each equation – are presented in Table 6.[22]

Proposition 1(i) of our theoretical analysis states that – given identical energy demand elasticities – stronger lobby power induces lower sectoral tax rates. As the central result of our empirical estimations, we identify a significantly negative impact of the number of lobby representatives on the taxes for electricity and oil.

Result 1: *The higher the number of sectoral lobby representatives, the lower the electricity and oil taxes in the respective sector.*

This result suggests that German industries represented by stronger associations – in terms of political communication – were able to lobby for lower energy taxes. The finding underpins our theoretical analysis of section 2.1, where we showed that more effective lobbying results in a reduced tax rate and differentiated taxes are driven by interest group activities.[23] Moreover, Result 1 is in line with the theoretical assessments on lobbying influence by Grossman and Helpman (2001) and Potters and van Winden (1992).

According to Olson (1965), more concentrated industries should have a higher degree of interest organization and should therefore be more capable to put forward their political positions. This should also hold for arguments against environmental taxation, as in this case the tax incidence is concentrated on a smaller number of businesses. In fact our estimations show significantly negative coefficients of market concentration in the electricity and oil tax equations, implying that more concentrated industries face lower energy taxes (see Table 6). This finding is in line with previous empirical studies testing Olson's theory, which confirmed that the industry's structure is an important determinant of political activity of firms (Masters and Keim 1986, Pittman 1988).

In order to investigate the impact of international trade exposure on Germany's environmental tax design, we use sector-specific elasticities of substitution between domestically produced goods and competing imports (so-called Armington elasticities) as a control variable. Unilateral environmental (energy) taxation increases the price of domestically produced energy-intensive goods, which leads to a decline in domestic production as untaxed competing imports become relatively cheaper. The higher the Armington elasticities are, the

[22] In Table 6, each column represents one regression equation; non-empty cells refer to coefficients of the respective explanatory variables.

stronger is – ceteris paribus – this substitution effect. Armington elasticities may, therefore, serve as an indirect measure for the relocation of domestic production facilities to abroad. In policy practice, relocation is a wide-spread argument of energy- and trade-intensive industries to claim exemption from unilateral environmental taxation (Böhringer and Rutherford 1997). In our estimations we find significantly negative coefficients of the Armington elasticity – both in the gas and oil tax regression. We conclude that international trade exposure is a significant determinant of Germany's environmental taxation – more exposed industries are taxed at a lower level. We can summarize these results as follows:

Result 2: *The higher the market concentration (international trade exposure), the lower the electricity and oil (gas and oil) taxes in the respective industry.*

Our theoretical analysis of section 2.1 indicated that energy demand elasticities inversely influence the tax rate. Table 6 reveals that we do not find empirical evidence for this proposition. Rather than demand elasticities, the energy intensity of a sector seems to be relevant: we observe significantly negative coefficients of the electricity and gas intensity in the respective tax regressions. According to our dataset, Germany's environmental tax reform discriminates in favor of energy-intensive sectors – a result that is consistent with the tax break regulations at the firm level. However, we observe a significantly positive effect of the total energy intensity on the net burden, suggesting that despite the tax break regulations, in overall terms more energy-intensive sectors are negatively affected by the reform. One reason is that for higher sectoral energy intensities corresponding to lower labor intensities, the reform's beneficial reimbursements of the energy tax yield in terms of a reduction of employer's social security contributions are lower for these industries.

Result 3: *The higher the sectoral electricity and gas intensity, the lower the respective energy taxes.*

Our theoretical analysis of section 2 suggested that energy-intensive sectors benefit most from reduced tax rates (see Proposition 2) while it was ambiguous if this translates into reduced tax rates for energy-intensive sectors (as they might not be able to influence the tax rate). However, given our empirical findings (Result 3) we conclude that the theoretical analysis

[23] Note that a potential endogeneity problem of lobby formation should be attenuated by our deliberate choice of observation years for lobby employees (1995) and tax rates (1999).

which is based on the *marginal* effect of tax rate changes does not capture tax determinants based on average cost considerations.

We finally turn to the role of sectoral employment. Here, we find a significantly positive effect on the oil tax, i.e. sectors with a larger working force bear higher oil taxes. Regarding the net burden of the reform as a dependent variable, we find a highly significant negative effect of employment on the net reform burden: overall, sectors with high employment levels benefit from the environmental tax reform, as the reimbursements of the energy tax yield more than compensate their energy tax payments.

In order to account for a potential correlation between the disturbance terms of the three energy tax equations, we employ the SURE approach. Estimation results are presented in Table 7. We see that the SURE results in general confirm the OLS results. The significance of the impact of energy intensities, employment, market concentration and international trade exposure on energy taxation is (partly substantially) increased. However, the SURE estimation eliminates the significance of the lobby coefficient in the oil tax regression, suggesting a lower overall stand-alone impact of lobby power on tax differentiation. In the following, we therefore investigate the role of interactions between lobby power and other independent variables for energy taxation in order to analyze how the effect of the lobby variable depends on the magnitude of other factors.[24]

The interaction with energy demand elasticities

Proposition 1 (ii) of our theoretical analysis indicates that the effects of lobbying should be more pronounced in sectors with inelastic energy use. We can investigate this theoretical assertion empirically by extending the central model specification through the introduction of a multiplicative interaction term between the number of lobby representatives and the price elasticity of fuel demand. Here, our theoretical proposition implies a negative coefficient of the demand elasticity and a positive one of the interaction term in the energy tax equations.

The associated SURE coefficient estimates for the three energy tax regression and the OLS estimates for the net burden equation can be found in Table 9. The results substantiate our previous findings regarding the role of international trade exposure, energy intensities and employment in environmental taxation, while the significance of the market concentration coefficient is decreased and the stand-alone impact of lobby power on energy taxes is insignificant. We find support for our theoretical predictions regarding the role of energy demand elasticities and their interaction with lobby power: in the gas and oil tax regression as well as in the net burden equation we observe significantly negative coefficients of energy demand elasticities, i.e. sectors with less elastic energy demand are taxed at a higher level. In the same regression equations we find an (additional) significantly *positive* impact of the interaction term between the lobby variable and energy demand elasticities on the tax level: less elastic sectors with more powerful lobbies feature lower tax levels and net burdens than those with weaker interest groups (and vice versa).[25] In other words, lobbying counteracts the negative stand-alone effect of energy demand elasticities on energy taxation and net burdens, thereby alleviating the sectoral burden of the environmental tax reform.[26]

Result 4: *In the absence of lobby power, sectors with a less elastic energy demand face higher gas and oil taxes and higher net burdens. However, more powerful lobbying counteracts these adverse effects in less elastic industries.*

2.2.4 The determinants of lobby power

Section 2.1.3 analyzed the central determinants of sectoral lobby power from a theoretical perspective. As a result, Proposition 2 stated that while lobbying incentives are not necessarily larger for emission-intensive industries, lobby power is stronger both for sectors with less elastic emissions and higher labor intensities. In this section, we empirically assess these theoretical findings.

We specify an OLS regression model in which lobby power serves as the dependent variable that is explained by the remaining independent variables of our central regression specification (see again Table 6). The corresponding estimation results back the propositions of our theoretical analysis in section 2.1 and are presented in Table 10: firstly, our results confirm that energy demand elasticities constitute a significantly negative determinant of lobby power: lobby power is higher for sectors with less elastic emissions. In the regression in which the gas intensity and elasticity serve as independent variables, we find a significantly

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[24] Note that in order to highlight the robustness of our central estimation results, we perform several regression diagnostics and employ robust estimation techniques, all of which can be found in Appendix A.2.

[25] This result can be deduced by taking the partial derivative of the tax rate w.r.t. the respective energy demand elasticity, yielding a sum of the (negative) coefficient of the energy demand elasticity and the (positive) coefficient of the interaction term multiplied by the lobby variable.

[26] An alternative regression specification including an interaction term between the number of lobby representatives and the sectoral Armington elasticity does not yield significant estimation results for the respective coefficients (detailed results are available from the authors upon request).

negative effect on the lobby variable and a highly significant effect in the oil and total-energy regression. Secondly, conforming to our theoretical prediction, we do not empirically find energy intensities to promote lobbying power in a significant manner. Thirdly, sectoral employment has a weakly significant and positive effect on the lobby variable in the electricity, gas and oil regressions and a significantly positive impact on lobbying power in the total-energy regression. This suggests that industries with a larger labor force form stronger lobby groups to represent their interests.

Result 5: *Unlike industries with a higher energy intensity, sectors with less elastic emissions and a larger labor force exhibit higher lobbying power.*

While market concentration does not play a significant role for lobby power here, we also find the Armington elasticity to be a significantly positive determinant for lobby power in the gas, oil and total-energy regression, plausibly suggesting that sectors with a higher trade exposure have larger incentives to form powerful interest groups.

2.3 Conclusions

In this paper, we have analyzed the political economy of environmental tax differentiation both on theoretical and empirical grounds. Based on a common-agency approach, our theoretical analysis has identified substantial effects of lobbying in particular for sectors with highly inelastic energy demand: on pure efficiency grounds, such sectors would be assigned high taxes as they are less distortionary than those in other sectors. In our political-economy framework, however, the associated high tax burden for energy-intensive sectors implies strong lobbying incentives which in turn can translate into substantial tax-breaks for these sectors.

In the empirical analysis we have used sectoral data of Germany's environmental tax reform in order to test our theoretical propositions. A regression analysis based on OLS and seemingly unrelated regression estimation (SURE) underpins our theoretical results: both economic characteristics of industries and political interests determine the design of the tax scheme. Energy taxation within Germany's environmental tax reform clearly discriminates in favor of energy-intensive industries. In line with our theoretical propositions, the regression analysis shows that industries represented by more powerful associations (in terms of the number of lobby representatives) are better able to communicate their interests and enforce lower energy taxes. Interactions between lobby power and sectoral characteristics play an important role for environmental taxation: while industries with a less elastic energy demand may face higher energy taxes under the green tax reform, powerful lobbying is able to counteract this effect. Finally, the regression analysis provides evidence that – besides the activities of lobby groups – also market concentration and international trade exposure of industries play an important role for environmental tax differentiation.

Our combined theoretical and empirical analysis has explained differences in environmental tax rates across sectors within a political economy framework. On the one hand, tax differentiation might increase the acceptability of stricter emission goals, thereby leading to larger environmental benefits. On the other hand, sectoral tax differentiation can substantially increase the economy-wide cost to achieve a given environmental goal. An explicit analysis of such interactions between political economy aspects and pure efficiency considerations provides an interesting direction for future research.

While the present chapter analyzed the role of interest groups for environmental taxation, the following chapter investigates the political-economy aspects of a more recent market-based instrument of environmental policy: internationally tradable emissions allowances.

2.4 Appendix

2.4.1 List of tables

Table 2: Listing of German manufacturing sectors (Input-output classification)

Sector No. IOT 1993	Name of sector
1	Agricultural products
2	Forestry & fishery products
3	Electric power & steam & warm water
4	Gas
5	Water (distribution)
6	Coal & coal products
7	Minery products (without coal & gas & petroleum)
8	Crude oil & natural gas
9	Chemical products & nuclear fuels
10	Oil products
11	Plastics
12	Rubber
13	Stone & lime & cement
14	Ceramic
15	Glass
16	Iron & steel
17	Non-ferrous metals
18	Casting products
19	Rolling products
20	Production of steel etc
21	Mechanical engineering
22	Office machines
23	Motor vehicles
24	Shipbuilding
25	Aerospace equipment
26	Electrical engineering
27	Engineers' small tools
28	Metal and steel goods
29	Music instruments & toys etc
30	Timber
31	Furniture
32	Paper & pulp & board
33	Paper & board products
34	Printing and publishing
35	Leathers & footwear
36	Textiles
37	Clothing
38	Food products
39	Beverages
40	Tobacco products
41	Building & construction
42	Recovery & repair

Table 3: German manufacturing sectors and respective industrial associations

Sector No.	Name of sector	Industrial associations
1	Agricultural products	German Farmers Association (DBV)
2	Forestry & fishery products	German Forestry Council (DFWR) German Fishery Association (DFV)
3	Electric power & steam & warm water	German Electricity Association (VDEW)
4	Gas	Association of the German Gas and Water Industries (BGW)
5	Water (distribution)	Association of the German Gas and Water Industries (BGW)
6	Coal & coal products	German Mining Association (WVB) German Hard Coal Association (GVST) German Lignite Industry Association (DEBRIV)
7	Minery products (without coal & gas & petroleum)	German Mining Association (WVB)
8	Crude oil & natural gas	Association of the German Oil and Gas Producers (WEG)
9	Chemical products & nuclear fuels	Association of the German Chemical Industry (VCI)
10	Oil products	Association of the German Petroleum Industry (MWV)
11	Plastics	Association of the German Plastics Processing Industry (GKV) Federation of German Woodworking and Furniture Industries (HDH) Federation of German Paper, Cardboard and Plastics Processing Ind. (HPV)
12	Rubber	German Rubber Manufacturers' Association (WDK)
13	Stone & lime & cement	German Building Materials Association (BBS)
14	Ceramic	German Federation of Fine Ceramic Industry (AKI)
15	Glass	German Glass Industry Federation (BV Glas)
16	Iron & steel	German Steel Federation (WV Stahl) German Federation of Steel and Metal Processing (WSM)
17	Non-ferrous metals	Federation of the German Non-Ferrous Metals Industry (WVM) Federation of German Steel and Metal Processing (WSM)
18	Casting products	German Foundry Association (DGV)
19	Rolling products	Association of German Drawing Mills (STV) Association of German Cold Rolling Mills (FVK)
20	Production of steel etc	German Structural Steel and Power Engineering Association (SET)

Table 3 (continued): *German manufacturing sectors and respective industrial associations*

Sector No.	Name of sector	Industrial associations
21	Mechanical engineering	Federation of the German Engineering Industry (VDMA)
22	Office machines	–
23	Motor vehicles	Association of the German Automotive Industry (VDA)
24	Shipbuilding	German Shipbuilding and Ocean Industries Association (VSM)
25	Aerospace equipment	German Aerospace Industries Association (BDLI)
26	Electrical engineering	German Electrical and Electronic Manufacturers' Association (ZVEI)
27	Engineers' small tools	German Industrial Association for Optical, Medical and Mechatronical Technologies (SPECTARIS) Federation of German Jewellery, Watches, Clocks, Silverware and Related Industries
28	Metal and steel goods	–
29	Music instruments & toys etc.	National Association of German Musical Instruments Manufacturers (BDMH) German Association of the Toy Industry (DVSI)
30	Timber	Federation of German Woodworking and Furniture Industries (HDH) Association of the German Sawmill and Wood Industry (VDS)
31	Furniture	Federation of German Woodworking and Furniture Industries (HDH)
32	Paper & pulp & board	German Pulp and Paper Association (VDP)
33	Paper & board products	German Pulp and Paper Association (VDP) Federation of German Paper, Cardboard and Plastics Processing Industry (HPV)
34	Printing and publishing	German Printing Industry Federation (BVDM)
35	Leathers & footwear	German Leather Federation (VDL) Federation of the German Shoe Industry (HDS)
36	Textiles	Federation of German Textile and Fashion Industry
37	Clothing	Federation of the German Clothing Industry (BBI)
38	Food products	Federation of the German Food and Drink Industries (BVE)
39	Beverages	Federation of the German Food and Drink Industries (BVE)
40	Tobacco products	Federation of the German Cigarette Industry (VdC)
41	Building & construction	German Construction Industry Federation (HDB)
42	Recovery & repair	German Construction Industry Federation (HDB)

Table 4: Description of regression variables

Variable	Description
Electricity tax	Electricity tax (€ / MWh)
Gas tax	Gas tax (€/MWh)
Oil tax	Fuel oil tax (€ / 1000l)
Net burden	Net burden (m €)
Electricity intensity	Electricity intensity (GWh / €)
Gas intensity	Gas intensity (GWh/€)
Oil intensity	Fuel oil intensity (1000l / €)
Total energy intensity	Total energy intensity (GWh / €)
Employment	Employment (1000)
Electricity elasticity	Price elasticity of electricity demand (absolute value)
Gas elasticity	Price elasticity of gas demand (absolute value)
Oil elasticity	Price elasticity of fuel oil demand (absolute value)
Total fuel elasticity	Price elasticity of total fuel demand (absolute value)
Lobby	Total number of lobby representatives per sector
Lobby_Electricity	Interaction term (*Lobby * Electricity elasticity*)
Lobby_Gas	Interaction term (*Lobby * Gas elasticity*)
Lobby_Oil	Interaction term (*Lobby * Oil elasticity*)
Lobby_Fuel	Interaction term (*Lobby * Total fuel elasticity*)
Lobby_Employment	Interaction term (*Lobby * Employment*)
Concentration	Herfindahl-Hirschman Index, HHI (x 1000)
Armington Elasticity	Armington Elasticity between imports and domestic goods
Lobby_Armington	Interaction term (*Lobby * Armington Elasticity*)

Table 5: Summary statistics for regression variables

VARIABLE	OBS.	MEAN	STD. DEV.	MIN.	MAX.
Electricity tax	42	5.57	3.83	1.31	19.91
Gas tax	42	0.61	0.31	0.32	1.61
Oil tax	42	7.73	3.82	4.05	20.19
Net burden	42	-30.36	68.49	-278.16	68.97
Electricity intensity	42	0.29	0.34	0.00	1.63
Gas intensity	42	0.47	0.74	0.00	3.23
Oil intensity	42	5.16	5.11	0.08	29.29
Total energy intensity	42	0.82	0.95	0.03	4.27
Employment	42	294.36	380.97	9.00	1709.00
Electricity elasticity	42	0.26	0.09	0.19	0.39
Gas elasticity	42	0.62	0.15	0.10	0.82
Oil elasticity	42	0.58	0.18	0.10	0.89
Total fuel elasticity	42	0.46	0.13	0.16	0.69
Lobby	42	49.50	67.09	0.00	350.00
Concentration	36	62.87	84.63	2.80	357.65
Armington Elasticity	35	0.69	0.48	0.08	2.36

Table 6: Parameter estimation of the central regression specification – OLS with robust standard errors

Dependent variable (model) / Explanatory variables	*Electricity tax* (log-linear)	*Gas tax* (log-linear)	*Oil tax* (log-linear)	*Net burden* (lin-log)
Electricity intensity	-0.198 *** (-5.25)			
Gas intensity		-0.105 ** (-2.17)		
Oil intensity			-0.086 (-1.11)	
Total energy intensity				0.335 ** (2.58)
Employment	0.110 (1.66)	0.060 (0.97)	0.144 *** (2.91)	-0.3442338 (-2.50) **
Electricity elasticity	-0.193 (-0.85)			
Gas elasticity		0.118 (1.09)		
Oil elasticity			-0.075 (-0.34)	
Total fuel elasticity				-0.072 (-0.55)
Concentration	-0.107 * (-1.95)	-0.059 (-1.24)	-0.118 ** (-2.12)	0.139 (1.11)
Armington Elasticity	-0.082 (-0.87)	-0.216 ** (-2.21)	-0.250 ** (-2.33)	0.210 (0.96)
Lobby	-0.115 * (-1.74)	-0.076 (-1.57)	-0.137 ** (-2.36)	-0.224 (-1.03)
Constant	0.984 * (1.81)	-0.683 ** (-2.38)	1.954 *** (3.94)	101.951 * (1.93)
Goodness of fit	$R^2 = 0.73$	$R^2 = 0.65$	$R^2 = 0.57$	$R^2 = 0.57$

T-statistics in parentheses. * (**, ***) indicates that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test). All coefficients have been standardized (yielding so-called *Beta coefficients*).

Table 7: Parameter estimation of the central tax regressions specification – SURE

Explanatory variables \ Dependent variable (model)	*Electricity tax* (log-linear)	*Gas tax* (log-linear)	*Oil tax* (log-linear)
Electricity intensity	-0.150 *** (-3.64)		
Gas intensity		-0.040 * (-1.93)	
Oil intensity			-0.007 (-0.20)
Employment	0.128 * (1.96)	0.094 ** (1.98)	0.126 ** (2.37)
Electricity elasticity	-0.088 (-0.43)		
Gas elasticity		0.026 (0.31)	
Oil elasticity			0.017 (0.13)
Concentration	-0.112 ** (-2.25)	-0.079 ** (-1.99)	-0.082 * (-1.77)
Armington Elasticity	-0.143 (-1.50)	-0.258 *** (-3.49)	-0.282 *** (-3.39)
Lobby	-0.107 * (-1.71)	-0.081 (-1.59)	-0.095 (-1.57)
Constant	1.097 ** (2.16)	-0.739 ** (-2.45)	1.747 *** (4.92)
Goodness of fit Chi-square	$R^2 = 0.71$ $\chi^2 = 60.81$ ***	$R^2 = 0.59$ $\chi^2 = 42.95$ ***	$R^2 = 0.52$ $\chi^2 = 30.77$ ***

Z-statistics in parentheses. * (**, ***) indicates that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test).

Table 8: Regression diagnostics

Test \ Regression (model)	*Electricity tax* (log-linear)	*Gas tax* (log-linear)	*Oil tax* (log-linear)	*Net burden* (lin-log)
Ramsey RESET (fitted values)	F = 0.51	F = 2.01	F = 1.00	F = 6.54 ***
Ramsey RESET (independent values)	F = 0.73	F = 1.89	F = 2.03	F = 5.03
Breusch-Pagan	$\chi^2 = 4.12$ **	$\chi^2 = 0.51$	$\chi^2 = 1.18$	$\chi^2 = 8.19$ ***

* (**, ***) indicates that the respective null hypothesis can be rejected at the 10% (5%, 1%) level of significance.

Table 9: Parameter estimation of the extended regression specification including interaction term between Lobby and energy demand elasticities – SURE and OLS with robust standard errors

Explanatory variables \ Dependent variable (model)	*Electricity tax* (log-linear, *SURE*)	*Gas tax* (log-linear, *SURE*)	*Oil tax* (log-linear, *SURE*)	*Net burden* (lin-log, *OLS*)
Electricity intensity	-0.159 *** (-3.83)			
Gas intensity		-0.035 * (-1.72)		
Oil intensity			0.004 (0.12)	
Total energy intensity				0.411 ** (2.69)
Employment	0.130 ** (2.00)	0.134 *** (2.75)	0.162 *** (3.03)	-0.137 (-0.88)
Electricity elasticity	-0.363 (-0.75)			
Gas elasticity		-0.926 ** (-2.57)		
Oil elasticity			-0.821 * (-1.79)	
Total fuel elasticity				-1.359 ** (-2.34)
Concentration	-0.115 ** (-2.32)	-0.053 (-1.34)	-0.048 (-1.02)	0.264 (1.71)
Armington Elasticity	-0.137 (-1.43)	-0.251 *** (-3.45)	-0.266 *** (-3.33)	0.319 (1.62)
Lobby	0.0342 (0.16)	0.036 (0.54)	0.036 (0.42)	0.413 (1.38)
Lobby_Electricity	0.106 (0.70)			
Lobby_Gas		0.260 *** (2.68)		
Lobby_Oil			0.235 ** (1.99)	
Lobby_Fuel				1.610 * (2.03)
Constant	0.725 (0.92)	-1.431 *** (-3.64)	1.008 ** (1.98)	-132.561 (-1.36)
Goodness of fit Chi-square	$R^2 = 0.70$ $\chi^2 = 61.82$ ***	$R^2 = 0.61$ $\chi^2 = 51.87$ ***	$R^2 = 0.56$ $\chi^2 = 38.98$ ***	$R^2 = 0.65$

Z-statistics in parentheses. * (**, ***) indicates that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test). OLS coefficients have been standardized (yielding so-called *Beta coefficients*).

Table 10: Parameter estimation for the determinants of lobby power – OLS with robust standard errors

Dependent variable (model) / Explanatory variables	*Lobby* (log-linear)	*Lobby* (log-linear)	*Lobby* (log-linear)	*Lobby* (log-linear)
Electricity intensity	0.103 (0.66)			
Gas intensity		-0.070 (-0.61)		
Oil intensity			-0.286 * (-1.75)	
Total energy intensity				0.038 (0.26)
Employment	0.478 * (1.82)	0.359 * (1.76)	0.370 * (2.03)	0.447 ** (2.20)
Electricity elasticity	-1.107 (-1.24)			
Gas elasticity		-0.899 ** (-2.55)		
Oil elasticity			-1.190 *** (-3.13)	
Total fuel elasticity				-1.440 *** (-3.25)
Concentration	0.095 (0.47)	-0.076 (-0.41)	-0.176 (-0.98)	0.004 (0.03)
Armington Elasticity	0.495 (1.72)	0.603 ** (2.34)	0.584 ** (2.28)	0.578 ** (2.20)
Constant	-0.738 (-0.30)	1.146 (0.93)	1.662 (1.32)	-0.028 (-0.02)
Goodness of fit	$R^2 = 0.34$	$R^2 = 0.42$	$R^2 = 0.49$	$R^2 = 0.44$

T-statistics in parentheses. * (**, ***) indicates that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test). All coefficients have been standardized (yielding so-called *Beta coefficients*).

2.4.2 Impacts of lobbying on equilibrium profits

Derivation of (14)

In equilibrium, contributions of the lobby group of sector *s* are given by $C_s(TS) = \kappa_s \pi_s(TS) + \text{const.}$ The constant thereby must satisfy that the regulator is better off with implementing the resulting policy and receiving the contribution than by implementing the policy which would result from not receiving any contributions from sector *s*, i.e. maximizing $G^{-s}(TS) = W(TS) + \lambda \sum_{t \neq s} \kappa_t \pi_t(TS)$ which we assume results in policy TS^{-s}. That is, the contributions of the lobby in sector *s* in equilibrium $TS(\kappa_s)$ satisfy

$$G^{-s}(TS(\kappa_s)) + \lambda C_s(TS(\kappa_s)) = G^{-s}(TS^{-s})$$

We can now consider the equilibrium profits of a sector *s* net of lobby contributions as a function of κ_s:

$$\hat{\pi}_s(\kappa_s) = \pi_s(TS(\kappa_s)) - C_s(TS(\kappa_s)) = \pi_s(TS(\kappa_s)) - [G^{-s}(TS^{-s}) - G^{-s}(TS(\kappa_s))] / \lambda$$

$$\begin{aligned} \frac{d\hat{\pi}_s(\kappa_s)}{d\kappa_s} &= \frac{d}{dTS}\pi_s(TS(\kappa_s))\frac{d}{d\kappa_s}TS(\kappa_s) + (1/\lambda)\frac{d}{dTS}G^{-s}(TS(\kappa_s))\frac{d}{d\kappa_s}TS(\kappa_s) \\ &= (1-\kappa_s)\frac{d}{dTS}\pi_s(TS(\kappa_s))\frac{d}{d\kappa_s}TS(\kappa_s) \\ &= (1-\kappa_s)\left[-e_s(\tau(\kappa_s))\frac{d}{d\kappa_s}\tau_s(\kappa_s) + l_s(\tau(\kappa_s))\frac{d}{d\kappa_s}\sigma(\kappa_s)\right] \\ &= (1-\kappa_s)\overline{E}\left[-\alpha_s\frac{d\tau_s(\kappa_s)}{d\kappa_s} + \gamma_s L/\overline{E}\frac{d\sigma(\kappa_s)}{d\kappa_s}\right] \end{aligned} \tag{14}$$

where we used the first-order conditions for the regulator as well as the envelope theorem to determine the marginal change of the net profit of sector *s*.

Derivation of (16)

Starting with a situation in which $\kappa_t = \overline{\kappa}$, we now consider the marginal effect of increased lobbying power on tax rates and rebates. Differentiating (15) yields:

$$\frac{d\tau_t}{d\kappa_s}(\kappa_{t'} = \overline{\kappa}) = \frac{d\mu_1}{d\kappa_s}\frac{\overline{\tau}}{\mu_1} - \lambda\frac{\overline{\tau}^2}{\mu_1}\gamma_s + \lambda\frac{\overline{\tau}^2}{\mu_1}(\gamma_s - \delta_{t=s})/\eta_t \tag{15'}$$

where $\delta_{t=s} = 1$ if $t = s$ and $\delta_{t=s} = 0$ otherwise. Since we know that $\overline{E} = \sum_t e_t$ and therefore

$$0 = -\sum_t \frac{de_t}{d\kappa_s} = \sum_t \eta_t \frac{e_t}{\tau_t} \frac{d\tau_t}{d\kappa_s}$$

we obtain

$$\left[\frac{d\mu_1}{d\kappa_s} \frac{\overline{\tau}}{\mu_1} - \lambda \frac{\overline{\tau}^2}{\mu_1} \gamma_s \right] \sum_t \eta_t \alpha_t = \lambda \frac{\overline{\tau}^2}{\mu_1} [\alpha_s - \gamma_s]$$

where $\alpha_t = e_t / E$. Therefore,

$$\frac{d\tau_t}{d\kappa_s}(\kappa_{t'} = \overline{\kappa}) = \lambda \frac{\overline{\tau}^2}{\mu_1} \left[\frac{\alpha_s - \gamma_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} + \frac{\gamma_s - \delta_{t=s}}{\eta_t} \right]$$

Note that the right hand side is linear in γ_s. For $s = t$ and at $\gamma_s = 0$, we obtain a value of the bracket of $\frac{\alpha_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} - \frac{1}{\eta_t} \leq \frac{\alpha_s}{\eta_s \alpha_s} - \frac{1}{\eta_t} = 0$, while at $\gamma_s = 1$, the value is given by $\frac{\alpha_s - \gamma_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} + \frac{\gamma_s - 1}{\eta_t} = \frac{\alpha_s - 1}{\sum_{t'} \eta_{t'} \alpha_{t'}} \leq 0$. We therefore obtain $\frac{d\tau_s}{d\kappa_s} \leq 0$.

Furthermore, the revenue neutrality requires

$$\frac{d\sigma}{d\kappa_s} L / E = \sum_t [1 - \eta_t] \alpha_t \frac{d\tau_t}{d\kappa_s}$$

which proves condition (16).

Derivation of lobbying effects on sectoral profits

Plugging these equations into (14), gives an explicit expression for the change in profits of sector *s* induced by a marginal increase in κ_s:

$$\begin{aligned}
\frac{d\hat{\pi}_s(\kappa_s)}{d\kappa_s} / [\overline{E}(1-\kappa_s)] &= \left[-\alpha_s \frac{d\tau_s}{d\kappa_s} + \gamma_s \sum_t [1 - \eta_t] \alpha_t \frac{d\tau_t}{d\kappa_s} \right] \\
&= \lambda \frac{\overline{\tau}^2}{\mu_1} \left(-\alpha_s \left[\frac{\alpha_s - \gamma_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} + \frac{\gamma_s - 1}{\eta_s} \right] + \gamma_s \left[\frac{\alpha_s - \gamma_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} + \gamma_s \sum_t \frac{\alpha_t}{\eta_t} - \frac{\alpha_s}{\eta_s} \right] \right) \\
&= \lambda \frac{\overline{\tau}^2}{\mu_1} \left(\alpha_s \frac{1 - \alpha_s}{\sum_{t'} \eta_{t'} \alpha_{t'}} + \alpha_s (1 - 2\gamma_s) \left(\frac{1}{\eta_s} - \frac{1}{\sum_{t'} \eta_{t'} \alpha_{t'}} \right) + \gamma_s^2 \underbrace{\left(\sum_t \frac{\alpha_t}{\eta_t} - \frac{1}{\sum_{t'} \eta_{t'} \alpha_{t'}} \right)}_{\geq 0} \right)
\end{aligned}$$

2.4.3 Regression diagnostics and robust estimation

To check the robustness of our central estimation results, we performed regression diagnostics and employed robust estimation techniques. Firstly, specification errors may arise as a consequence of the omission of a relevant variable from the model. In this case the influence of the omitted variable is incorporated in the disturbance term of the respective model. In order to test for potential specification errors, we employ the *RESET* (regression specification error test), adding a proxy for the (unknown) omitted variable(s) to the set of regressors in the respective model and testing the coefficient estimate(s) of that proxy against the zero vector by means of a traditional F-test (Kennedy, 2003). We perform both versions of the *RESET* test using the powers of the fitted values of the dependent variable and the powers of the independent variables. Table 8 shows that – except for the net burden regression in the fitted values test version – we cannot reject the null hypothesis of no specification error for any of the tax regressions, i.e. we do not find substantial evidence for misspecification.

Secondly, the problem of heteroskedasticity emerges if the diagonal elements of the variance-covariance matrix of a disturbance term are not all equal, varying in size with an independent variable. In order to test for heteroskedasticity, we employ the Breusch-Pagan test for the null hypothesis of equal variance. Table 8 indicates that we can reject the null hypotheses for the electricity tax regression and the net burden. As a consequence, in all regression specifications (except for the SURE models) we provide White's heteroskedasticity-robust OLS estimators.

Thirdly, the presence of influential outliers, i.e. influential observations lying outside the typical relationship between the dependent and explanatory variables revealed by the remaining data, can lead to estimation problems by both hiding relevant or creating non-existing relationships (Barnett and Lewis, 1994, Temple, 2000). In order to account for potential outliers in our sample, we perform an *Iteratively Reweighted Least Squares* regression, i.e. an OLS regression reducing the influence of observations with large residuals by assigning lower weights to cases with larger residuals.[27] Comparing the results to the initial OLS estimation (see Table 6) confirms that our overall previous findings are robust to potential outliers. In the robust approach the price elasticity of oil demand has a significantly negative impact on the oil tax. This result provides (albeit weak) empirical evidence for our

[27] The corresponding outlier-robust coefficient estimates are available from the authors upon request.

theoretical prediction of section 2.1 that – ceteris paribus – sectors with a less elastic energy demand will be burdened with a higher energy tax.

3 Public Interest vs. Interest Groups: Allowance Allocation in the EU Emissions Trading Scheme [28]

A central instrument of Europe's current climate policy is the EU Emissions Trading Scheme (EU ETS) which was established in 2005 and entered its second trading period in 2008 (EU, 2003). Aiming at emission reductions at least cost, the EU ETS was celebrated as a "new grand policy experiment" already before its implementation (Kruger and Pizer, 2004). However, the actual implementation of the EU ETS suggests that due to a generous allowance allocation to covered industries, the induced emission abatement has been rather limited at least in the first phase (from 2005 to 2007). This paper investigates whether the permit allocation design in the EU ETS is representing public interest in terms of economic efficiency or can be explained by the presence of sectoral interest groups.

The outspoken objective of the EU ETS is to achieve Europe's greenhouse gas emission reduction commitments under the Kyoto Protocol at minimal cost through the tradability of emission rights (or likewise abatement efforts) across major emission sources. In its first two phases, the EU ETS covers more than 10,000 energy-intensive installations that belong to mainly five industrial sectors: power, heat and steam generation; oil refineries; iron and steel production; mineral industries (e.g. cement, lime and glass); pulp and paper plants (EU, 2003). During these two phases, each Member State is obligated to set up an annual National Allocation Plan (NAP) where it defines the cap on emission allowances for sectors (installations) included in the trading scheme and the specific allocation rule for grandfathering, i.e. the entitlement with free pollution rights based on historical emissions.

In this paper we present a political-economy analysis of allowance allocation in the EU ETS. We develop a stylized theoretical framework for the allocation of emission allowances in a cap and trade system, where the regulator values political contributions from sectoral interest groups when determining the stringency of allowance allocation. In the stylized model, the regulator implements an inefficiently high level of allowance allocation, thereby shifting the regulatory burden to those sectors excluded from the trading system. Within the emissions

[28] This chapter is based on the paper: Anger, N., Böhringer, C., and U. Oberndorfer (2008): "Public Interest vs. Interest Groups: Allowance Allocation in the EU Emissions Trading Scheme", *ZEW Discussion Paper* 08-023, Mannheim. The manuscript was submitted to and is currently under review for the *Scandinavian Journal of*

trading scheme, the distribution of permits is biased in favor of those sub-sectors featuring more powerful lobby groups. However, the impact of lobbying depends on the level of sub-sectoral emissions and the government's weight on political contributions. We test the predictions of our analytical model with an empirical analysis on the political-economy determinants of permit allocation in the EU ETS for a large cross section of regulated firms in Germany. Our results suggest that the allocation of emission allowances has been partly driven by sectoral interest groups: large carbon emitters that were heavily exposed to emission regulation and simultaneously represented by powerful interest groups received higher levels of emission allowances. The combination of lobbying for permits and high emitting activity thus affects the distribution of allowances, but also leads to a deviation of the observed permit allocation from its economically efficient level.

Standard economic theory suggests that the introduction of market-based instruments of environmental policy – such as (uniform) emissions taxes or (auctioned) tradable emission allowances – can generate cost-efficient emission reductions by equalizing marginal abatement costs across polluters. Against this background, the mainly free allowance allocation in the EU ETS has been criticized for its generous and differential treatment of regulated industries, as well as its incomplete sectoral coverage. While a number of studies on the economic impacts of EU ETS regulation indicate the existence of such a burden shifting (see Böhringer et al., 2005; Kallbekken, 2005; or Peterson, 2006), its rationale has remained implicit to date.

The lacking welfare-economic explanation for the observed regulatory design represents the initiation of the political-economy analysis of environmental policy. Building on Olson's (1965) theory of the formation and power of interest groups, general positive theories have presented alternative approaches to study the political-economy determinants of policy outcomes (see Oates and Portney, 2003 for the context of environmental policy). In particular, the literature emphasizes the exchange of truthful information between interest groups and policy makers as a channel of influence, upon which politicians base their decisions (Grossman and Helpman, 2001; Naevdal and Brazee, 2000; Potters and van Winden, 1992). Previous studies on political-economy determinants of environmental taxation include Frederiksson (1997) and Aidt (1997, 1998) who investigate the implications of international competition and revenue recycling for the design of environmental tax reforms. In this context, Anger et al. (2006) provide a first combined theoretical and empirical analysis of the

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Economics. As the corresponding author of the manuscript, I contributed to all sections of the chapter, with a focus on the theoretical framework in 3.1.

role of interest groups in environmental tax differentiation. They show that a sectoral differentiation of green tax reforms is not only determined by the activity of lobby groups favoring reduced environmental tax rates, but also by the groups' interest in revenue rebates to labor. The existing political-economy literature on emission regulation by tradable permits focuses on the choice between free permit allocation based on historic emission levels and auctioning of pollution rights. Hanoteau (2005) theoretically shows that in the presence of interest groups an environmental regulator prefers a free allocation of permits over auctioning, and relaxes the underlying emission cap. Likewise, Markussen and Svendsen (2005) argue that dominant industrial lobby groups influenced the corresponding EU ETS directive towards a grandfathered allocation rule. An empirical study by Hanoteau (2003) suggests that political influence by means of financial campaign contributions affected the distribution of permits within the U.S. sulphur emissions trading system. Existing empirical studies on EU ETS have focused on the formation of the EU allowance price (Benz and Trück, forthcoming) and its economic effects (Oberndorfer, forthcoming).

The present paper tries to complement the political-economy analysis of the EU ETS with an explicit and combined theoretical and empirical assessment of the role of interest groups in the EU emissions trading system by providing a twofold contribution: First, we develop a stylized *common-agency* framework for the allocation of emission allowances in a cap and trade system. Second, we provide an empirical analysis on the political-economy determinants of permit allocation in the EU ETS for a large cross section of regulated firms in Germany. To our best knowledge, we thereby provide the first theoretical and empirical political-economy assessment of EU emission allowance allocation.

The remainder of this paper is structured as follows. In section 3.1, we develop a political-economy framework for the allocation of emission allowances in a cap and trade system. In section 3.2, we present an empirical analysis of the determinants of permit allocation in the EU ETS. In section 3.3, we conclude.

3.1 Theoretical framework

In this section we present a stylized analytical framework of the role of interest groups for the allocation of emission allowances in a cap and trade system. The model is structured as a *common-agency* problem, in which principals (interest groups) aim to induce an action from an agent (the government). As introduced by Grossman and Helpman (1994) in the context of international trade, lobby groups may influence political decisions – here: the stringency of allowance allocation – if the government does not only care about social welfare but also values political contributions by interest groups.

In order to analyze the firm's behavior on the emission market, we build on the one-sector partial equilibrium model by Böhringer and Lange (2005) assessing emission-based allocation rules in cap-and-trade systems. In our model we consider an emission-constrained economy with two aggregate production sectors $i \in \{ets, nets\}$, one of which is regulated by an emissions trading scheme (*ets*) while the other is excluded from the scheme (*nets*). Sectoral emissions e_i are the product of the emission rate (or intensity) μ_i and the output level q_i ($e_i = \mu_i q_i$). Marginal production costs $c(\cdot)$ are constant in output, decreasing in emission rate ($c(\mu) \geq 0,\ c'(\mu) < 0,\ c''(\mu) > 0$). Inverse demand for output $P(q)$ is decreasing in q and differentiable.

In order to fulfill a given economy-wide emission target $\overline{E}$ (as committed to e.g. under the Kyoto Protocol) the national government implements a hybrid system of emission regulation: tradable emission allowances for the covered *ets* sector and emissions taxation for the remaining (*nets*) sector of the economy. Motivated by the EU Emissions Trading Scheme, emission permits are freely allocated to the *ets* sector based on pollution levels, i.e. emission rates and output levels. The stringency of emission regulation is represented by an *allocation factor* α that denotes the fraction of benchmark emissions freely allocated as allowances, so that the sectoral permit allocation equals $\alpha\mu_{ets}q_{ets}$. Emission allowances are tradable internationally at an exogenous permit price σ. For the *nets* sector, the regulator allows the remaining emission budget of $\overline{E} - \alpha\mu_{ets}q_{ets}$ in order to fulfill the economy-wide target.

The political process involves an incumbent government (i.e. an environmental regulator) and an industrial lobby group that represents sectoral (i.e. firms') interests. Motivated by current EU emission regulation, we assume the formation of interest groups only for the covered *ets* sector, while the *nets* industry does not feature lobbying activities. We base this assumption on the fact that the EU Emissions Trading Scheme covers mainly energy-intensive industries and represents the dominant instrument of environmental regulation for these sectors. In contrast, the remaining segments of EU economies (e.g. the transport sector or households) are subject to a more diverse set of environmental policy instruments (such as energy taxes or subsidies). Besides their single-targeted motive of lobbying for free emission allowances, energy-intensive industries also feature a relatively high degree of concentration, which according to Olson (1965) should enable a better organization of interests by overcoming the problem of free-riding.

Motivated by Grossman and Helpman (1994), in the model the lobby group can offer a set of political contributions $K_{ets}(\alpha)$ to the government depending on the envisaged policy decision. In our context, sectoral contributions are thus a function of the allocation factor. Political contributions may either represent monetary campaign donations by interest groups or a more general form of political support, such as information transfer between interest groups and policy makers (Grossman and Helpman, 2001). In our analysis we abstract from interest group formation and behavior and thus focus on the political equilibrium in which lobby contributions $K_{ets}(\alpha)$ reflect the true preferences of interest groups: a marginal change in the lobby contribution for a marginal policy change corresponds to the effect of the policy change on the group's welfare.

Against this political-economy background, aggregate profit maximization in sector *ets* (firms are price taker on the goods and emission market), including the costs or revenues from emissions trading as well as efforts for political contributions, is given as:

$$\max_{q_{ets},\mu_{ets}} \pi_{ets} = p_{ets}q_{ets} - c_{ets}(\mu_{ets})q_{ets} - \sigma(1-\alpha)\mu_{ets}q_{ets} - K_{ets}(\alpha).$$

Likewise, aggregate profit maximization in the *nets* sector which is regulated by an emissions tax (firms are price taker on the goods market) is given as:

$$\max_{q_{nets},\mu_{nets}} \pi_{nets} = p_{nets}q_{nets} - c_{nets}(\mu_{nets})q_{nets} - \tau\mu_{nets}q_{nets}.$$

The corresponding first-order conditions of the firm can be found in Appendix 3.4.1. Social welfare (gross of political contributions) is composed of aggregate consumer and producer surplus including the costs or revenues from international emissions trading:[29]

$$W = \sum_i \int_0^{q_i} P_i(r_i)dr_i - \sum_i c_i(\mu_i)q_i - \sigma(1-\alpha)\mu_{ets}q_{ets}.$$

3.1.1 The political equilibrium

The problem of the incumbent government is to maximize its political support. To this aim it values the level of political contributions by interest groups besides social welfare (the latter

[29] Note that emission tax revenues are assumed to be redistributed on a lump-sum basis, so that they emission taxation does not enter the welfare function.

presuming that a higher standard of living increases the chances for reelection). The regulator thus maximizes a weighted sum of contributions and welfare given an environmental constraint (i.e. the total emission target) by choosing the allocation factor for the *ets* sector and the emissions tax for the *nets* industry:

$$\max_{\alpha,\tau} G(\alpha,\tau) = \theta K_{ets}(\alpha) + (1-\theta)W \quad \text{s.t.} \quad \overline{E} = \alpha\mu_{ets}q_{ets} + \mu_{nets}q_{nets} .$$

In this framework, the government maximizes a social-welfare function that weights sectors represented by a lobby group with the weight of 1 and the remaining members of society with the smaller weight of $1-\theta$. Obviously, the higher the value of θ, the higher the regulator values political contributions by interest groups in comparison to social welfare (the regulator fully ignores lobby contributions in the extreme case of θ equal to zero, whereas she only cares about political contributions for θ=1). We restrict the value of θ to 0<θ<1, abstracting from negative weights on social welfare within government's objective function.

In the following, we analyze the regulatory behavior of the government in terms of allowance allocation and emissions taxation. Denoting the Lagrange multiplier as λ yields the following Lagrange function for the government:

$$L = G(\alpha,\tau) + \lambda(\overline{E} - \alpha\mu_{ets}q_{ets} - \mu_{nets}q_{nets}) .$$

The first-order conditions of the firm as well as the environmental constraint imply that μ_{ets} and q_{ets} are implicit functions of α. Derivation of the government's objective function w.r.t. the allocation factor thus gives:

$$0 = \frac{\partial L}{\partial \alpha} = \theta K_{ets}'(\alpha) + (1-\theta)\left\{\left[p_{ets} - c_{ets}(\mu_{ets})\right]\frac{\partial q_{ets}}{\partial \alpha} - \left[c_{ets}'(\mu_{ets}) + \sigma(1-\alpha)\right]\frac{\partial \mu_{ets}}{\partial \alpha}q_{ets} - \sigma(1-\alpha)\frac{\partial q_{ets}}{\partial \alpha}\mu_{ets} + \sigma\mu_{ets}q_{ets}\right\}$$
$$-\lambda\left[\mu_{ets}q_{ets} + \alpha\left(\frac{\partial q_{ets}}{\partial \alpha}\mu_{ets} + \frac{\partial \mu_{ets}}{\partial \alpha}q_{ets}\right)\right]. \quad (1)$$

Using the firm's first-order conditions (13) and (14) yields the political equilibrium in terms of the allocation factor for the *ets* sector:

$$\alpha = \frac{\theta K_{ets}'(\alpha) + \left[(1-\theta)\sigma - \lambda\right]\mu_{ets}q_{ets}}{\lambda\left(\frac{\partial q_{ets}}{\partial \alpha}\mu_{ets} + \frac{\partial \mu_{ets}}{\partial \alpha}q_{ets}\right)} . \quad (2)$$

Given that all determinants on the right hand side of condition (2) are positive and 0<θ<1, it shows that while the impacts of the government's weight on political contributions relative to social welfare, the emission rate and the output level are indeterminate, the allocation factor is increasing both in marginal political contributions by the lobby group and the international permit price. Condition (2) thus suggests that if the *ets* sector's interest group is able to increase political contributions to a larger extent for a higher allocation factor (i.e. if the lobby group is sufficiently strong), the regulator implements a higher allocation factor. However, the impact of lobbying depends on the government's weight on political contributions. Moreover, α is decreasing in the shadow-price of the environmental constraint and the sensitivity of sectoral output and emission to the allocation factor.[30]

Proposition 1: *In the political equilibrium, the allocation factor chosen by the government is the larger, the lower the shadow-price of the environmental constraint and the more powerful the sectoral lobby group. The impact of lobbying depends on the government's valuation of political contributions by interest groups.*

At this stage, we can distinguish between two extreme cases: the government fully ignoring lobby contributions and only maximizing social welfare (θ=0), and the regulator valuing only political contributions by interest groups in its objective function (θ=1). In the first case, condition (2) translates into the welfare-maximizing allocation factor:

$$\alpha^W = \frac{(\sigma-\lambda)\mu_{ets}q_{ets}}{\lambda\left(\frac{\partial q_{ets}}{\partial\alpha}\mu_{ets}+\frac{\partial\mu_{ets}}{\partial\alpha}q_{ets}\right)}. \tag{3}$$

In the second case of θ=1, we arrive at the regulation that maximizes political contributions for the government:

$$\alpha^{PC} = \frac{K_{ets}'(\alpha)-\lambda\mu_{ets}q_{ets}}{\lambda\left(\frac{\partial q_{ets}}{\partial\alpha}\mu_{ets}+\frac{\partial\mu_{ets}}{\partial\alpha}q_{ets}\right)}. \tag{4}$$

The regulatory behavior of the government in terms of emissions taxation on the *nets* sector can be derived analogously to the allocation factor. The first-order conditions of the firm and the environmental constraint imply that μ_{nets} and q_{nets} are implicit functions of τ. Derivation of the government's objective function w.r.t. the emissions tax thus gives:

$$0=\frac{\partial L}{\partial\tau}=(1-\theta)\left\{\left[p_{nets}-c_{nets}(\mu_{nets})\right]\frac{\partial q_{nets}}{\partial\tau}-c_{nets}'(\mu_{nets})\frac{\partial\mu_{nets}}{\partial\tau}q_{nets}\right\}-\lambda\left(\frac{\partial q_{nets}}{\partial\tau}\mu_{nets}+\frac{\partial\mu_{nets}}{\partial\tau}q_{nets}\right).$$

[30] Note that conditions (13) and (14) in the Appendix imply that $\partial q_s/\partial\alpha>0$ and $\partial\mu_s/\partial\alpha>0$.

Using the firm's first-order conditions (15) and (16) yields the political equilibrium in terms of the emissions tax on the *nets* sector:

$$\tau = \frac{\lambda}{1-\theta}. \tag{5}$$

The resulting tax rate equals the shadow price of the environmental constraint, adjusted by the government's weight on political contributions relative to social welfare. As for regulation in the *ets* sector, we can distinguish between two extreme cases: the government fully ignoring lobby contributions and only maximizing social welfare (θ=0), and the regulator valuing only political contributions by interest groups in its objective function (θ=1). In the first case, condition (5) translates into the welfare-maximizing emissions tax:

$$\tau^W = \lambda.$$

Efficient emission regulation thus requires that the tax rate equals the shadow price of the environmental constraint. In contrast, once the government values political contributions by interest groups from the *ets* sector (θ>0), condition (5) implies that the emissions tax on the *nets* sector is increased to an inefficiently high level. In the extreme case of θ=1, a regulator only valuing political contributions implements an emissions tax of $\tau^{PC} \rightarrow \infty$ on the *nets* sector in order to maximize its political support from the *ets* sector.

3.1.2 Efficiency and distributional implications of lobbying

For a given λ, condition (5) suggests that a higher government's weight on political contributions relative to social welfare increases the emissions tax on the *nets* sector. For a given economy-wide emission target $\overline{E}$, the associated lower emissions of the *nets* sector decrease the shadow price of the environmental constraint λ. Following Proposition 1, the lower the level of λ, the higher the allocation factor, and the lower the stringency of regulation in the *ets* sector. The simultaneous (indirect) effect decreasing the emissions tax in condition (5) attenuates the previous (direct) increasing effect on the tax rate. However, the positive impact of an increase in θ on taxation is not reversed, as in the environmental constraint a higher allocation factor in the *ets* sector necessarily implies lower emissions of the *nets* sector in order to reach a given emission target, i.e. a higher tax level.

We conclude that if the government values political contributions by interest groups (θ>0), it implements an emissions tax on the *nets* sector and a corresponding allocation factor for the *ets* sector which exceed the respective levels of an efficient instrument mix (τ^W, α^W).

Proposition 2: *The government's valuation of political contributions by interest groups from sectors covered by the emissions trading scheme leads to inefficiently high levels of emissions taxation and allowance allocation, thereby shifting the regulatory burden from covered sectors to the remaining industries of the economy.*

In the following, we analyze the sub-sectoral distribution of allocated allowances within the emissions trading scheme. To this aim we describe the *ets* sector as being composed of $s = 1...S$ sub-sectors, each of which is represented by an industrial lobby group. Political contributions at the sub-sectoral level depend on a sub-sectoral allocation factor and are given by $K_s(\alpha_s)$. The political equilibrium within the *ets* sector can then be derived analogously to condition (2) by profit maximization in the respective sub-sectors and the political-support maximizing behaviour of the government on the aggregate sectoral level.

We now analyze comparative statics in the resulting political equilibrium. Considering two exemplary sub-sectors 1 and 2, the corresponding allocation factors are given by:

$$\alpha_1 > \alpha_2 \Leftrightarrow \left[\frac{\theta K_1'(\alpha_1) + \left[(1-\theta)\sigma - \lambda\right]\mu_1 q_1}{\lambda\left(\frac{\partial q_1}{\partial \alpha_1}\mu_1 + \frac{\partial \mu_1}{\partial \alpha_1} q_1\right)} \right] > \left[\frac{\theta K_2'(\alpha_2) + \left[(1-\theta)\sigma - \lambda\right]\mu_2 q_2}{\lambda\left(\frac{\partial q_2}{\partial \alpha_2}\mu_2 + \frac{\partial \mu_2}{\partial \alpha_2} q_2\right)} \right]. \quad (7)$$

For 0< θ <1, the sub-sectoral allocation factor is – ceteris paribus – higher and thus regulatory stringency lower for sub-sectors of the emissions trading scheme featuring: (i) higher marginal contributions of sub-sectoral interest groups (ii) and lower sensitivities of sectoral output levels and emission rates to the allocation factor. In contrast, the effects of different sectoral emission rates and output levels are indeterminate. Result (i) implies that sub-sectors represented by lobby groups which are able to increase political contributions to a larger extent for a higher sub-sectoral allocation factor (i.e. that are more powerful) face a lower regulatory burden.

Denoting $e_s = \mu_s q_s$ as sub-sectoral emissions and $A_s = \alpha_s \mu_s q_s$ as the level of allowance allocation, condition (7) translates into:

$$A_1 > A_2 \Leftrightarrow \left[\frac{\theta K_1'(\alpha_1) e_1 + \left[(1-\theta)\sigma - \lambda\right] e_1^2}{\lambda\left(\frac{\partial q_1}{\partial \alpha_1}\mu_1 + \frac{\partial \mu_1}{\partial \alpha_1} q_1\right)} \right] > \left[\frac{\theta K_2'(\alpha_2) e_2 + \left[(1-\theta)\sigma - \lambda\right] e_2^2}{\lambda\left(\frac{\partial q_2}{\partial \alpha_2}\mu_2 + \frac{\partial \mu_2}{\partial \alpha_2} q_2\right)} \right]. \quad (8)$$

Our theoretical framework thus predicts that, ceteris paribus, firms belonging to industries that are represented by more powerful lobby groups also receive a higher *level* of allowance allocation. However, marginal political contributions do not have a stand-alone effect on absolute permit allocation: condition (8) suggests that – unlike in the case of the allocation factor – the impact of lobbying depends on the level of sub-sectoral emissions besides the government's weight on political contributions (as shown by condition (2)). Furthermore, quadratic emissions levels play a (yet indeterminate) role for the implemented allowance allocation.

Proposition 3: *In an emissions trading scheme with several sub-sectors, those industries featuring higher lobbying power but lower sensitivities of sectoral output and emissions to the allocation factor receive a higher level of allowance allocation. The role of lobbying for the sub-sectoral distribution of allowances depends on the level of sub-sectoral emissions.*

In the next section, we will test our theoretical Propositions 2 and 3 by means of an empirical analysis on the determinants of allowance allocation in the EU Emissions Trading Scheme.

3.2 Empirical analysis for Germany

In this section we present an empirical assessment of the determinants of EU ETS emission allowance allocation at the German firm level in order to test our central theoretical predictions of the previous section. In its first trading phase, the EU ETS exclusively covers installations in energy-intensive sectors (such as electricity, iron and steel, or paper and pulp), while the remaining industries of EU economies (such as households or the transport sector) have to be regulated by complementary abatement policies in order to meet the countries' overall emission targets. The EU ETS prescribes the (in the two first phases mainly free) allocation of emission allowances to installations according to historic levels by means of National Allocation Plans (NAPs) of the respective Member States, specifying an overall cap in emissions for the covered sectors. Our regression analysis particularly aims at investigating the role of interest groups for the allowance allocation design of the first trading phase of the EU Emissions Trading Scheme. It focuses both on the question whether lobbying may have induced a deviation of actual allowance allocation from its economically efficient level (as predicted by theoretical Proposition 2) and on the distributional impacts of lobbying among regulated firms (as predicted by Proposition 3).

3.2.1 Data and variables

For the empirical analysis, we use a unique economic and environmental cross-sectional data set for Germany at the firm level. It is a data compilation based on three different sources: First, we employ the CREDITREFORM database, an economic database of German firms, from which we selected those firms regulated by the EU ETS (see Appendix 3.4.2 for details of the data base). In this respect, it should be noted that Germany is the most important country within the EU ETS in terms of carbon emissions, its companies representing roughly a quarter of all allowances allocated. Second, we make use of a data set on verified emissions and EU ETS allowances allocated in 2005 that is publicly available from the EU Community Independent Transaction Log (EU, 2007b). Given the fact that the Community Transaction Log contains information at the installation level only, emission and allowance data were aggregated at the firm level. Third, for our political-economy analysis we integrated data on representatives of German industrial associations. This interest group data refers to the subsectoral level and was generated from a telephone survey conducted in 2004 (see further down). All in all, data including 175 German firms could be consistently compiled.

Important variables related to the political process of allowance allocation in the EU ETS are the number of allowances allocated to regulated firms as well as the so-called allocation factor (allocation relative to baseline emissions) and its deviation from an economically efficient level – all of which representing the governmental decision of emission regulation in the EU ETS. Our dataset consists of allowance allocation and emission data at the firm level, both for the year 2005. Another central variable for our analysis is the number of sectoral lobby representatives, measuring potential political support provided by sectoral interest groups (see below). Our data basis is completed by information on employment (i.e. the number of employees) at the firm level, both referring to 2004, the year of decision concerning allowance allocation for the first EU ETS phase as well as to preceding years (2000-2002). Moreover, we employ interaction terms between and nonlinear transformations of selected variables: In addition to verified emissions and the lobby variable we can include squared verified emissions, as well as interaction terms of the lobby variable with verified emissions and employment as explanatory variables for the regression analysis. The importance both of squared emission levels and the interaction term between the emission level and the lobby variable have been laid out in our theoretical framework. The corresponding descriptive statistics are presented in Table 13. In the following, we describe the variables of our dataset in greater detail.

Table 13 shows that our data set includes a broad firm interval of verified emissions and allowances allocated, e.g. allowances per firm ranging from 272 up to 346.000.000 tons of CO_2-equivalent. Regarding the relationship between the number of allowances allocated and the verified emissions in 2005, the table suggests that the number of allocated allowances is relatively high compared to the level of 2005 emissions. In our German sample, the (firm) mean of allowances allocated is 533645.9 against 511996.5 (tons of CO_2-equivalent) of verified emissions, which means that in 2005 allowance allocation to regulated firms exceeded actual emissions by about 30 per cent.[31] This implies that the sample mean of the allocation factor (defined as the allowances allocated divided by the verified emissions) amounts to 1.3. Given the EU's emission reduction commitment under the Kyoto protocol and Germany's corresponding reduction target of 21 percent below 1990 emissions, the high allocation factor in our sample stands in clear contrast to an efficient allowance allocation. In this context, numerical simulations provided e.g. by Böhringer et al. (2005) suggest an economically efficient allocation factor – ensuring equalized marginal abatement costs across all sectors of the economy – amounting to 0.903 for Germany under the Kyoto Protocol. This allocation factor ensures that the national emission budget is divided efficiently between those sectors covered by the ETS and the remaining, non-covered sectors. In order to account for such efficiency problems, we construct a variable proxying the absolute deviation of the observed firm-level allowance allocation to the efficient allocation. We calculate this variable as the actual allowance allocation less the efficient one. Given the unavailability of ex-ante emission data (i.e. from 2004 or earlier), the latter is derived by multiplying the optimal allocation factor (0.903) with verified emissions. Descriptive statistics suggest that the average deviation of actual compared with efficient allowance allocation for our sample amounts to 37 per cent.

Our result of a long position in the first ETS phase is in line with the findings of previous studies on EU ETS emission allocation (see Kettner et al., 2008 or Anger and Oberndorfer, 2008). In this context, it is important to note that verified EU ETS ex-ante emissions (e.g. from 2004 or earlier) were not published by the European Commission. Given this, verified emissions from 2005 are, on the one hand, the best available proxy variable for historical emissions as the main official allocation criterion. This lack of historical emission data makes it impossible to exactly identify why verified emissions in 2005 exceeded the respective number of allowances allocated. Although Ellerman and Buchner (forthcoming) or Kettner et

[31] Table 14 in Appendix A.3 underpins that allowances allocated and emissions are strongly interrelated.

al. (2008) have considered abatement of emissions in the early EU ETS phase as both less important and realistic – and have therefore interpreted the phenomenon of verified emissions exceeding allocated allowances mainly as a sign of "over-allocation" of firms with EU allowances[32] – it cannot be excluded that absolute or relative allocation affected verified emissions of the respective companies. However, our sample with 91 per cent of companies being long in EU emission allowances due to grandfathering based on the German NAP, together with the existing literature, implies that little abatement at most has taken place inside of the ETS during its first phase. This is in opposition to the claim of e.g. Böhringer et al. (2005), Kallbekken (2005), or Peterson (2006) that abatement of arount 10 per cent would have been economically efficient. Our econometric study starts at this point and addresses the determinants both of allowance allocation in general and of the deviation between actual and efficient allocation using firm-level data, and particularly focuses on potential lobbying influence on the allocation process.

As a potential determinant of allowance allocation within the EU ETS, the CREDITREFORM database reports the number of employees at the firm level. Here, we can especially make use of time series information from 2000 to 2004 on employment of the respective EU ETS firms. Given that EU ETS allowance allocation for the first trading phase was decided on in 2004 and the EU ETS came into force in 2005, 2004 employment levels could represent a determinant of allowance allocation, as worker lay-offs are traditionally a prominent argument of industries against environmental regulation (Kirchgässner and Schneider, 2003). However, also 2002 to 2000 employment levels are relevant for our analysis as they may serve as instrumental variables in the case of endogeneity problems.

The central explanatory variable of our political-economy analysis is the number of lobby employees of the representative industrial association in each subsector. Subsectoral classification is based on the Input-Output Table (IOT) 1993 (see Table 16 in Appendix 3.4.3 for a mapping between all IOT sectors and respective associations). This is the best available proxy for potential political support of sectoral interest groups for the government, as data on e.g. financial budgets of interest groups is not available for Germany. One example of political support provided by interest groups is information transfer from interest groups to policy makers (see e.g. Grossman and Helpman, 2001). Accordingly, political support is the stronger, the more representatives a lobby group employs (e.g. by processing and providing a larger amount of relevant information to the policy maker). Our lobby variable contains the

[32] According to this interpretation, participating firms had received allowances for a higher amount of CO_2 emissions than they actually emitted, implying a very loose emissions cap of the EU ETS.

number of lobby representatives of industrial associations based on an extensive telephone survey conducted in 2004, the year of the decision on EU ETS allowance allocation for the first trading phase.[33] For our sample, we can make use of lobby representative data of 14 EU ETS subsectors. On average, each of these sectors employed 108 representatives. However, the number of such employees at the sectoral level is very heterogeneous, ranging from 7 to 350. In order to differentiate between sectoral differences in allowance allocation that originate from lobbying activities and other sectoral factors (e.g. Buchner et al., 2006), we additionally generate three dummy variables (electricity, other energy, and manufacturing, with other sectors as reference category; see Appendix 3.4.2) at the aggregate sectoral level in order to control for such industry effects. Controlling for industry effects at the less aggregated sub-sectoral level according to the Input-Output Table 1993 is not feasible as it would lead to perfect multicollinearity of sectoral dummy variables with the employed lobby variable.

3.2.2 Methodology

For our cross-sectional analysis, we depart from the ordinary least squares estimator (OLS) for equation:

$$y_i = \beta' x_i + \varepsilon_i \tag{9}$$

with y_i representing allowances allocated of firm i, x_i being the vector of explanatory variables of the respective firm as presented in the previous section, and β giving the vector of coefficients to be estimated. ε_i is a disturbance term that is independent and identically distributed across firms $i = 1,2,...,N$. Using OLS, the parameter vector is determined by:

$$\beta = \left[X' X\right]^{-1} X' y \tag{10}$$

where matrix X consists of rows x_i', and y is the dependent variable's vector. While OLS serves as the starting point for our empirical analysis, it does not take into account the important issues of potential reverse causality.

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33 The survey has been conducted at the Centre for European Economic Research (ZEW) in Mannheim, Germany, during June and July, 2004. Contact details of associations were taken from a database of German industrial organizations (Hoppenstedt, 2003). For 42 manufacturing subsectors of the German economy (only 14 are relevant for our sample given the restriction of EU ETS to the four industry domains energy, production and processing of ferrous metals, minerals and pulp and paper) we covered the representative industrial associations, with a focus on members of the Federation of German Industries (BDI).

Within the OLS approach, reverse causality problems may cause biased parameter estimation. As lined out in the preceding chapter, firm data on historical emissions is not available to date, which is why 2005 verified emissions (and possible variations of it) have to be used as explanatory variable(s) in the analysis of allowance allocation. Given the nature of the EU ETS allocation process that is officially based on historical emissions, neglecting emission data when analyzing allowance allocation is not an option due to the problem of causing biased parameter estimates because of omitted variables. Still, firm emissions in 2005 could have been influenced by the number of allocated emission allowances. Such an effect would cause reverse causality problems rendering the regression with allowances allocated (as dependent variable) and verified emissions (as explanatory variable) biased and inconsistent. Instrumental variable technique is the usual remedy to such econometric problem. Within a Two Stage Least Squares (2SLS) approach, in the first stage the fitted values x_i^* from a regression of the (possibly) endogenous variables x_i on the instruments z_i are produced, while in the second those fitted values x_i^* replace the endogenous regressors x_i in the regression of actual interest:

$$y_i = \gamma' x_i^* + \varepsilon_i . \tag{11}$$

Given this, the 2SLS estimator for the parameter vector γ can be written as:

$$\gamma = \left[X^{*\prime} X^{*}\right]^{-1} X^{*\prime} y \tag{12}$$

where matrix X^* consists of rows x_i^* (first stage regression fitted values for endogenous explanatory, i.e. emission variables, and exogenous explanatory variables, respectively). In the 2SLS approach, for instrumental variables to be valid two prerequisites have to hold: correlation between z_i and the endogenous variable to be instrumented x_i should be non-negligible, while z_i and the second-stage error term (ε_i from equation (11)) have to be uncorrelated. Firm employment levels and squared terms between 2000 and 2002 are chosen as instrumental variables in this analysis: they can be interpreted as indicators of firm size, a natural determinant of the amount of CO_2 emissions of energy-intensive companies. Moreover, being predetermined, there is no reason to expect correlation with the second stage regression error term. This should particularly hold as the regression analysis controls for an effect of 2004 (the year of the NAP decision) employment on the allocation outcome. Clearly, the validity of firm employment variables from 2000 to 2002 as instrumental variables could be challenged if allowance allocation in the year 2004 was determined by employment levels of earlier periods. However, as current – instead of past – employment reflects the threat of possible worker lay-offs due to regulation (Kirchgässner and Schneider, 2003), lagged 2000 to 2002 employment figures should not have affected the allocation outcome in 2004. Consequently, firm employment variables from 2000 to 2002 appear to be appropriate instruments for the verified emissions and respective transformations.

3.2.3 Estimation results

In the following, we empirically assess the determinants of EU ETS allowance allocation at the German firm level. To this aim, we pursue a twofold goal: (i) to address potential inefficiencies of allowance allocation – referring to theoretical Proposition 2 of this paper – and (ii) to analyze factors determining the distribution of allocated allowances within the EU ETS – referring to theoretical Proposition 3 presented in section 3.1.

Efficiency implications of lobbying

First, Proposition 2 suggested that the government's consideration of interest groups from ETS sectors can lead to inefficiently high levels of allowance allocation. We aim at testing this proposition by assessing the determinants of the variable measuring the deviation from efficient allocation – derived as the actual allowance allocation less the efficient one. As mentioned above, however, it cannot be excluded that actual allocation – and therefore also the deviation from efficient allocation – affected verified emissions of the respective companies. In this case, estimation by OLS would yield biased and inconsistent results due to reverse causality problems. This can be circumvented by applying an instrumental variable approach such as 2SLS. In the 2SLS estimation, the verified emissions variable and its interaction terms and nonlinearities are instrumented in a first stage regression by lags (2000 to 2002) and the associated squared terms of the employment variable in addition to the explanatory variables of the 2SLS second stage equation. The corresponding estimation results – both for OLS and 2SLS – are presented in Table 11.

The empirical set-up provides a good fit to our data set here, as shown by a high R-squared for both econometric techniques used. Accordingly, also the null hypothesis of joint insignificance of all explanatory variables can be rejected at the 1%-level for both techniques (F-Test). According to the F-Test, there is also no indication for a misspecification of the 2SLS approach. First stage regressions of the verified emissions, squared verified emissions and the interaction terms between verified emissions and the lobby variables on the instruments (2000 to 2002 levels and squared terms of employment at the firm level) are well specified, as the null hypothesis of joint insignificance of all explanatory variables can be rejected at any conventional level (see Table 15 in Appendix 3.4.3).

For the OLS regression, Table 11 shows a positive sign of the estimated coefficient of the verified emissions variable. In contrast, IV regression does not indicate that verified emissions actually impacted on the deviation from efficient allocation for the respective firm. This underpins the reasoning that verified emissions are endogenous in this setting: If, compared to its efficient level, a generous allowance allocation would have caused additional CO_2 emissions of the respective firm, OLS (in contrast to 2SLS) estimation should yield an upward biased verified emissions coefficient. This corresponds to our results, with a positive and significant OLS verified emissions coefficient and an insignificant (and even negative) 2SLS verified emissions coefficient.

Table 11: Estimation results: Deviation from efficient allocation

Dependent variable: Deviation from efficient allocation	**OLS**	*2SLS*
Verified Emissions	2.30*** (0.00)	-0.42 (0.75)
Squared Verified Emissions	-2.20** (0.01)	-4.36*** (0.00)
Employment 2004	-0.17 (0.25)	-0.03 (0.79)
Lobby	-0.07 (0.16)	-0.06 (0.33)
Lobby x Verified Emissions	0.54 (0.58)	5.50*** (0.00)
Lobby x Employment 2004	0.16 (0.32)	0.03 (0.82)
No. Obs. **R-sq.** **F-Test (P-Val.)**	175 0.83 0.00***	131 0.89 0.00***

Note: Deviation from efficient allocation defined as Allowances allocated minus efficient allocation (see section 3.2.1). Standardized coefficients (regression coefficients obtained by standardizing all variables to have a mean of 0 and a standard deviation of 1) are reported. P-values in brackets (based on White robust std. errors). Estimations include sectoral dummy variables (estimated coefficients not reported). *, **, and *** indicate significance at the 10%-, 5%-, and 1%-level, respectively.

For both estimation techniques, the squared term of the emission variable (included in order to control for nonlinearities in the relationship between emissions and the allocation process) enters highly significantly into the estimated regression equation. Its negative sign suggests that – for a given effect of absolute emission levels on allowance allocation – large emitters received relatively less allowances compared to small emitters as measured by the deviation of the actual from an efficient level of allowance allocation.

Let us now turn to the role of interest groups in EU ETS allowance allocation. The estimated coefficient for the variable indicating the number of lobby employees does not significantly differ from zero at any conventional level, a result which at first sight does not confirm our theoretical prediction of Proposition 2 in the previous section. This holds for both estimation techniques applied. The estimated coefficient for the lobby variable does neither alter substantially when the instrumental variable technique to verified emissions-related variables is applied. However, we find an interesting result concerning the coefficient of the interaction term between the lobby and emission variable: while standards OLS estimation does not yield significant parameter estimates, the coefficient of the interaction term is highly significant and positive under 2SLS. Note that the latter represents the adequate technique for our setting, as it eliminates estimation biases due to reverse causality of the emission variable. This central empirical result suggests that the combination of high emissions at the firm level and powerful lobbying activities in the respective sector induced – ceteris paribus – an upward deviation of actual compared to an efficient level of allocated allowances for German firms in the EU ETS. Consequently, the analysis corroborates our theoretical Proposition 2, which suggested a positive impact of lobbying power on the deviation of allowance allocation from an efficient level. However, the estimations show that lobbying was only beneficial for large emitters. This empirical finding implies that the effect of lobbying on the deviation of allowances allocated to an efficient scenario is conditional on firm characteristics. The level of employment of a firm did, according to our dataset, not have an impact on the deviation of allowances allocated from an efficient setting. Moreover, the effect of lobbying power was not increased by the argument of high employment of the respective firm, as measured by the corresponding interaction term that does not significantly differ from zero in both empirical settings. Both estimations include dummy variables indicating the sectoral affiliation at an aggregate level (electricity, energy, and manufacturing sector) in order to control for general sectoral effects within the allocation process. These central results also hold when these sectoral indicator variables or, alternatively, insignificant explanatory variables are eliminated from the estimation (all detailed estimations are available on request from the authors).

Clearly, these firm-level results do not directly provide evidence for an economy-wide inefficiency of emission regulation in terms of a too high allowance allocation for ETS sectors, as the observed deviations from the optimal allocation factor could potentially cancel out across firms. However, as our descriptive statistics show that as much as 91 per cent of German companies featured a long position in EU emission allowances, and that the average position of our sample firms was long by about 30 per cent, such an aggregation effect can be excluded. As a consequence, the 2SLS estimation results support our theoretical proposition of an inefficient allowance allocation process due to the presence of sectoral interest groups.

Result 1: *Sectoral lobbying induces a deviation of the actual allocation of emission allowances from its economically efficient level, if the corresponding firms are highly exposed to emission regulation.*

Distributional implications of lobbying

Second, theoretical proposition 3 suggested that in an emissions trading scheme with several sub-sectors, those industries featuring higher lobbying power receive a higher absolute level of allowance allocation. In the following, we test this distributional hypothesis using our German firm-level dataset. In the first phase of the EU ETS, absolute allowance allocation was based on historical emissions, which we can proxy by using the verified emissions variable available in the community transaction log. All variables employed in the analysis presented above can also be considered in the analysis of allocation distribution. As in the case of the deviation of the actual from an efficient level of allowances allocated, however, it cannot be excluded that absolute allocation affected verified emissions of the respective companies. Therefore, also for the following estimations, employing 2SLS and using the same instrumental variables as in the previous regressions should be the most adequate empirical approach (therefore, the first stage regressions are also identical to those ones presented in Table 15 in Appendix 3.4.3, and well specified).

The corresponding estimation results – both OLS and 2SLS – are shown in Table 12. As expected, the empirical set-up provides a very good fit (an even better fit compared to the results presented in Table 11) to our data set here, as shown by a very high R-squared for both econometric techniques used. Particularly verified emissions of the firms analyzed here have very strong explanatory power for the allowances allocated manifesting in a high statistical significance of the respective coefficients (at the 1%-level for each estimation technique). The null hypothesis of joint insignificance of all explanatory variables can be rejected at the 1%-level for both techniques (F-Test), giving no indication for misspecification. Note that the estimation results presented in Table 12 partly resemble their counterparts shown in Table 11.

This may underpin the robustness of those results, but is also due to the fact that the dependent variable construction for the deviation from efficient allocation was also based on allowances allocated

Table 12 shows a positive sign of the estimated coefficient of the verified emissions variable, which corresponds to the nature of the EU ETS allocation process suggesting that emission levels have a positive impact on the level of allowance allocation. For both estimation techniques, also the squared term of the emission variable (included in order to control for nonlinearities in the relationship between emissions and the allocation process) enters highly significantly into the estimated regression equation. Its negative sign suggests a concave relationship between verified emissions and allowances allocated. This result substantiates our theoretical finding of condition (8), which stated that quadratic emissions levels play a role for the implemented allowance allocation.

Table 12: Estimation results: Distribution of allowances

Dependent variable: Allowances allocated	**OLS**	*2SLS*
Verified Emissions	1.13*** (0.00)	0.91*** (0.00)
Squared Verified Emissions	-0.19*** (0.01)	-0.32*** (0.00)
Employment 2004	-0.01 (0.25)	-0.00 (0.79)
Lobby	-0.01 (0.16)	-0.00 (0.33)
Lobby x Verified Emissions	0.05 (0.58)	0.40*** (0.00)
Lobby x Employment 2004	0.01 (0.32)	0.00 (0.82)
No. Obs.	175	131
R-sq.	0.99	0.99
F-Test (P-Val.)	0.00***	0.00***

Note: Standardized coefficients (regression coefficients obtained by standardizing all variables to have a mean of 0 and a standard deviation of 1) are reported. P-values in brackets (based on White robust std. errors). Estimations include sectoral dummy variables (estimated coefficients not reported). *, **, and *** indicate significance at the 10%-, 5%-, and 1%-level, respectively.

As in the regression analysis assessing the efficiency of allocation, the estimated coefficient for the variable indicating the number of lobby employees does not significantly differ from zero at any conventional level, while the coefficient of the interaction term between lobby representatives and verified emissions is highly significant and positive under 2SLS. Also in this setting, 2SLS represents the adequate technique, as it eliminates estimation biases due to reverse causality of the emission variable.[34] This central empirical result suggests that the combination of high emissions at the firm level and powerful lobbying activities in the respective sector induced higher levels of allocated allowances for German firms in the EU ETS. Consequently, the empirical analysis corroborates our theoretical Proposition 3, which predicted a positive impact of sub-sectoral lobbying power and simultaneously high emission levels on the allocation of allowances. In particular, it underlines that the role of lobbying for the distribution of allocated allowances in the EU ETS is conditional on firm characteristics.

Given the insignificant coefficients of the lobby variable itself, the employment variable and the employment-lobbying interaction term, together with the theoretical model the 2SLS estimation results indicate that lobbying may influence the allocation process only in combination with specific economic characteristics of the respective industries: a high exposure to environmental regulation in terms of a high emission level. In contrast, there is no indication that the level of firm employment matters for allowance allocation. Put differently, we find that in the EU ETS industrial arguments against environmental policy which were directly linked to regulatory exposure played a more critical role than more indirect policy issues. The estimations include sectoral dummy variables (see above) but are robust to their or the elimination of insignificant explanatory variables from the estimation.

Result 2: *Allowance allocation in the EU Emissions Trading Scheme is distributed in favour of sectors represented by powerful lobby groups, if the corresponding firms are highly exposed to emission regulation.*

3.3 Conclusions

This paper assessed the political-economy aspects of allowance allocation in the EU Emissions Trading Scheme (EU ETS) both on theoretical and empirical grounds. We developed a simple analytical framework of the role of interest groups for the allocation of emission allowances in a cap and trade system. The model is structured as a *common-agency*

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[34] The magnitude of the (highly significant) estimated coefficient of the emissions variable for 2SLS is smaller than for OLS estimation, which may be a sign of actual reverse causality of the emissions variable, as one would expect the effect of allowances allocated on verified emissions to be positive. For this case, i.e. that "over-allocation" led to higher actual emissions and more stringent allowance allocation led to more abatement, OLS would over-estimate the impact of verified emissions on allowances allocated. Such a bias can be eliminated using the 2SLS technique.

problem, in which several principals (sectoral interest groups) aim to induce an action from a single agent (the government). In the stylized model, lobbying may influence political decisions, as the government does not only value social welfare but also political contributions by interest groups. As a consequence, the government's valuation of political contributions by interest groups from sectors covered by the emissions trading scheme leads to inefficiently high levels of allowance allocation, thereby shifting the regulatory burden from those sectors covered by the trading scheme to the remaining industries of the economy. In order to fulfill the national emission target, the latter have to be regulated by an inefficiently high emissions tax. Besides this efficiency result, we find that the distribution of permits within the emissions trading scheme is biased in favor of those sub-sectors that feature more powerful lobby groups and higher emission levels.

An empirical analysis of the first trading phase of the EU ETS corroborates our two central theoretical findings predicting a strong role of interest groups for an inefficient emission regulation and a positive impact of sub-sectoral lobbying power on allowance allocation. The empirical analysis suggests that the presence of interest groups has induced a deviation of the actual allocation of EU ETS emission allowances from its economically efficient level. However, the estimations show that lobbying was only beneficial in combination with a high level of CO_2 emissions. This implies that large carbon emitters that were heavily exposed to emission regulation and simultaneously represented by powerful interest groups received inefficiently high levels of emission allowances. In contrast, stand-alone threats of potential worker layoffs did not exert a significant influence on the EU ETS allocation process. Furthermore, in accordance with our theoretical findings the estimation results suggest that the lobbying effect on the distribution of permits within the EU ETS is conditional on emissions, i.e. specific firm characteristics. These empirical results emphasize that the combination of lobbying for permits and high emitting activity affect both the distribution of allowances and the efficiency of regulation.

Suggesting that industrial lobbying has played a crucial role for emission allocation at the German level, our results corroborate the existing critique on the allocation process of the EU ETS. The findings of both our theoretical and empirical analysis thus provide arguments in favor of the use of auctioning instead of a grandfathered allowance allocation. The claim for an increased use of auctioning in emissions trading systems has, up to now, been mainly based on theoretical arguments concerning the reduction of tax distortions, the enhanced provision of innovations, and the elimination of potential lobbying influence (Cramton and Kerr, 2002). Despite the more stringent allowance allocation in the second trading phase of the EU ETS and the increasing application of auctioning, our empirical results thus provide new support for the use of auctioning in emissions trading. To complement our primary insights into the determinants of EU emission allowance allocation, empirical assessments for additional EU Member States as well as the second EU ETS trading phase constitute interesting directions for future research.

The previous two chapters have analyzed the political-economy determinants of the design of climate policy for the case of two market-based instruments: environmental taxes and tradable emissions permits. Against this background, the following chapter assesses political-economy aspects of economic policy advice in the context of environmental tax reforms.

3.4 Appendix

3.4.1 Theoretical framework: Firm behavior

Profit maximization in sector *ets* yields the following first-order conditions for firms in the *ets* sector:

$$0=\frac{\partial \pi_{ets}}{\partial q_{ets}}=p_{ets}-c_{ets}(\mu_{ets})-\sigma(1-\alpha)\mu_{ets} \;\Leftrightarrow\; p_{ets}=c_{ets}(\mu_{ets})+\sigma(1-\alpha)\mu_{ets} \tag{13}$$

$$0=\frac{\partial \pi_{ets}}{\partial \mu_{ets}}=-c_{ets}'(\mu_{ets})q_{ets}-\sigma(1-\alpha)q_{ets} \;\Leftrightarrow\; -c_{ets}'(\mu_{ets})=\sigma(1-\alpha)\,. \tag{14}$$

While condition (13) states that given the firm's behavior the marginal benefit of sectoral production equals its social cost, condition (14) implies that the marginal cost of emission abatement equals the permit price adjusted by the marginal cost or benefit from allowance allocation. Moreover, differentiation of the profit function w.r.t. α implies that $K_{ets}'(\alpha)=\sigma\mu_{ets}q_{ets}>0$, i.e. political contributions increase in the allocation factor (as do sectoral profits).

Profit maximization in sector *nets* yields the following first-order conditions:

$$0=\frac{\partial \pi_{nets}}{\partial q_{nets}}=p_{nets}-c_{nets}(\mu_{nets})-\tau\mu_{nets} \;\Leftrightarrow\; p_{nets}=c_{nets}(\mu_{nets})+\tau\mu_{nets} \tag{15}$$

$$0=\frac{\partial \pi_{nets}}{\partial \mu_{nets}}=-c_{nets}'(\mu_{nets})q_{nets}-\sigma q_{nets} \;\Leftrightarrow\; -c_{nets}'(\mu_{nets})=\tau\,. \tag{16}$$

Analogously to the first-order conditions in the *ets* sector, condition (15) states that the marginal benefit of *nets* production equals its social cost, while condition (16) implies that the marginal cost of emission abatement equals the value of the emissions tax.

3.4.2 Empirical analysis: The CREDITREFORM database

The CREDITREFORM database is a financial and economic database that includes information of sales and employment of German firms. It is the most comprehensive database on German firms, containing a random sample of 20,000 solvent and 1,000 insolvent firms in Germany. From the CREDITREFORM database, we use levels and differences from firm revenue and employment data between 2002 and 2005. Those data have been matched with the allocation factor (allowances allocated divided by verified emissions) from the EU Independent Community Transaction Log. This has been conducted by supplementing allocation data that has been aggregated at the firm level with CREDITREFORM data. The main criteria for this database matching were the respective company names and addresses. The matching results have been carefully checked for consistency reasons. Sectoral dummy variables have been constructed as follows: electricity: NACE code between 4000 and 4020; other energy: NACE code between 4020 and 4500; manufacturing: NACE code between 2600 and 3700.

3.4.3 List of tables

Table 13: Descriptive Statistics

	Obs.	***Mean***	***Std. Dev.***	***Min.***	Max.
Allowances Allocated	175	533645.90	2808694	272	3.46e+07
Deviation from Efficient Allocation	175	71313.05	244591.7	-8542.70	1687941
Verified Emissions (t CO_2)	175	511996.50	2907576.00	50	3.65e+07
Squared V. Emissions	175	8.67e+12	1.01e+14	2500	1.33e+15
Lobby (no. of representatives)	175	108.39	74.77	7	350
Lobby x Emissions	175	6.48e+07	4.50e+08	8000	5.84e+09
Lobby x Employment 2004	175	114553.80	282992	14	2370760
Employment 2004	175	1279.56	3422.74	1	33810
Employment 2002	175	1351.07	3875.96	1	33049
Employment 2001	155	1088.37	3191.49	1	37707
Employment 2000	144	1370.72	4645.31	1	42317
Employment 2002 squared	175	1.68e+07	1.16e+08	1	1.09e+09
Employment 2001 squared	155	1.13e+07	1.14e+08	1	1.42e+09
Employment 2000 squared	144	2.33e+07	1.82e+08	1	1.79e+09

Table 14: Correlation matrix of selected regression variables

	Allowances Allocated	Verified Emissions	Squared V. Emissions	Employ-ment	Lobby	Lobby x Emissions	***Lobby x Employ-ment***
Allowances Allocated	1.0000						
Verified Emissions	0.9988	1.0000					
Squared V. Emissions	0.9792	0.9870	1.0000				
Employ-ment 2004	0.0631	0.0648	0.0667	1.0000			
Lobby	0.0858	0.0799	0.0591	-0.0790	1.0000		
Lobby x Emissions	0.9985	0.9996	0.9872	0.0608	0.0892	1.0000	
Lobby x Employ-ment 2004	0.7180	0.1531	0.1519	0.8775	0.2450	0.1531	1.0000

Note: 131 observations. Pearson's correlation coefficient for the respective variable pairs is given.

Table 15: Specification tests for first stage regressions

Dependent variable	Verified Emissions	Squared V. Emissions	Lobby x Emissions
F-Test first stage regression specification (1)	0.00***	-	-
F-Test first stage regression specification (2)	0.00***	0.00***	0.00***

Note: 131 observations. F-Test (p-value) on null hypothesis of joint insignificance of all explanatory variables.*, **, and *** indicate significance at the 10%-, 5%-, and 1%-level, respectively. The full results from these first stage regressions are available on request from the authors.

Table 16: German manufacturing sectors and respective industrial associations

Sector No.	Name of sector	Industrial associations
1	Agricultural products	German Farmers Association (DBV)
2	Forestry & fishery products	German Forestry Council (DFWR) German Fishery Association (DFV)
3	Electric power & steam & warm water	German Electricity Association (VDEW)
4	Gas	Association of the German Gas and Water Industries (BGW)
5	Water (distribution)	Association of the German Gas and Water Industries (BGW)
6	Coal & coal products	German Mining Association (WVB) German Hard Coal Association (GVST) German Lignite Industry Association (DEBRIV)
7	Minery products (without coal & gas & petroleum)	German Mining Association (WVB)
8	Crude oil & natural gas	Association of the German Oil and Gas Producers (WEG)
9	Chemical products & nuclear fuels	Association of the German Chemical Industry (VCI)
10	Oil products	Association of the German Petroleum Industry (MWV)
11	Plastics	Association of the German Plastics Processing Industry (GKV) Federation of German Woodworking and Furniture Industries (HDH) Federation of German Paper, Cardboard and Plastics Processing Ind. (HPV)
12	Rubber	German Rubber Manufacturers' Association (WDK)
13	Stone & lime & cement	German Building Materials Association (BBS)
14	Ceramic	German Federation of Fine Ceramic Industry (AKI)
15	Glass	German Glass Industry Federation (BV Glas)
16	Iron & steel	German Steel Federation (WV Stahl) German Federation of Steel and Metal Processing (WSM)
17	Non-ferrous metals	Federation of the German Non-Ferrous Metals Industry (WVM) Federation of German Steel and Metal Processing (WSM)
18	Casting products	German Foundry Association (DGV)
19	Rolling products	Association of German Drawing Mills (STV) Association of German Cold Rolling Mills (FVK)
20	Production of steel etc	German Structural Steel and Power Engineering Association (SET)

Table 16 (continued): *German manufacturing sectors and respective industrial associations*

Sector No.	Name of sector	Industrial associations
21	Mechanical engineering	Federation of the German Engineering Industry (VDMA)
22	Office machines	–
23	Motor vehicles	Association of the German Automotive Industry (VDA)
24	Shipbuilding	German Shipbuilding and Ocean Industries Association (VSM)
25	Aerospace equipment	German Aerospace Industries Association (BDLI)
26	Electrical engineering	German Electrical and Electronic Manufacturers' Association (ZVEI)
27	Engineers' small tools	German Industrial Association for Optical, Medical and Mechatronical Technologies (SPECTARIS) Federation of German Jewellery, Watches, Clocks, Silverware and Related Industries
28	Metal and steel goods	–
29	Music instruments & toys etc.	National Association of German Musical Instruments Manufacturers (BDMH) German Association of the Toy Industry (DVSI)
30	Timber	Federation of German Woodworking and Furniture Industries (HDH) Association of the German Sawmill and Wood Industry (VDS)
31	Furniture	Federation of German Woodworking and Furniture Industries (HDH)
32	Paper & pulp & board	German Pulp and Paper Association (VDP)
33	Paper & board products	German Pulp and Paper Association (VDP) Federation of German Paper, Cardboard and Plastics Processing Industry (HPV)
34	Printing and publishing	German Printing Industry Federation (BVDM)
35	Leathers & footwear	German Leather Federation (VDL) Federation of the German Shoe Industry (HDS)
36	Textiles	Federation of German Textile and Fashion Industry
37	Clothing	Federation of the German Clothing Industry (BBI)
38	Food products	Federation of the German Food and Drink Industries (BVE)
39	Beverages	Federation of the German Food and Drink Industries (BVE)
40	Tobacco products	Federation of the German Cigarette Industry (VdC)
41	Building & construction	German Construction Industry Federation (HDB)
42	Recovery & repair	German Construction Industry Federation (HDB)

4 Paying the Piper and Calling the Tune? A Meta-Analysis of Modeling the Double-Dividend Hypothesis[35]

The preceding chapter discussed taxes on energy or emissions as an important instrument of environmental policies in industrialized countries. The revenues from environmental levies are commonly used to cut back taxes on labor with the goal of simultaneously reducing energy-related emissions and increasing employment. A prominent example is Germany's ecological tax reform introduced in the late 1990s, which imposes higher taxes on energy use while recycling additional tax revenues through a reduction of employer's social security contributions.

In environmental economics, the prospect of emission reductions along with an increase in employment has been established as the double dividend hypothesis of environmental taxation (Pearce, 1991), where the first dividend relates to higher environmental quality and the second dividend relates to potential employment gains.[36] The employment dividend of environmental tax reforms plays a particularly prominent role in the European Union, where most Member States are worried about high and persistent unemployment rates.[37]

Given its political importance, a large number of model-based simulation studies have assessed the employment dividend hypothesis for environmental tax reforms. These studies stand out for a large variation in simulated employment effects, which raises the question on the underlying reasons for the differences in quantitative or even qualitative results. Obviously, data input and model-specific assumptions on economic mechanisms such as labor market rigidities play a major role (see e.g. Carraro et al., 1996; Welsch, 1996; Bach et al., 2001). Another line of reasoning about the large variation in simulation results is based on political economy aspects of policy advice. Kirchgässner (2005) argues that applied economic

[35] This chapter is based on the paper: Anger, N., Böhringer, C., and A. Löschel (2008): "Paying the Piper and Calling the Tune? A Meta-Analysis of Modeling the Double-Dividend Hypothesis". The manuscript is currently submitted to the journal *Ecological Economics*. As the corresponding author of the manuscript, I contributed to all sections of the chapter.

[36] Note that in the public finance literature the second dividend from an environmental tax reform is typically referred to as an efficiency dividend: If the tax reform reduces the excess cost of raising public revenues, then a dividend in terms of overall efficiency gains might arise (Goulder, 1995).

[37] Theoretical analysis on conditions of existence for an employment double dividend highlights the importance of labor market settings (see e.g. Markandya, 2006, for an overview): While in the situation of voluntary unemployment only an increased labor supply can induce employment gains, in the case of involuntary unemployment labor demand has to be increased in order to create additional employment.

research can obtain "desired" results on seemingly scientific grounds because economic theory is ambiguous on the sign and magnitude of the employment dividend. His analysis suggests that the economic paradigm of self-interested, rational behavior should be applied to the process of economic advising itself and contracting bodies might matter for the modeling outcome.

Cross-comparisons of the simulation results on the economic impacts of environmental tax reforms have been performed previously, indicating that specific model characteristics are significant determinants of simulation results. Barker et al. (2002) use a meta-regression analysis to evaluate the literature on the economic impacts of climate policies. Bosquet (2000) provides a qualitative survey article on the empirical evidence for a second dividend. Patuelli et al. (2005) undertake a meta-analytical synthesis of simulation studies on environmental tax reforms.

Our meta-regression analysis which builds on a large pool of model-based studies on the employment effects of environmental tax reforms complements the existing literature in three respects. First, we assess more closely the role of different labor market specifications for the model-based simulation outcomes. Second, we exploit the explanatory information of the publication outcome which is not covered by observable study characteristics. Third, we follow the suggestion of Kirchgässner (2005) and test for political economy aspects of economic policy advice by classifying simulations studies according to contracting bodies: Does he who pays the piper also call the tune?

The remainder of this paper is organized as follows. Section 4.1 presents the methodology and dataset of our meta-regression analysis. Section 4.2 provides the estimation results across model-based simulation studies on environmental tax reforms. Section 4.3 concludes.

4.1 Meta-Regression Analysis

Given the broad range of results across model-based simulation studies on the double dividend hypothesis, we aim to identify central determinants of publication outcomes. In this section, we first lay out the methodology of meta-regression analysis, before describing our dataset and the estimation approach.

4.1.1 Methodology

We employ meta-regression analysis (MRA) to assess the influence of central study characteristics on the simulated employment effect of an environmental tax reform in which revenues are recycled for labor tax cuts or the reduction of social security contributions. Stanley and Jarrell (1989) proposed MRA as a quantitative methodology of systematically reviewing the economic literature: Applying statistical methods, MRA may overcome biases of qualitative literature surveys.[38]

The basic meta-regression model can be written as:

$$Y_j = \Psi + \sum_{k=1}^{K} \beta_k Z_{jk} + \varepsilon_j \qquad (1)$$

where

Ψ denotes the 'true' value of the parameter of interest,

Y_j captures the reported estimate of Ψ by the *j*-th study,

Z_{jk} refers to the meta-independent variable measuring relevant characteristics of an empirical study,

β_k is the meta-regression coefficient incorporating the effect of particular study characteristics *k* on the reported estimate, and

ε_j reflects the disturbance term.

The explicit goal of MRA is to explain the variation among empirical study results by central study features captured in Z_{jk}.

4.1.2 Dataset and estimation approach

Our dataset comprises 41 published studies on the employment double-dividend hypothesis for four selected regions: Germany, Austria, Switzerland and the aggregate European Union (EU). As a number of studies provide multiple results for alternative model assumptions, our full dataset includes 73 different study specifications (i.e. observations). Appendix 4.4.2 lists the complete set of studies for our meta-regression analysis.

[38] The development of meta-analysis goes back to Glass (1976), who introduced it in the context of educational research.

We start the analysis with a simple linear multiple regression model estimated by ordinary least squares (OLS). Adopting the notations of equation (1), the linear regression model reads as:

$$Y_j = \alpha + \beta_1 Z_{1j} + \beta_2 Z_{2j} + ... + \beta_K Z_{Kj} + \varepsilon_j \tag{2}$$

where α denotes a constant.

The variation in study outcomes Y_j on the simulated employment effect can be explained by central study characteristics captured in Z_{kj}. Previous analyses such as Bosquet (2000) and Patuelli et al. (2005) have discussed a number of determinants which we incorporate into our regression analysis: the stringency of the environmental policy, the time period of policy simulations, the choice of regions (countries), and the model type underlying the simulation. In addition, we pay special attention to the role of labor market imperfections where we distinguish three alternative ways of characterizing involuntary unemployment. In this paper, the regional focus of the study is covered by two dummy variables, one for Germany and one for Austria and Switzerland (reference category: EU). Another dummy variable controls for the employed model type, i.e. the use of a macroeconometric model (reference category: CGE model). Finally, alternative specifications of imperfect labor markets are controlled for by three dummy variables; one for fixed real wage regimes, one for unionized labor markets, and one for the wage curve mechanism (reference category: perfect labor market with flexible wages).[39]

As a central objective of this paper is to assess the role of contracting bodies for the findings of commissioned studies, the potential influence of the contracting body is captured by two additional dummy variables for the contractor who commissioned the study: One for an environmental contracting body and one for an industrial contracting body of the study (reference: no contracting body). A contracting body is classified "environmental" when being a related governmental entity (such as a ministry of environment) or an environmental non-governmental organization. It is considered "industrial" when being a related governmental body, an industrial enterprise or an industrial association. Published studies without explicit third-party funding (e.g. university studies) or studies commissioned by research-related governmental bodies were classified as "no contracting body". A description of all variables employed in the linear regression model can be found in Table 19 of Appendix

[39] The wage curve reflects empirical evidence on the inverse relationship between the level of wages and the rate of unemployment (Blanchflower and Oswald, 1994).

4.4.2. Table 20 and 5 of Appendix 4.4.2 report the summary statistics for metric and dummy variables.

Besides assessing these observable determinants of publication outcomes, we additionally control for unobservable study characteristics. Following Nelson and Kennedy (2008), we include dummy variables for those studies that feature multiple results via alternative model assumptions and thus have a relatively high weight in our sample of publications (yielding in total 15 study dummies).[40] These dummy variables take over the value 1 for each simulation result of a study and 0 otherwise. They capture all explanatory information of the publication outcome that is not covered by our core regressors, thus accounting for omitted variable bias and representing unobservable study characteristics not reported consistently across the respective articles. We test for the joint significance of these additional dummy variables using the Wald test for the parameters of the correspondingly fitted regression model.

Finally, Stanley and Jarrell (1989) emphasize that meta-regression errors are likely to be heteroscedastic[41] because studies may differ in the employed datasets and other characteristics. Thus, we will test for heteroscedasticity and employ robust estimation techniques.

4.2 Estimation results

In this section, we summarize and discuss the quantitative estimation results from our meta-regression analysis, which aims at identifying the central determinants of the outcome of the reviewed model-based simulation studies. We start the analysis by assessing observable study characteristics as laid out above, before controlling for unobservable features of publications on the employment double-dividend hypothesis.

4.2.1 Assessing observable study characteristics

Our first set of estimations assesses the role of observable study characteristics for the outcome of double dividend publications. Regression diagnostics support the concerns by

[40] In this case, the reference category consist of all studies that feature only one observation, i.e. one result. Note that alternatively we could include dummy variables for each study. However, this causes perfect correlation with other dummy variable regressors, thereby leading to computational problems and omitted variable bias, and further goes at the expense of degrees of freedom (Nelson and Kennedy, 2008).

[41] That is diagonal elements of the variance-covariance matrix of a disturbance term vary in size with an independent variable.

Stanley and Jarrell (1989) regarding heteroscedasticity: For the standard OLS model, the Breusch-Pagan test ($\chi^2(1) = 13.73$) indicates that we must reject the null hypothesis of equal variance. As a consequence, we account for White's heteroskedasticity-robust coefficient estimators. Furthermore, due to differing units of our regression variables, coefficients have been standardized yielding so-called Beta coefficients.

Table 17 presents the OLS parameter estimation for the linear regression model with the simulated employment effect as the dependent variable. It shows that if we account for observable study characteristics, employment effects are significantly determined by the magnitude of emission reduction: the higher the emission reduction due to environmental taxation, the smaller the prospects for an employment dividend (i.e. higher emission reductions increase employment losses or likewise decrease employment gains). Table 17 further indicates that for our data set the employment effects of double-dividend studies are not significantly influenced by the underlying simulation period. The same finding is true both for the regional focus of the study as well as the choice of the model type.

Table 17: Observable study characteristics: parameter estimation by OLS

Independent variables \ Dependent variable	*Employment*
Emissions	0.333 *** (3.54)
Simulation period	-0.041 (-0.39)
Germany	-0.047 (-0.31)
Austria_Switzerland	-0.135 (-1.17)
Model_Macro	-0.222 (-1.42)
Labor_Fixed	0.328 * (1.97)
Labor_Bargaining	0.136 ** (2.03)
Labor_WageCurve	0.039 (0.40)
Contract_Environment	-0.040 (-0.42)
Contract_Industry	-0.278 ** (-2.23)
Constant	0.013 ** (2.46)
Number of observations Goodness of fit F-test Ramsey RESET test	73 $R^2 = 0.41$ F(10, 62) = 4.08 *** F(6, 56) = 1.72

T-statistics in parentheses. * (**, ***) implies that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test).

We further find that employment effects are driven by labor market assumptions: Table 17 reveals that the assumption of imperfect labor markets – either represented by fixed real wages or a unionized labor market with a bargaining process – leads to significantly larger simulated employment gains (or smaller losses) than the assumption of a perfect labor market (i.e. the reference category). This result confirms the theoretical arguments that (i) in the presence of (long-term) real wage rigidities a cut in labor taxes or a reduction of social security contributions may reduce labor costs and increase employment and (ii) in wage-bargaining models the chance for an employment dividend increases, as tax shifting from workers to the unemployed becomes possible, leading to wage moderation and thus to lower producer wages. On the contrary, the simulated employment effects of modeling labor market imperfections via a wage curve mechanism do not differ significantly from assuming a perfect labor market.

Our meta-regression analysis yields an interesting result concerning the contracting body: a significantly negative impact of the dummy variable *Contract_Industry* on the employment effect. While studies with an environmental contracting body do not show significantly different labor market impacts than non-commissioned studies, it implies that those publications commissioned by an industrial contracting body identify larger employment losses (or smaller gains) induced by the environmental tax reform. Given that employment losses are a popular and effective argument against environmental regulation in the context of high unemployment rates, this result seems to back the reservation of industrial interest groups towards environmental tax reforms. Besides looking at the order of magnitude of employment changes, we run additional regressions to assess the sign of employment effects in order to reflect the "existence debate" of the double dividend debate.42

The lower part of Table 17 provides additional diagnostics for our linear regression model: Besides a goodness of fit of 0.41, it shows a high overall significance of the included independent variables (see F-test). Moreover, we employ the *RESET* test using the powers of the independent variables in order to test for potential specification errors. It shows that we are not able to reject the null hypothesis of no specification error for our regression model (in other words, we do not find significant evidence for misspecification).

4.2.2 Controlling for unobservable characteristics

Our second regression model additionally controls for the role of unobservable study characteristics. As discussed in the previous section, the additional dummy variables capture all explanatory information that is not covered by our core regressors representing observable study features. As before the regression diagnostics supports the concerns by Stanley and Jarrell (1989) regarding heteroscedasticity: For the standard OLS model, the Breusch-Pagan test ($\chi2(1) = 57.86$) indicates that we must reject the null hypothesis of equal variance. We

[42] Employing a logistic regression model with the simulated employment effect as a dichotomous dependent variable largely confirms the above results (the corresponding estimation results are available upon request from the authors).

therefore take into account White's heteroskedasticity-robust coefficient estimators and present Beta coefficients. Table 18 presents the corresponding estimation results.

Table 18: Controlling for unobservable study characteristics: parameter estimation by OLS

Independent variables \ Dependent variable	*Employment*
Emissions	0.354 *** (2.68)
Simulation period	0.211 (0.71)
Germany	0.210 (1.10)
Austria_Switzerland	-0.051 (-0.24)
Model_Macro	-0.198 (-1.02)
Labor_Fixed	0.304 (1.15)
Labor_Bargaining	0.152 (0.78)
Labor_WageCurve	0.168 (1.15)
Contract_Environment	0.024 (0.20)
Contract_Industry	-0.376 (-1.35)
Constant	0.515 (0.66)
Number of observations Goodness of fit F-test Ramsey RESET test	73 $R^2 = 0.61$ F(25, 47) = 9.33 *** F(6, 41) = 0.97

T-statistics in parentheses. * (**, ***) implies that the null hypothesis of the respective parameter being zero can be rejected at the 10% (5%, 1%) level of significance (according to the corresponding two-tailed test).

The table presents an interesting finding of the extended regression model that controls for unobservable study characteristics: Compared with the initial regression model that explained the simulated employment effect by observable study features alone, only the coefficient of the emissions variable is equally significant. This emphasizes the crucial importance of the stringency of environmental taxation for the prospects of obtaining a double dividend. When we account for unobservable study characteristics, neither the specification of imperfect labor markets, nor the industrial contracting body exerts a significant stand-lone impact on the simulated employment effect.[43] Nevertheless, the three model assumptions that entered significantly in our first regression (*Emissions, Labor_Fixed and Labor_Bargaining*) still play a joint role for the publication outcome: for our second regression, the corresponding Wald test is highly significant (F(3, 47) = 3.79***). At the same time, also the Wald test for the parameters of those dummy variables representing unobservable study characteristics shows a high joint significance of the corresponding parameters (F(15, 47) = 4.11***), which substantiates the high relevance of implicit publication features. We conclude that when controlling for non-observable study characteristics, both the contracting body and specific model assumptions do no longer play a significant role for the simulated employment effect of environmental taxation. In contrast, the average publication outcome of our sample is determined by a joint set of modeling features as well as implicit study characteristics.

The lower part of Table 18 provides additional diagnostics for our linear regression model: Besides an improved goodness of fit of 0.61, it shows a higher overall significance of the included independent variables as the previous model accounting for observable study features only (see F-test). While we do not find significant evidence for misspecification either, the extended regression model controlling for the role of unobservable study characteristics features an even lower F-statistics of the *RESET* test.

4.3 Conclusions

Taxes on energy or emissions have become a core instrument of environmental policies in industrialized countries. In view of high unemployment levels, the majority of implemented environmental tax reforms aim at obtaining a "double dividend": simultaneously reducing energy-related emissions and increasing employment. Meanwhile there is a larger number of model-based simulation studies on the employment dividend hypothesis for environmental tax reforms that recycle the proceeds to reduce employers' social security contributions. The studies are characterized by a large variation in simulated employment effects, which invokes

[43] These results are robust with respect to the exclusion of those explanatory variables that turned out as insignificant in our first regression.

scientific interest in the identification of central determinants of the associated publication outcomes.

In this paper we have employed a meta-regression analysis to investigate the implications of central model assumptions and contracting bodies for the outcome of simulation studies on the double-dividend hypothesis. Besides assessing these observable determinants of publication outcomes, we explicitly control for unobservable study characteristics.

We find that employment effects are negatively determined by the assumed stringency of environmental regulation: the higher the emission reduction due to environmental taxation, the smaller the prospects for an employment dividend. Regarding all other potential determinants of study outcomes, however, our estimation results are less unambiguous and reveal the importance of unobservable study characteristics for the prospects of a simulated double dividend. While at first glance the choice of labor market settings and the contracting body seem to play a central role for the publication outcome, we find these observable features not to be decisive determinants when controlling for unobservable study characteristics. According to our dataset, thus he who pays the piper does *not* call the tune. In contrast, the employment effects of environmental tax reforms reported in our sample are determined by a joint set of modeling features as well as implicit characteristics of the respective publications.

Within the first part of this dissertation, the preceding three chapters have assessed the political-economy determinants of international emissions trading and environmental taxation. As the design of climate policy instruments translates into economic impacts of their implementation, the second part of this thesis will analyze the economic consequences induced by alternative policy designs.

4.4 Appendix

4.4.1 List of tables

Table 19: Description of regression variables

Variable	Description
Employment	Simulated employment effect (relative change vs. baseline)
Emissions	Simulated effect on emissions (relative change vs. baseline)
Simulation period	Underlying simulation period (years)
Germany	Dummy variable for region Germany (reference: EU)
Austria_Switzerland	Dummy variable for region Austria or Switzerland (ref. EU)
Model_Macro	Dummy variable for macroeconometric model (ref. CGE model)
Labor_Fixed	Dummy variable for imperfect labor market modeled by fixed wage rates (ref. perfect labor market)
Labor_Bargaining	Dummy variable for unionized labor market with bargaining process (ref. perfect labor market)
Labor_WageCurve	Dummy variable for imperfect labor market modeled by a wage curve mechanism (ref. perfect labor market)
Contract_Environment	Dummy variable for environmental contracting body (ref. none)
Contract_Industry	Dummy variable for industrial contracting body (ref. none)

Table 20: Summary statistics for metric variables

VARIABLE	OBS.	MEAN	STD. DEV.	MIN.	MAX.
Employment	73	0.004	0.019	-0.055	0.104
Emissions	73	-0.109	0.100	-0.520	0.085
Simulation period	73	15.767	14.594	0	51

Table 21: Summary statistics for dummy variables

VARIABLE	OBS.	1	0
Germany	73	47.9%	52.1%
Austria_Switzerland	73	21.9%	78.1%
Model_Macro	73	30.1%	69.9%
Labor_Fixed	73	41.1%	58.9%
Labor_Bargaining	73	9.6%	90.4%
Labor_WageCurve	73	5.5%	94.5%
Labor_Perfect	73	43.8%	56.2%
Contract_Environment	73	9.6%	90.4%
Contract_Industry	73	17.8%	82.2%

4.4.2 List of studies within meta-regression analysis

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Part II

Economic Impacts of Climate Policy

5 Emissions Trading beyond Europe: Linking Schemes in a Post-Kyoto World [44]

By the initiation of the European Greenhouse Gas Emissions Trading Scheme in January 2005, for the first time international trading of carbon emissions allowances became feasible for energy-intensive companies at the installation level. Introducing the largest multi-country emissions trading scheme (ETS) world-wide, the EU aims at cost-efficient compliance with the reduction commitments of its Member States under the Kyoto Protocol (UNFCCC, 1997). In the future, carbon trading will however not be limited to Europe: The EU ETS directive proposes that "agreements should be concluded with third countries listed in Annex B to the Kyoto Protocol which have ratified the Protocol to provide for the mutual recognition of allowances between the Community scheme and other greenhouse gas emissions trading schemes" (EU, 2003). At the same time, countries beyond the EU are contemplating the set up of domestic ETS with the intention of linking up to the European scheme – which would enable companies outside the EU to trade emissions with European firms. From 2008 on, company trading among linked schemes would however occur in parallel with trading among countries, as the Kyoto Protocol facilitates international government trading of emissions between Annex-B parties at the country level. To quantify the economic implications of these overlapping future climate policies is the goal of this paper.

Developments of domestic ETS outside the EU have already made substantial progress in Norway and Switzerland who are designing schemes similarly to the European system. Since discussions on linking are already underway, chances are high that these countries will already be linked to the EU ETS until 2010 (Sterk, 2005). In the medium-term perspective up to 2020, further candidates for linking to the EU ETS appear on the stage: Canada has promoted the Large Final Emitter System to cover energy-intensive companies which account for almost 50 percent of total Canadian greenhouse gas emissions (CEPA Environmental Registry, 2005). The scheme aims to be based on intensity targets and to include a "Price Assurance Mechanism" capping allowance costs at 15 Canadian dollars. Japan has started the Pilot Project of Domestic Emissions Trading Scheme on a voluntary basis, with about 30 private companies participating in the program (Japanese Ministry of the Environment, 2004).

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[44] This chapter is based on the publication: Anger, N. (2008): "Emissions Trading beyond Europe: Linking

Russia – having ratified the Kyoto Protocol – could have incentives to develop a domestic emissions trading system in order to be linked to the European scheme and exploit a larger market for the sale of excess emissions permits – so-called "Hot Air" – due to lower *Business-as-Usual* (BAU) than target emissions committed to.

Although the United States and Australia have not ratified the Kyoto Protocol, individual states in both countries are promoting emissions trading schemes: In the U.S. the Regional Greenhouse Gas Initiative, aiming at a regional ETS, is pushed by several Northeast and Mid-Atlantic states (RGGI, 2007). In Australia the New South Wales Greenhouse Gas Abatement Scheme is already operating at the state level (New South Wales government, 2006) and more recently, Australian state premiers have released early proposals for a national cap and trade system starting in 2010 (Point Carbon, 2006). Also these schemes could quickly arouse interest in EU-ETS decision makers, as "the Commission should examine whether it could be possible to conclude agreements with countries listed in Annex B to the Kyoto Protocol which have yet to ratify the Protocol" (EU, 2004). In summary: There are strong signs for future ETS to be established in non-EU countries and potentially linked with the European scheme by 2020.

At the same time, three flexible mechanisms proposed by the Kyoto Protocol will facilitate various emissions market operations by Annex B parties from 2008 on: International Emissions Trading makes government trading of *Assigned Amount Units* (AAUs) possible at the country level; the Clean Development Mechanism (CDM) enables project-based emissions reductions in developing countries in order to generate *Certified Emission Reductions* (CERs), and Joint Implementation (JI) facilitates project-based abatement in other Annex B regions, generating *Emission Reduction Units* (ERUs).

However, the use of the project-based mechanisms will not be restricted to governments: The amending directive linking the European ETS with the Kyoto Protocol's project-based mechanisms (EU, 2004) allows European companies to generate emissions reductions by means of the CDM or JI. Imports of CDM and JI credits may serve as substitutes for ETS allowances since they are interchangeable with the European allowances. Moreover, EU ETS allowances are simultaneously labeled as Kyoto units (AAUs). Consequently, four types of emissions reduction credits – ETS allowances, Kyoto units, CDM and JI credits – may be used by countries to comply with their reduction commitments under the Kyoto Protocol. This

Schemes in a post-Kyoto World", *Energy Economics*, 30(4), 2028-2049.

paper analyzes these parallel climate policies due to regulation at the country and installation level by both emissions trading and project-based crediting.

Previous studies have assessed the economic aspects of international emissions trading schemes both in theoretical and applied model frameworks. Rehdanz and Tol (2005) consider the coordination of domestic carbon permit markets in which countries determine their own emissions reduction targets. Using a theoretical two-country model they find that linking such schemes benefits both countries but may cause the exporting country to decrease its emissions reduction target and increase permit exports. Quantitative studies have on the one hand focused on efficiency aspects of segmented carbon markets under the current European ETS in partial or general equilibrium frameworks (see Böhringer et al., 2005 or Peterson, 2006), and on interactions between the European ETS and the project-based Kyoto mechanisms (Klepper and Peterson, 2006). These studies find that hybrid emissions regulation (i.e. EU emissions trading in energy-intensive sectors and complementary domestic emissions regulation for the remaining segments) may lead to substantial excess costs – as compared to a comprehensive emissions trading system covering all segments of the economy or an emissions tax imposed unilaterally by each Member State. Moreover, they find that unlimited access to emissions abatement via CDM and JI substantially contributes to reducing the costs of meeting the European Kyoto targets. On the other hand, economic impacts of country-level trading under the Kyoto Protocol have been assessed through multi-model evaluations (see Springer, 2003 or Weyant and Hill, 1999), partly focusing on the economic potential of the CDM and associated investment barriers (Anger et al., 2007). While these studies focus *either* on the present EU ETS *or* government trading in the first commitment period of the Kyoto Protocol, a comprehensive simultaneous assessment of these parallel regulations in a future climate policy regime is still lacking.

Against this background, the contribution of the present paper is threefold: In a quantitative approach it (i) addresses the economic impacts of company-based emissions trading *beyond* the European ETS by linking to emerging non-EU schemes, (ii) analyzes the efficiency implications of linkage in the presence of *parallel* country-level trading and the CDM under a post-Kyoto regime, and (iii) introduces a possible *joint* future trading system between ETS companies and Kyoto governments. Based on a numerical multi-country, two-sector partial equilibrium model of the world carbon market economic impacts are assessed quantitatively.[45] The model features explicit marginal abatement cost functions for 2020

[45] Note that this analysis focuses on emissions trading of carbon dioxide as the most important greenhouse gas.

calibrated to energy-system data and considers transaction costs and investment risk for CDM host countries.

The remainder of this paper is organized as follows. In section 5.1, the theoretical background for the analysis is derived. Section 5.2 lays out the numerical framework for the subsequent policy assessment. Section 5.3 specifies illustrative scenarios of climate policy in 2020. Quantitative simulation results are presented in section 5.4 and section 5.5 concludes.

5.1 Theoretical background

The theoretical foundations of the numerical simulation model employed in the next section can be derived by a simple analytical model of the emissions market. Given the heterogeneous emissions reduction commitments under the Kyoto Protocol, first the analysis will focus on the emissions market behavior of countries with alternative reduction targets. Second, the efficiency aspects of emissions trading among ETS companies and governments will be discussed. Third, the parallel existence of linked ETS and government trading is introduced. In a stylized setting, *R* regions are assumed ($r=1,...,R$) committing to individual emissions targets (e.g. targets under the Kyoto Protocol), yielding absolute emissions budgets $\overline{E}_r$ for each region. Abatement costs of energy-intensive sectors (in the following referred to as *EIS*) and non-energy-intensive sectors (in the following referred to as *NEIS*) in each region are denoted by $AC_r^{EIS}(e)$ and $AC_r^{NEIS}(e)$ respectively. Cost functions are decreasing, convex and differentiable in emissions *e*. Total abatement costs $AC_r(E_r)$ are the sum of sectoral costs $AC_r^{EIS}(e_r^{EIS})$ and $AC_r^{NEIS}(e_r^{NEIS})$.

5.1.1 Emissions market behavior

On a competitive market for emissions *R* regions are considered, committing to alternative emissions targets. A region committing to a binding (absolute) emissions target $\overline{E}_r$ aims to minimize its total abatement costs for complying with its commitment. Moreover, it may either buy emissions permits from other committing regions (or import them from CDM and JI host countries) or sell them at the exogenous world market price σ, yielding the following cost minimization problem:

$$\min_{e_r^{EIS},e_r^{NEIS}} \left[AC_r^{EIS}\left(e_r^{EIS}\right) + AC_r^{NEIS}\left(e_r^{NEIS}\right) + \sigma(e_r^{EIS} + e_r^{NEIS} - \overline{E}_r) \right] \qquad (1)$$

Here, a positive (negative) term $e_r^{EIS} + e_r^{NEIS} - \overline{E}_r$ implies that a region is an importer (exporter) of emissions permits. A region without a binding emissions target, such a CDM host country, aims to maximize its revenues from permit sales $\sigma(\overline{E}_r - e_r^{EIS} - e_r^{NEIS})$ less abatement costs from reducing emissions below the target $\overline{E}_r$ (which for these countries equals BAU emissions) and generating the respective credits. Its profit maximization problem directly corresponds to the cost minimization problem of condition (1): CDM host countries aim to minimize total abatement costs for credit generation and (negative) import costs (i.e. maximize revenues from permit exports).[46]

Consequently, for all regions cost minimization or profit maximization with respect to e_r^{EIS} and e_r^{NEIS} yields the following first-order condition:

$$\sigma = -\frac{\partial AC_r^{EIS}}{\partial e_r^{EIS}} = -\frac{\partial AC_r^{NEIS}}{\partial e_r^{NEIS}} = -\frac{\partial AC_r}{\partial (e_r^{EIS} + e_r^{NEIS})} \qquad (2)$$

For each region and sector marginal abatement costs equal the permit price σ and are thereby equalized across all emissions sources. A competitive emissions market therefore ensures that optimizing behavior of individual market participants with heterogeneous reduction commitments (such as parties of the Kyoto Protocol) and without any commitments (such as CDM host countries) leads to the aggregate cost-efficient solution of equalized marginal abatement costs. Optimal emissions can then be derived as $E_r^*, e_r^{EIS^*}, e_r^{NEIS^*}$ where $E_r^* = e_r^{EIS^*} + e_r^{NEIS^*}$. The difference between the total emissions budget $\overline{E}_r$ and aggregate optimal emissions E_r^* yields the optimal total trade volume in emissions permits.

5.1.2 Efficiency implications of alternative trading regimes

Besides the emissions market behavior of countries with alternative reduction targets, regions with binding commitments may face different compliance costs when deciding for government trading at the country level (in the following referred to as Kyoto trading) or company trading among linked emissions trading schemes (in the following referred to as ETS trading). In order to assess the economic impacts of parallel climate policies, first the two trading systems shall be contrasted theoretically. Figure 1 illustrates the corresponding

[46] Since at a positive permit price any emissions reduction below the BAU level results in revenues from permit sales exceeding abatement costs, i.e. in profits, it can be assumed that for this region $e_r^{EIS} + e_r^{NEIS} < \overline{E}_r$ holds and no permits will be imported.

efficiency aspects from a sectoral perspective – for transparency, in the absence of CDM and JI – in terms of compliance costs.

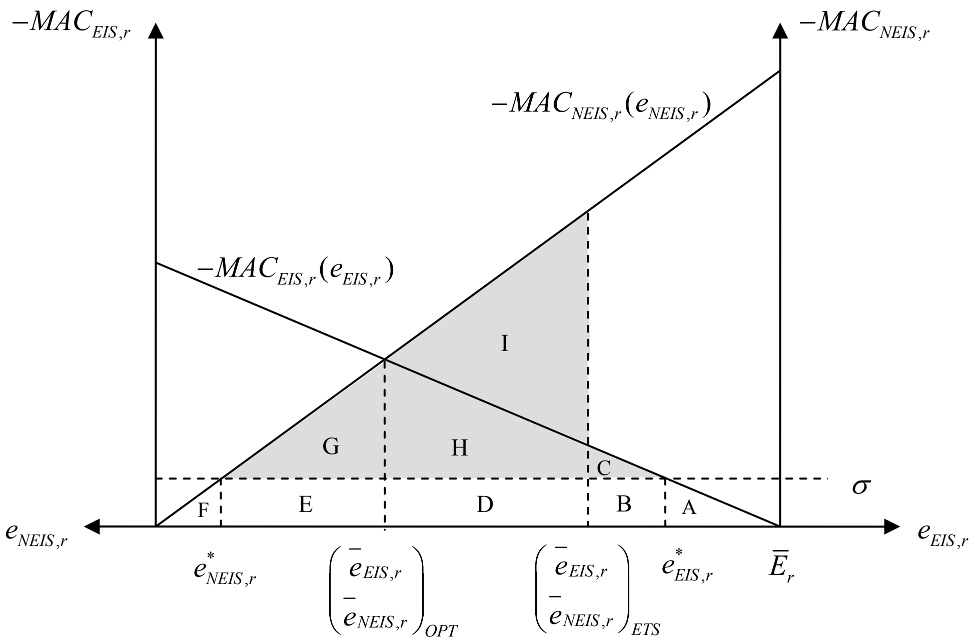

Figure 1: Efficiency gains from international emissions trading under alternative regimes

The figure presents the economic impacts of the two trading schemes for a representative region *r* with energy-intensive and non-energy-intensive sectors and – for simplicity linear – respective marginal abatement costs $MAC_{EIS,r}(e_{EIS,r})$ and $MAC_{NEIS,r}(e_{NEIS,r})$. Marginal abatement costs for NEIS are assumed to be generally higher than for EIS (see section 5.2.3 for a numerical underpinning and more complex functional forms). Equal maximum emissions are assumed for EIS and NEIS.

ETS trading currently implies a national allocation of permits $(\bar{e}_{EIS,r}, \bar{e}_{NEIS,r})_{ETS}$, representing a relatively generous allocation to covered industries as compared to the optimal national allocation $(\bar{e}_{EIS,r}, \bar{e}_{NEIS,r})_{OPT}$ (see also section 5.2.2). Given a world-market permit price σ arising from the international trading activities among EIS, and a national emissions target $\bar{E}_r$, EIS face costs equal to areas A+B in order to comply with the emissions target implied by their sectoral budget. This yields internationally optimal emissions $e^*_{EIS,r}$, permit imports equal to $e^*_{EIS,r} - (\bar{e}_{EIS,r})_{ETS}$ and cost savings from international emissions trading equal to area C. NEIS face abatement costs equal to areas D+E+F+G+H+I in order to reach the sectoral target, yielding emissions $\bar{e}_{NEIS,r}$. For NEIS no cost savings from international emissions trading occur since they do not participate in the trading scheme. Consequently, in the case of internationally linked ETS total compliance costs equal areas A+B+D+E+F+G+H+I including cost-savings from international emissions trading equal to C.

While ETS trading exclusively covers energy-intensive industries, country-level (Kyoto) trading *de facto* involves the entire economy. For transparency, in this case the same initial emissions allocation and the same world-market permit price as under ETS trading is assumed. While for EIS the same efficiency implications as under ETS trading hold, NEIS may now participate in international emissions trading, facing compliance costs equal to areas D+E+F in order to reach the sectoral target. This yields optimal emissions $e^*_{NEIS,r}$ and cost savings from international emissions trading equal to areas G+H+I. Consequently, in the case of international trading at the country level total compliance costs equal areas A+B+D+E+F including cost-savings from international emissions trading equal to G+H+I+C (highlighted).

In summary, Kyoto trading at the country level shows a large efficiency advantage over ETS trading. While the former yields optimal emissions levels by sector – independent of the national emissions allocation by sector – through unrestricted international emissions trading, the latter implies an exclusion of NEIS from international emissions trading *and* a generous allocation of permits to included EIS. Higher marginal abatement costs of NEIS as compared to EIS and large abatement efforts of non-trading NEIS induced by the allowance allocation explain the magnitude of this efficiency advantage.[47]

The project-based mechanisms CDM and JI could serve as an important substitute for high-priced emissions permits within the respective trading systems. The potential efficiency gains would however depend on relative permit prices of alternative policy regimes: Only for decreasing world market prices through the inclusion of CDM and JI the cost savings from international emissions trading (areas G+H+I and area C) can be increased.

5.1.3 Parallel existence of trading regimes

While the previous section focused on contrasting ETS trading to Kyoto trading from an efficiency perspective, this section presents the emissions market implications of a *parallel* existence of these two trading regimes. This is only the case if a post-Kyoto climate policy agreement establishes international government trading at the country level. A domestic ETS exclusively covering energy-intensive installations enables the respective companies to trade emissions internationally with other covered EIS companies. In the case of a coexisting Kyoto trading regime at the country level, a reasonable assumption is that no double regulation of industries covered by a national ETS takes place. Kyoto trading then only applies to the remaining industries of each region, i.e. takes place between the uncovered non-energy-intensive industries. From an intuitive perspective, trading between NEIS should be interpreted as trading activities of national governments *representing* these sectors. Figure 2 extends the unilateral perspective of Figure 1 by introducing an additional world region (yielding two regions, 1 and 2) with two sectors.

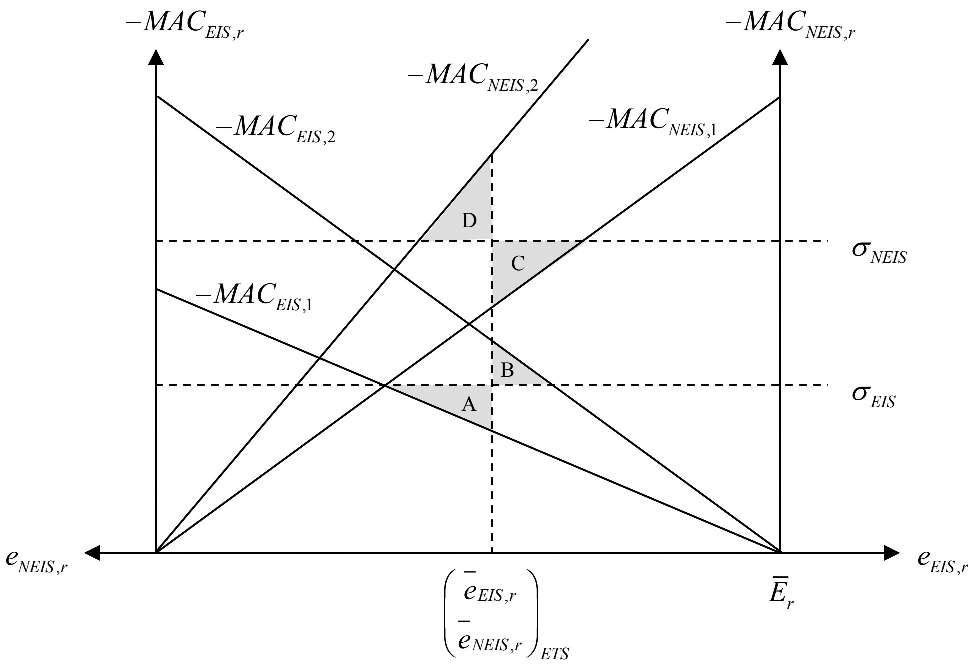

Figure 2: Efficiency gains from parallel international emissions trading

In the figure, regional marginal abatement costs are denoted by $MAC_{NEIS,1}(e_{NEIS,1})$ and $MAC_{NEIS,2}(e_{NEIS,2})$. The marginal abatement cost functions of region 2 represent more costly options than of region 1. For transparency, maximum total emissions of both regions are equal

[47] The illustration of Figure 1 applies to regions with relatively high marginal abatement costs, i.e. regions that are net buyers of emissions permits at the world market. A higher international permit price could transform a region into a net permit seller. The presented economic reasoning could however be applied analogically.

and both allocate the same amount of emissions allowances $(\bar{e}_{EIS,r}, \bar{e}_{NEIS,r})_{ETS}$ to the two sectors. As there is no interconnection between the ETS and Kyoto emissions markets, there are two permit prices (σ_{EIS} and σ_{NEIS}) arising from the sectoral market interactions – the price under Kyoto trading among NEIS (with more costly abatement options) resulting higher than from ETS trading among EIS. On the emissions market, region 2 is importing permits from region 1 in each sector: International trading activities of EIS under (linked) ETS trading equalize marginal abatement costs of the two regions, yielding efficiency gains in terms of export benefits for region 1 and abatement cost savings for region 2 (see areas A and B in Figure 2). In parallel, permit export benefits and cost savings from Kyoto trading apply to NEIS of the two regions (see areas C and D). As compared to the initial allocation, the low-cost region 1 emits less, while region 2 increases emissions. In this parallel-regime setting, Kyoto trading may serve as a compensation mechanism for the inefficiencies of ETS trading and the otherwise large compliance costs of NEIS.

Unlimited access to the project-based mechanisms CDM and JI may establish a connection between the otherwise separated (parallel) carbon markets. If both EIS and NEIS of trading regions have access to the international pool of project-based credits, for a lower CER price than the world market prices for emissions permits the CDM may de facto interconnect the two segments internationally and induce full where-flexibility. In contrast, a potential restriction of CDM access would decrease the chances of such efficiency gains.

5.2 Numerical specification

5.2.1 Baseline emissions and a post-Kyoto regime

This section summarizes baseline emissions and reduction commitments associated with a potential post-Kyoto climate policy regime. Baseline (i.e. BAU) carbon dioxide emissions trajectories are based on van Vuuren et al. (2006) who provide a nationally downscaled dataset from the implementation of global IPCC-SRES scenarios (IPCC, 2001) into the environmental assessment model IMAGE 2.2. Emissions reduction targets represent a possible post-Kyoto regime building on the Kyoto Protocol, in which industrial countries agreed on cutting greenhouse gas emissions by 5.2% on average during 2008-2012 as compared to 1990 levels. For this reason, the derivation of post-Kyoto reduction commitments in the year 2020 starts from 2010 as the central year of the protocol's first commitment period.[48] Generally 2020 is chosen as the reference year here, since domestic emissions trading schemes can be expected to be developed and linked on the global level only in the medium term.

Emissions reduction targets in 2010 for countries that have ratified the agreement correspond to the targets outlined in Annex B of the protocol. For EU Member States the aggregate eight percent target under Kyoto is redistributed according to an internal Burden Sharing Agreement (EU, 1999). Regarding non-ratifying Annex B parties, the United States national commitment to reduce its greenhouse gas intensity (i.e. emissions levels per GDP) by 18 percent by 2012 is translated into an absolute requirement (White House, 2002). Australia is assigned its Kyoto target as the government intends to comply with this commitment despite non-ratification of the Protocol (Commonwealth of Australia, 2002). For non-Annex B regions no emissions reduction commitments are assumed, as developing countries have so far refrained from assuming any quantified targets under the Kyoto Protocol. As the inclusion of these countries under the CDM requires a baseline, developing regions are assigned their BAU emissions.

Reduction commitments in 2020 are then extrapolated from the 2010 targets: For EU Member States, in 2020 an aggregate emissions reduction of 15 percent versus 1990 levels is assumed, which represents the lower bound of a recently proposed range of 15-30 percent (Council of the EU, 2005). It is further assumed that all EU Member States have to contribute the same relative proportion to this aggregate target as in 2010. Emissions reduction commitments of non-EU industrial countries in 2020 are derived from the EU-wide rate of reduction. As these countries have committed to lower reduction targets than the EU in 2010, they are assumed to also exhibit a less ambitious pace of reduction: Emissions reduction rates from 2010 to 2020 are five percentage points below the EU-wide rate of reduction in the same period. Similar to the year 2010, developing countries are assumed to not have committed to any quantified reduction targets in 2020.

Table 24 in Appendix 5.6.1 lists regional carbon dioxide emissions from energy and industry for 1990 (the reference year of the Kyoto commitments), as well as projected emissions for 2010 and for 2020. The table further shows the resulting emissions reduction requirements in 2010 and 2020 versus to 1990 emissions levels, as well as the effective reduction requirements in 2020 versus BAU emissions levels in 2020. The table illustrates regional

[48] The assumption of an existing binding international agreement in 2020 building on the Kyoto Protocol abstracts from long-term stability aspects of such agreements. For a comprehensive introduction into related game-theoretic approaches to international environmental agreements see Finus (2001).

emissions reduction requirements to be very heterogeneous but to become stricter for all regions when moving from 2010 to 2020. The negative reduction requirement of the Former Soviet Union in 2020 versus BAU levels reflects excess emissions permits – so-called “Hot Air” – due to lower projected BAU emissions than the target level implied by its reduction commitment in 2020.

5.2.2 Allocation of emissions allowances in 2020

At present the EU Emissions Trading Directive exclusively covers energy-intensive installations while the remaining industries of EU economies such as households or the transport sector have to be regulated by complementary abatement policies in order to meet the countries’ overall emissions budgets. One reason for the exclusive sectoral coverage are administrative and monitoring tasks within the scheme. In the absence of a potential use of CDM and JI, domestic policies may include e.g. emissions taxes or subsidies for renewable energy use. If the allocation to covered sectors is relatively generous and these sectors feature relatively low-cost abatement options, such a hybrid regulation may cause large inefficiencies: The market segmentation then restricts potential efficiency gains from where-flexibility of international emissions trading and shifts abatement to costly reduction options of non-trading sectors (Böhringer et al., 2005). As the Canadian or Japanese proposals also aim to include mainly energy-intensive industries, the European ETS could likely serve as a “blueprint” for emerging non-EU schemes.

The EU directive prescribes the allocation of emissions allowances to installations according to historic levels by means of National Allocation Plans (NAPs) of the respective Member States, specifying an overall cap in emissions for the covered sectors. Emissions allocation can be described by *allocation factors* as the fraction of baseline emissions that are freely allocated in terms of emissions allowances. In this paper, allocation factors for EU Member States in the year 2020 are derived from a recent study on European emissions allocation in 2005 (Gilbert et al., 2004). The 2005 values, which are presented in Table 25 of Appendix 5.6.1, were then extrapolated to the year 2020 assuming a 20 percent decrease of values in 2020 compared to the year 2005.[49] Consistently, also for non-EU regions allocation factors in 2020 represent a 20 percent decrease as compared to 2005. For these regions, 2005

[49] This assumption is in line with the European Commission’s planned shortage of the EU’s total emissions allocation in the second ETS period (from 2008 on) to some six percent below the first ETS period allocation (EU, 2005). For simplicity it is further assumed that the sectoral coverage by domestic ETS of all regions in 2020 corresponds to the current EU ETS coverage.

"benchmark" allocation factors of equal to one were conservatively chosen according to the lowest EU factors, as the EU scheme is likely to serve as a blueprint for emerging trading systems outside Europe. The base year for emissions allocation reflects the target year of reduction requirements. Table 25 lists the corresponding allocation factors by region and year.

The table shows that the current allocation implies very low reduction efforts for energy-intensive sectors due to a relatively generous allocation of emissions (for political-economy determinants of inefficiencies in current environmental policy see Anger et al., 2006). Note that for the Former Soviet Union allocation factors in 2010 and 2020 are based on the reasoning that the region's excess permits – due to lower BAU emissions than the target level implied by its reduction commitment in the respective year – are allocated to energy-intensive installations proportionally to the corresponding sectors' share of emissions in the entire economy's emissions.[50] Moreover, for some regions the level allocation factors was assigned a minimum value so that EIS at most account for the national effective emissions reduction requirement (this holds for the regions Sweden, Central Europe and the United States).

5.2.3 Model implementation and marginal abatement costs

To assess the magnitude of economic impacts caused by parallel trading regimes including the CDM for a greater number of regions than in section 5.1, a numerical multi-country equilibrium model of the world carbon market is applied. Empirical data on baseline emissions and emissions allocation, as presented in the previous sections, is implemented into the numerical framework. In order to account for real-world complexities, the model incorporates calibrated marginal abatement cost functions and explicitly divides the regional economies into energy-intensive sectors (EIS) and remaining industries (NEIS). Building on the EU-wide version of Böhringer et al. (2005), the extended model explicitly features separated (parallel) carbon markets for ETS and Kyoto trading, incorporates CDM host countries as well as CDM access restrictions, and is calibrated to represent the world carbon market in the year 2020. An algebraic formulation is given in Appendix 5.6.2.[51]

To generate marginal abatement cost functions by region and sector, data simulated by the well-known energy system model POLES is used (Criqui et al., 1999), which explicitly covers energy technology options for emissions abatement in various world regions as well as in energy-intensive sectors (EIS) and remaining industries (NEIS) for the base-year 2020. In

[50] The assumption of excess permit allocation to installations will be relaxed in section 5.4.4.
[51] Note that in this analysis, installation-based trading is implemented as trading at the sectoral level.

the POLES simulations a sequence of carbon taxes (e.g. 0 to 400 US$ per ton of carbon) is imposed on the respective regions, resulting in associated sectoral emissions abatement.

To estimate the coefficients for marginal abatement cost functions in 2020, an ordinary least squares (OLS) regression of tax levels (i.e. marginal abatement costs) on associated emissions abatement is employed. Following Böhringer et al. (2005), in order to assure for functional flexibility a polynomial of third degree is chosen as the functional form of marginal abatement cost functions.[52] For region *r* and sector *i* this results in the following equation:

$$-MAC_{ir}(e_{ir}) = \beta_{1,ir}(e_{0ir} - e_{ir}) + \beta_{2,ir}(e_{0ir} - e_{ir})^2 + \beta_{3,ir}(e_{0ir} - e_{ir})^3 \quad (3)$$

with MAC_{ir} as marginal abatement cost in region r and sector $i \in \{EIS, NEIS\}$, $\beta_{1,ir}$, $\beta_{2,ir}$ and $\beta_{3,ir}$ as marginal abatement cost coefficients, e_{0ir} as baseline emissions level and e_{ir} as emissions level after abatement. Table 26 in Appendix 5.6.1 shows the resulting least-square estimates of marginal abatement cost coefficients by region and sector in 2020.[53]

5.3 Scenarios of future climate policy

In the following, scenarios of linking emissions trading schemes in the presence of a post-Kyoto agreement in 2020 are specified. The scenarios can be classified by two dimensions: The *regional* dimension distinguishes scenarios of countries that establish a climate policy regime, whereas the *institutional* dimension distinguishes alternative schemes of carbon regulation. Table 22 presents the three regional scenarios: As a reference case, scenario EU represents EU ETS participants in 2020, i.e. current members of the European Union including the recently acceded countries Bulgaria and Romania.[54] Scenario EU^{+} indicates the potential linkage of the current EU ETS to emerging ETS in countries that ratified the Kyoto Protocol: Japan, Canada and the Former Soviet Union. Scenario EU^{++} assumes linking the current EU ETS not only to Kyoto ratifiers but to emerging ETS in countries that have not ratified the Kyoto Protocol, such as Australia and the United States. For all regional scenarios alike five central developing countries are assumed to host CDM projects, representing major

[52] We use the OLS approach as a standard estimation technique, which for our data yields parameter estimations with a high overall goodness-of-fit. Clearly alternative estimation approaches and functional forms could be chosen here.

[53] The marginal abatement cost coefficients have the following units: $\beta_{1,ir}$ [(€2005/tCO_2)/MtCO_2], $\beta_{2,ir}$ [(€2005/tCO_2)/(MtCO_2)^2] and $\beta_{3,ir}$ [(€2005/tCO_2)/(MtCO_2)^3].

[54] Note that the region EU-27 is approximated by EU-15 Member States (excluding Luxemburg) and the POLES model region Central Europe, which essentially covers new Member States as well as Bulgaria and Romania.

suppliers on the CDM carbon market (World Bank, 2006): China, India, Brazil, Mexico and South Korea.[55]

Table 22: Regional scenarios for 2020

<table>
<tr><th>Regional scenario</th><th>Regions participating in emissions trading</th><th>CDM regions</th></tr>
<tr><td>EU</td><td>EU-27</td><td rowspan="3">Brazil
China
India
Mexico
South Korea</td></tr>
<tr><td>EU⁺</td><td>EU-27
Japan
Canada
Former Soviet Union</td></tr>
<tr><td>EU⁺⁺</td><td>EU-27
Japan
Canada
Former Soviet Union
Pacific OECD
United States</td></tr>
</table>

Table 23 lists institutional scenarios which in total involve ten cases. As a reference case, *NOTRADE* represents cost-efficient domestic action by the respective regions, e.g. by sectorally uniform domestic carbon taxation. Clearly this scenario should not be interpreted as a representation of real-world climate policy in the absence of emissions trading, but as an economically efficient reference case. In order to assess linked emissions trading schemes, scenario *ETS* describes international emissions trading only between energy-intensive companies (i.e. sectors), reflecting hybrid regulation with permits and taxes and assuming the sectoral emissions allocation in 2020 shown in Table 25 of Appendix 5.6.1. For transparency, this setting abstracts from the existence of a country-level trading regime. Scenario *PARALLEL* introduces government trading under a post-Kyoto Protocol, existing in parallel to the linked emissions trading schemes (and for the sake of illustration, applying only to the linked regions). This regime assumes a post-Kyoto climate policy agreement establishing international trading at the country level. In such a setting of coexisting trading regimes, a reasonable assumption is that no double regulation of industries covered by a national ETS

[55] The present analysis focuses on the CDM as a project-based mechanism, as JI projects are hosted by Annex B parties who participate in international emissions trading. Abstracting from its project-based character, JI may therefore be represented by international emissions trading of the respective regions.

takes place – Kyoto trading then only applies to the remaining industries of each region.[56] Consequently, *PARALLEL* describes ETS trading for energy-intensive sectors, while it assumes Kyoto trading among the remaining non-energy-intensive sectors.[57] Finally, scenario *JOINT* represents a potential interconnection between ETS and Kyoto trading: International emissions trading both among energy-intensive sectors via companies and among countries via governments and *between* companies and governments. This institutional setting is equivalent to international trading across all sectors and regions, except of intranational and international trading between different sectors.

Table 23: Institutional scenarios for 2020

<table>
<tr><th>Institutional scenario</th><th colspan="2">CO_2 regulation</th><th colspan="2">International emissions trading</th><th colspan="2">CDM access</th></tr>
<tr><th></th><th>EIS</th><th>NEIS</th><th>EIS with</th><th>NEIS with</th><th>EIS</th><th>NEIS</th></tr>
<tr><td>NOTRADE</td><td>Tax</td><td>Tax</td><td>No</td><td>No</td><td>No</td><td>No</td></tr>
<tr><td>ETS</td><td rowspan="3">Permits</td><td rowspan="3">Tax</td><td rowspan="3">foreign EIS</td><td rowspan="3">No</td><td>No</td><td rowspan="3">No</td></tr>
<tr><td>ETS_CDM</td><td>Unlimited</td></tr>
<tr><td>ETS_SUP</td><td>10% of allocation</td></tr>
<tr><td>PARALLEL</td><td rowspan="3">Permits</td><td rowspan="3">Permits</td><td rowspan="3">foreign EIS</td><td rowspan="3">foreign NEIS</td><td>No</td><td>No</td></tr>
<tr><td>PARALLEL_CDM</td><td>Unlimited</td><td>Unlimited</td></tr>
<tr><td>PARALLEL_SUP</td><td>10% of allocation</td><td>50% of reduction</td></tr>
<tr><td>JOINT</td><td rowspan="3">Permits</td><td rowspan="3">Permits</td><td rowspan="3">foreign EIS foreign NEIS</td><td rowspan="3">foreign EIS foreign NEIS</td><td>No</td><td>No</td></tr>
<tr><td>JOINT_CDM</td><td>Unlimited</td><td>Unlimited</td></tr>
<tr><td>JOINT_SUP</td><td colspan="2">50% of national reduction</td></tr>
</table>

Regarding CDM and JI, the Marrakech Accords to the Kyoto Protocol demand that "the use of the mechanisms shall be supplemental to domestic action" (UNFCCC, 2002). Although the Marrakech formulation lacks precision, one attempt to quantify a CER import limit was made

[56] As in section 5.1.3, trading between NEIS should be interpreted as trading activities of national governments *representing* their non-energy-intensive sectors.

[57] Here it is assumed that each ETS region has committed to a post-Kyoto agreement enabling government emissions trading.

by the European Union, essentially stating that no more than 50 percent of an Annex-B party reduction commitment may be fulfilled by imports from the project-based mechanisms (Langrock and Sterk, 2004). Besides the supplementarity issue under the Kyoto Protocol regarding government trading, there is a separate supplementarity debate regarding installation-based trading: The EU ETS amending directive states that “Member States may allow operators to use CERs and ERUs from project activities in the Community scheme up to a percentage of the allocation of allowances to each installation” (EU, 2004). Also in the EU ETS amending directive no quantitative limit for the import of CDM and JI credits is specified and it is the obligation of each Member State to ensure that the use of the Kyoto mechanisms is supplemental to domestic action by means of its national allocation plan. However, in a recent communication to the European Parliament the Commission states that it will assess consistency with supplementary obligations based on an import limit of ten percent of a Member State’s assigned emissions cap (EU, 2006).

Within the institutional scenarios for the present analysis, the following CDM regimes are applied: While the reference case *ETS_CDM* assumes the *ETS* trading regime including the option of unlimited CER imports (only) by EIS companies from conducting CDM projects, *PARALLEL_CDM* and *JOINT_CDM* represent the respective regime with unlimited CDM access for governments, i.e. all sectors. Supplementarity considerations are taken into account by three scenarios: *ETS_SUP* restricts CER imports of energy-intensive industries to ten percent of allocated permits. *PARALLEL_SUP* reflects a sectorally differentiated supplementarity rule, limiting CDM access of EIS to ten percent of allocated allowances, while regulating that in NEIS a maximum of 50 percent of the (sectorally downscaled) NEIS emissions reduction commitment may be fulfilled via the CDM. Finally, *JOINT_SUP* assumes one uniform CDM restriction across all sectors, i.e. a 50 percent maximum CDM import share of the national reduction commitment, as sectors are de facto interconnected via joint trading.[58]

The model considers the following barriers to CDM projects: First, it features transaction costs for the purchase of CERs of 0.5 US$ (1 US$) per ton of CO_2 for energy-intensive (non energy-intensive) sectors of CDM host countries.[59] Second, following Böhringer and Löschel (2008) country-specific investment risk for CDM projects, e.g. from country and project risks, is derived by CDM-region-specific bond-yield spreads between long-term government bonds

[58] Regarding supplementarity rules of non-EU regions, as in the case of sectoral emissions allocation similar regulation as in the EU is assumed.

[59] The magnitude of transaction costs is in line with recent estimates (see Michaelowa and Jotzo, 2005).

of the respective developing country and the United States (as a risk-free reference region). It is assumed that investors are risk-neutral and discount the value of emissions reduction credits generated by CDM projects with the mean risk value of the respective host country. The underlying data stems from the International Monetary Fund's International Financial Statistics (IMF, 2000). Third, a CDM adaptation tax is incorporated amounting to two percent of CER revenues as proposed under the Marrakech Accords (UNFCCC, 2002). Transaction costs, investment risk and the CDM tax enter the model via a premium on marginal abatement costs of CDM host countries, thereby increasing the international CER price.[60]

5.4 Simulation results

In this section, the economic impacts of linking emissions trading schemes in the presence of a post-Kyoto agreement in 2020 are simulated using the numerical multi-country equilibrium model of the world carbon market presented in section 5.2.3. Regarding climate policy scenarios laid out in the previous section, alternative combinations of the regional and institutional dimension are implemented as scenarios in the simulation model. First, the efficiency aspects of alternative trading regimes, such as *ETS*, *PARALLEL* and *JOINT* trading schemes are assessed. Subsequently, the role of the CDM and the associated supplementarity considerations for the international carbon market are addressed.

5.4.1 Economic impacts of linking ETS

As a reference case, the economic impact assessment starts with the climate policy setting of linking the EU ETS with emerging schemes outside Europe in the absence of a post-Kyoto agreement establishing country-level trading and CDM. The efficiency implications are presented in terms of sectoral and total compliance costs associated with the fulfilment of national emissions reduction commitments and are contrasted to the cost-efficient *NOTRADE* reference scenario. Figure 3 first illustrates the corresponding numerical simulation results for the EU in the institutional scenario *ETS* for various regional constellations of linked schemes (for the detailed simulation results see Table 28 in Appendix 5.6.3). In the figure, e.g. scenario *ETS [EU^+]* represents institutional scenario *ETS* in combination with regional scenario *EU^+*.

[60] An alternative approach to account for barriers to CDM project development is presented in Kallbekken et al.

Focusing first on the European Union, it shows that for all regional constellations aggregate EU compliance costs under scenario *ETS* are drastically higher than under *NOTRADE*: Trading emissions among European energy-intensive companies – at a permit price amounting to 28.5 € per ton of CO_2 – implies substantially higher overall adjustment costs than efficient domestic action (assuming an economy-wide uniform carbon tax). This inefficiency is due to a generous emissions allocation to the (benefiting) EIS causing high reduction efforts of NEIS which are excluded from the trading scheme. Considering their high marginal abatement costs, these sectors almost account for the entire economic burden of the reduction commitment (sectoral burden shifting).

Comparing regional trading scenarios, the results suggest that linking the European ETS to other domestic schemes is not able to decrease total EU compliance costs by more than one percent (moving from *ETS [EU] to ETS [EU^{++}]*). As ETS trading exclusively covers energy-intensive sectors, only these industries benefit from an enlarged trading scheme (restricted where-flexibility). The essential part of the economic burden is carried by non-trading sectors and cannot be reduced by linking ETS.

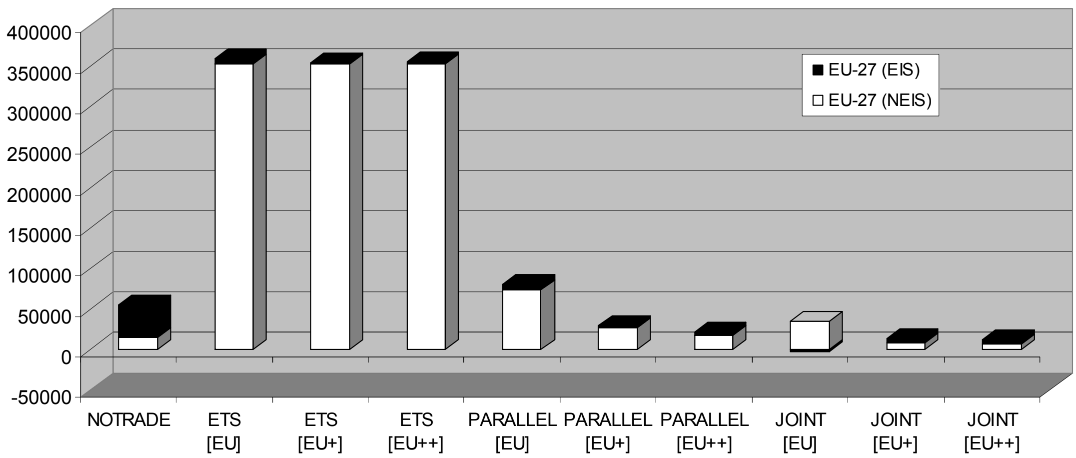

Figure 3: Trading regimes – EU compliance costs by sector and scenario (million €2005)

The economic impacts for non-EU countries from linking to the EU scheme are very heterogeneous: Linking of Canada, Japan and the Former Soviet Union (yielding regional scenario *EU*$^{+}$) implies drastic compliance costs for Canada, while Japan is benefiting and the

(2006), who introduce a "participation rate" reflecting that only some share of the potentially profitable CDM projects will be implemented.

Former Soviet Union is even net-benefiting from joining the EU scheme.[61] Although for Canada's EIS compliance costs are decreased substantially, overall adjustment costs of this region exceed total costs from cost-efficient domestic action, an effect which – as in the case of the EU – can be explained by an inefficient domestic allocation of emissions between sectors. Linking to the European Union cannot compensate for the domestic burden-shifting to non-energy-intensive sectors, since exactly these sectors do not benefit from emissions trading. The beneficial effect for Japan is the cause of a relatively heavy economic burden of EIS under domestic action, which can be significantly decreased by international emissions trading of these sectors. The international ETS permit price falls from 28.5 to 5.0 € per ton of CO_2 due to the sale of "Hot Air" by the Former Soviet Union, which generates large revenues from excess permit exports at the emissions market.

The perspectives of a further enlargement of the EU ETS are even less optimistic: Both Canada and Japan face higher compliance costs when the interlinked ETS with the European Union is further enlarged by Australia and the USA (yielding regional scenario EU^{++}). This effect is due to the increased demand for emissions permits of the new participants which causes a rise in the ETS permit price from 5.0 to 8.3 €. The United States and Australia again face higher compliance costs than under *NOTRADE* due to domestic inefficiencies. As a consequence, linking domestic ETS under the regional constellation EU^{++} is not beneficial for any participant except of the Former Soviet Union, which profits from the increased demand (and price) for its excess permits.

5.4.2 The presence of Kyoto trading

In the presence of a post-Kyoto agreement that enables international emissions trading at the country level, linking the European economies internationally has very different implications. Figure 3 further shows the respective simulation results for the *PARALLEL* and *JOINT* trading scenarios. Focusing first on a parallel ETS and Kyoto trading regime, it shows that already in the absence of linking, the European Union faces efficiency improvements through government trading: Scenario *PARALLEL [EU]* induces drastically lower adjustment costs than *ETS [EU]*, although total costs in the parallel setting are still higher than under efficient domestic action. Kyoto trading serves as a compensation mechanism, largely alleviating the inefficiencies of the EU ETS through parallel international trading among the formerly

[61] By definition, in each scenario of linking ETS non-participating regions face compliance costs equal to the *NOTRADE* scenario.

burdened non-energy-intensive sectors excluded from the scheme. Furthermore, linking the European economies to non-EU regions in the presence of enlarged Kyoto trading leads to a much greater fall in compliance costs – by linking to Canada, Japan and the Former Soviet Union (yielding regional scenario EU^{+}) total EU compliance costs can be reduced by more than 60 percent. The isolated economic impacts from linking the European ETS are obviously similar to the case of absent Kyoto trading, yielding the same economic impacts for EIS – who do not participate in government emissions trading – at a permit price of 5.0 € per ton of CO_2. Thus, it is NEIS that benefit from increased compliance-cost reduction through international Kyoto trading of the same countries – at a permit price of 51.2 €, which is drastically lower than NEIS marginal abatement costs under domestic action. A further enlargement of ETS and Kyoto trading to Australia and the USA (yielding regional scenario EU^{++}) yields increased benefits from a larger emissions market for NEIS, decreasing the permit price to 31.7 € and cutting EU compliance costs by almost 30 percent. Also for non-EU regions parallel trading regimes would result beneficial: All regions except of the Former Soviet Union (revenues from permit sales decrease by more than 30 percent) face lower compliance costs when linking to the European scheme and trading in parallel at the country level. However, emissions markets are still separated – and where-flexibility still restricted – as international trading is feasible only between the same sectors of the linked economies.

A joint emissions trading regime interconnecting energy-intensive companies and national governments is de facto equivalent to full where-flexibility, establishing international trading activities between all regions and sectors. Figure 3 shows that in the absence of linking, only the interconnected trading system *JOINT [EU]* implies efficiency gains for Europe as compared to cost-efficient domestic action. Here, EU compliance costs amount to only 40 percent of a parallel system and to less than ten percent of *ETS* trading. Linking the EU economies internationally in a *JOINT* trading system enables the participating energy-intensive ETS companies not only to trade internationally among each other, but also with governments of the participating countries. Hereby, also an enlarged trading system causes a much stronger fall in EU compliance costs than under *ETS* or even *PARALLEL* trading, since now all sectors can benefit jointly from extended trading activities. Here, the cost decrease is most substantial moving from *EU* to EU^{+}, as the dominant emissions permit exporter Former Soviet Union is able to decrease the international permit price from 69.6 to 14 €. Consequently, also all non-EU regions benefit substantially from enlarged joint emissions trading to EU^{++} except of the Former Soviet Union, which due to a lower market price generates smaller revenues. Of all three trading regimes, this region benefits most from parallel trading (with all sectors trading at relatively high permit prices), followed by joint and ETS trading.

5.4.3 The role of the Clean Development Mechanism

Generating emissions reduction credits in developing countries via CDM projects may serve a substitute for emissions permits traded between industrial countries under the future climate policy regimes presented in section 5.3. Figure 4 illustrates that the impact of the CDM crucially depends on the underlying trading regime (for detailed simulation results see Table 29 in Appendix 5.6.3): While under linked ETS trading only energy-intensive sectors may import CDM permits, under a parallel or joint regime both EIS and NEIS may participate in project-based emissions crediting through national governments. As a consequence, in the context of an ETS regime unlimited CDM access only slightly reduces total compliance costs for all participating regions (see scenarios *ETS_CDM [EU^{+}]* to *[EU^{++}]*). This holds true although the CDM significantly lowers the ETS permit price for the energy-intensive part of the economy (carrying only a minor compliance burden), e.g. within the EU scheme from 28.5 to 4.5 € per ton of CO_2.

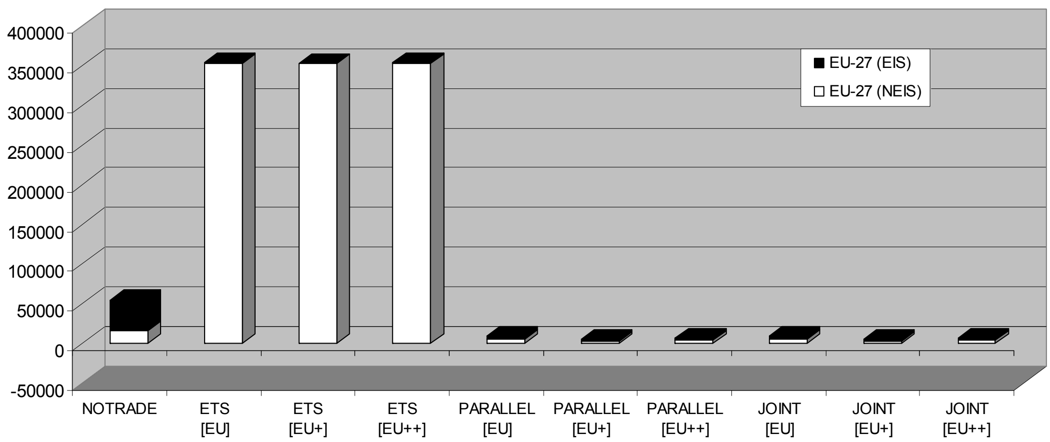

Figure 4: CDM access – EU compliance costs by sector and scenario (million €2005)

By contrast, in a *PARALLEL* trading regime the CDM reduces adjustment costs by almost 90 percent for the European scheme (see *PARALLEL_CDM [EU]*) as compared to the same scenario in the absence of the CDM. In this setting of coexisting trading regimes the sectorally uniform permit price amounts to 9.1 €. Figure 4 shows that compliance costs are in particular lowered for the formerly burdened NEIS who are now granted access to project-based credits, while for EIS the CDM induces even higher adjustment costs in the parallel regime than under *ETS_CDM* due to an increased CER demand and price for EU energy-intensive industries. This leads to a more even cost distribution between sectors and lower aggregate compliance costs than under *NOTRADE*. The additional efficiency gains via the CDM under a parallel regime reflect a stronger compliance-cost reduction of non-energy-intensive industries by abatement options in all sectors of CDM host countries, which are less costly than abatement options of NEIS in (industrialized) Kyoto countries.

Furthermore, Figure 4 shows that the economic effects of the CDM under a *JOINT* trading regime are for all regions identical to those of a parallel setting: As both EIS and NEIS of trading regions have access to the international pool of project-based credits, the CDM de facto interconnects the two sectors internationally and – due to a lower CER price than the world market price for emissions permits – induces full where-flexibility and identical outcomes in both trading regimes. While in a parallel or joint trading system all regions are generally benefiting from demanding CDM credits, the Former Soviet Union is disadvantaged by the enlarged trading activities with developing countries, generating smaller revenues from emissions permit sales due to a decreased demand and price.

Comparing regional scenarios involving the CDM implies that the economic benefits of enlarged emissions trading schemes are generally diminished in the presence of the CDM and can even be reversed: Under *PARALLEL_CDM* and *JOINT_CDM* trading, moving from *EU* to EU^{+} still cuts European compliance costs by almost half (dropping the ETS permit price from 9.1 to 4.8 €) and benefits the permit buyers Canada and Japan. However, further enlarging trading activities to EU^{++} causes efficiency losses by driving the permit price up to 6.4 Euros. This effect is due to an increased demand for emissions permits and CERs by linking to Australia and the USA. These two regions do however benefit from joining an EU^{++} regime despite the increased permit price, due to their higher marginal abatement costs under *NOTRADE*.

As a synopsis of the previous sections, Figure 5 presents the resulting permit prices within linked ETS for alternative trading regimes in the absence and presence of CDM access.

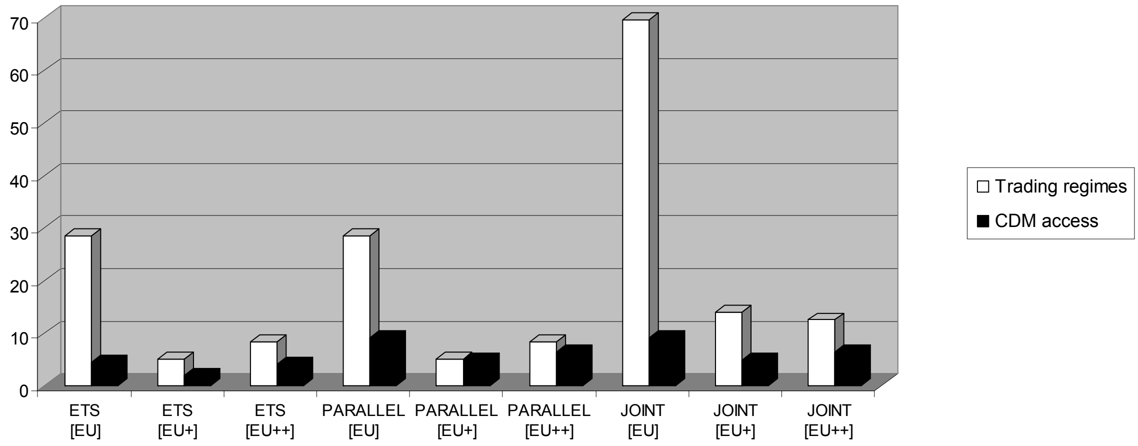

Figure 5: Trading regimes and CDM access – ETS permit price by scenario (€2005 per ton CO_2)

As one climate policy objective of the European Union is to achieve a major fraction of emissions abatement within its trading scheme, strong substitution patterns in favor of the CDM put supplementarity considerations, i.e. restrictions on CER imports, on the political agenda of the linking process. Table 29 in Appendix 5.6.3 shows that only in the absence of linking ETS, the alternative supplementarity scenarios laid out in section 5.3 have an impact on the emissions market for the EU. First, under scenario *ETS [EU]* a restriction of CER imports of EU energy-intensive industries to ten percent of allocated allowances only slightly increases total EU compliance costs (see scenario *ETS_SUP [EU]*). Due to the already minor contribution of unlimited CDM under ETS trading, this result holds despite a permit price increase from 4.5 to 15.1 €.

A supplementarity criterion in a parallel trading regime would restrict EIS imports from the CDM similarly to ETS trading, while NEIS may import a maximum of 50 percent of the downscaled NEIS reduction commitment. Total EU compliance costs may then result even *lower* as under unlimited CDM access: The (binding) import restriction in EIS again induces only a minor cost increase in these sectors of the EU, but the lower EIS demand decreases the CER price for governments (from 9.1 to 8.2 €) enough to transfer relatively larger cost savings to NEIS, for which the 50 percent import limit is not strict enough to be binding.

By contrast, in a joint emissions trading regime EU adjustment costs are more than ten percent higher when only 50 percent of the *national* emissions reduction commitment may be imported by all sectors via the CDM: Limiting the access to low-cost emissions reductions from developing countries reduces potential cost savings from project-based crediting in particular for non-energy-intensive EU industries (facing a sectorally uniform permit price of

26.4 €). Unlike the economic effects for Europe, for all non-EU regions the application of the supplementarity criterions within the enlarged trading schemes does not change the economic impacts of CDM access, as the respective thresholds of CDM imports are not reached under unlimited CDM access (see e.g. total compliance costs under *PARALLEL_CDM [EU^{++}]* versus *PARALLEL_SUP [EU^{++}]*).

5.4.4 Sensitivity analyses

The case of stricter allowance allocation

As a first sensitivity analysis of the core simulation results described in the previous sections, an alternative allocation of emissions allowances (previously described in section 5.2.2) may be assumed. Against the background of the medium-term trend implied by the European Commission's planned shortage of the EU's total emissions allocation in the second ETS period, in this section we assume a stricter allowance allocation implying further decreased allocation factors (EU, 2005). Specifically, a 30 percent decrease of allocation factor values in 2020 compared to the year 2005 is assumed (previously: 20 percent). The corresponding simulation results are presented in Table 30 and Table 31 of Appendix 5.6.4.

It shows that while for all trading regimes the stricter allowance allocation to energy-intensive industries induces a sectoral burden shifting from NEIS to EIS, in a *JOINT* trading regime overall compliance costs de facto remain unchanged due to full where-flexibility. Under *ETS* trading and a *PARALLEL* trading regime overall compliance costs are however significantly decreased for regions committing to emissions reduction targets, as a larger portion of abatement efforts is undertaken by energy-intensive sectors featuring less costly abatement options. In a parallel setting, for institutional scenarios limiting CDM access by supplementarity rules a stricter allocation modus increases the CDM demand of EIS. In this setting, a stricter allocation may even induce higher overall compliance costs as the relatively restrictive CDM access limit for EIS now induces an additional burden that is more than compensating the lower burden of NEIS.

The case of no "Hot Air" allocation

The simulation results presented in the previous sections implicitly assume an international climate policy regime in which excess emissions permits of the Former Soviet Union ("Hot Air") are allocated for free to the respective national installations. This situation would de facto imply a subsidy for EIS since allocated excess permits could directly be exported to other ETS regions. It is however not unambiguous whether such a strategy will prevail in the future: On the one hand, refraining from excess allocation could be a prerequisite for linking to the European scheme due to potential international competitiveness distortions between companies arising from the linking process. On the other, incentives for strategic behavior of the Former Soviet Union as a quasi monopolist on the emissions market could also restrict permit allocation to installations.[62]

For this reason, a second sensitivity case is introduced assuming that no excess permits will be allocated to installations of the Former Soviet Union. In this case, the region is assigned an emissions reduction target versus 1990 levels that resembles its BAU emissions in 2020 (here: 23.3 percent) and an allocation factor equal to one.

Table 32 and Table 33 in Appendix 5.6.4 present the corresponding regional compliance costs. It shows that the previous findings are generally robust to the existence of “Hot Air” from the Former Soviet Union. In the absence of allocated excess permits in each scenario involving this region all other countries face higher compliance costs due to a lower supply of the Former Soviet Union and an increased permit price. However, the higher adjustment costs for permit demanders do not necessarily imply larger revenues from permit sales: Only under *ETS* and *PARALLEL* trading regimes and regional constellation *[EU$^+$]* the lack of excess permits results beneficial for the Former Soviet Union – in all other scenarios the higher market price cannot compensate for the lower amount of permits exports.

5.5 Conclusions

Linkage of the EU Greenhouse Gas Emissions trading Scheme (ETS) to emerging schemes beyond Europe is a central strategic issue of current EU climate policy. At present, non-European countries like Canada, Japan or Australia are contemplating the set up of domestic ETS with the intention of linking up to the European scheme. From 2008 on, company trading among linked schemes would however occur in parallel to trading among countries, as the Kyoto Protocol facilitates international government trading of greenhouse gas emissions at the country level. Moreover, both companies and governments may undertake project-based emissions reductions in developing countries via the Clean Development Mechanism (CDM).

[62] The present paper abstracts from such strategic behavior. For a quantitative analysis of near-term implications of emissions market power by the Former Soviet Union see Böhringer et al. (2007).

The present paper assesses the economic impacts of linking the EU ETS in the presence of a post-Kyoto agreement in 2020. Based on a numerical multi-country, two-sector partial equilibrium model of the world carbon market the economic impacts of parallel climate policies are assessed quantitatively. The model covers explicit sectoral marginal abatement cost functions for the year 2020 calibrated to energy-system data, and considers transaction costs as well as investment risk for CDM host countries.

The simulations show that in the absence of post-Kyoto government trading, linking the European ETS induces no or only marginal economic benefits for the EU: Total compliance costs decrease no more than one percent in all linked schemes. As where-flexibility of international emissions trading is restricted to energy-intensive industries that are assigned generous initial emissions, the major compliance burden is carried by sectors excluded from the linked ETS (i.e. non-energy-intensive industries). These non-trading segments of the economy are not able to benefit from an enlarged trading scheme. Moreover, the economic impacts for non-EU countries from linking to the European scheme are very heterogeneous: Linking to Canada, Japan and the Former Soviet Union implies drastic compliance costs for Canada due to domestic inefficiencies, while Japan is benefiting and the Former Soviet Union is even net-benefiting from joining the EU scheme. A further linking process to Australia and the USA is not beneficial for any participant except for the Former Soviet Union which profits from an increased demand and price for its excess emissions permits ("Hot Air").

In the presence of parallel government trading under a post-Kyoto agreement, international emissions trading is not only feasible among energy-intensive sectors of linked ETS, but also among non-energy-intensive industries (represented by their governments). Linking the European economies to non-EU regions then leads to a much stronger fall in adjustment costs: By linking to Canada, Japan and the Former Soviet Union total EU compliance costs can be reduced by more than 60 percent. Here, it is the non-energy-intensive sectors that benefit from cost attenuation through enlarged international government trading of the same countries. A further linkage to Australia and the USA yields increased benefits from a larger emissions market, especially for non-energy-intensive sectors, further cutting EU compliance costs by almost 30 percent. Also for non-EU regions these parallel trading regimes would result beneficial. However, emissions markets are still separated – and where-flexibility still restricted – as international trading is feasible only among the same sectors of the linked economies.

From an efficiency perspective, a desirable future climate policy regime represents a joint trading system that enables international emissions trading between ETS companies and governments under a post-Kyoto agreement. Such a joint regime is de facto equivalent to full where-flexibility, establishing international trading activities between all regions and sectors. Via such a joint regime the formerly separated markets can be interconnected, generating large efficiency gains: Linking the EU economies internationally in a joint trading system causes an even stronger fall in EU compliance costs than under a parallel regime, since now all sectors can benefit jointly from extended trading activities. Here, the cost decrease is most substantial when linking to Canada, Japan and the Former Soviet Union, as the latter region is able to decrease the international permit price by supplying excess permits to a large extent.

The CDM is not able to alleviate the inefficiencies of linked ETS, since also project-based crediting is restricted to energy-intensive industries of ETS. By contrast, in a parallel trading regime government access to low-cost abatement options of developing countries induces large efficiency gains. Here, the CDM provides additional cost savings of more than 90 percent within the European scheme, largely reducing the compliance costs of non-energy-intensive industries. By providing access to project-based crediting for both energy-intensive and non-energy-intensive sectors, the CDM establishes an indirect link between the two segments of the economy and assures full where-flexibility. Due to this provision of an international credit pool for all sectors the CDM levels out the economic impacts under parallel and joint trading regimes. A restriction of CDM activities via a supplementarity criterion does not significantly decrease the economic benefits from project-based crediting, as the respective thresholds of CDM imports are generally not yet reached under unlimited CDM access.

While representing a fairly transparent model framework, the present partial market analysis clearly can only provide a restricted description of economic reactions to international climate policy. One limitation of partial analysis is the neglect of market interactions and spillovers (for related studies see Böhringer and Rutherford, 2002a, Bernard et al., 2003 or Klepper and Peterson, 2006a). Moreover, the direct costs of abatement may be altered by terms-of-trade effects on fossil fuel markets. However, these effects depend on the extent of global cuts in demand for fossil fuels as well as the level of regional fossil fuel supply elasticities, and may only be addressed in a multi-market, i.e. general equilibrium framework.

This paper laid out the efficiency implications of internationally linked emissions trading schemes, as well as alternative country-level compensation mechanisms for the expected inefficiencies of future schemes. In the long run however, uncertainties about future post-Kyoto agreements and the exhaustion of low-cost abatement options in developing countries raise concerns about the availability of such mechanisms. The projected large economic potentials of the CDM could also be substantially downscaled by the existence of implicit investment barriers such as incomplete information. Moreover, given the large number of participants it is company-based trading that provides a fertile ground for developing a competitive market for emissions. Considering the potential for efficiency improvements of future ETS – such as a stricter allowance allocation to covered installations or an enlarged sectoral scope – linking emissions trading schemes beyond Europe may thus become not only a fall-back option for a lacking international agreement, but a vital option for future climate policy at the global level.

Building on the carbon-market insights of this chapter, the following chapter investigates the linkage of emissions trading schemes from a macroeconomic perspective by assessing the corresponding implications for social welfare and international trade.

5.6 Appendix

5.6.1 Emissions market data

Table 24: *CO_2 benchmark emissions and reduction requirements by region* [63]

Regions	CO_2 emissions in 1990 (Mt CO_2)	CO_2 emissions in 2010 (Mt CO_2)	CO_2 emissions in 2020 (Mt CO_2)	Reduction requirements in 2010 (% vs. 1990)	Reduction requirements in 2020 (% vs. 1990)	Reduction requirements in 2020 (% vs. 2020)
Austria	59.6	73.4	74.1	13.0	19.7	35.4
Belgium	110.1	142.7	143.9	7.5	14.7	34.7
Denmark	50.4	58.6	59.1	21.0	27.1	37.9
Finland	54.2	64.7	65.2	0.0	7.7	23.3
France	377.3	418.0	421.0	0.0	7.7	17.3
Germany	988.3	954.6	963.0	21.0	27.1	25.2
Greece	75.8	105.5	106.1	-25.0	-5.3	24.7
Ireland	33.0	49.5	49.8	-13.0	-4.3	30.9
Italy	417.5	508.4	511.7	6.5	13.7	29.6
Netherlands	158.5	200.3	201.8	6.0	13.3	31.9
Portugal	43.6	74.3	74.7	-27.0	-17.2	31.7
Spain	225.8	349.0	351.1	-15.0	-6.1	31.8
Sweden	49.8	49.8	49.8	-4.0	4.0	4.0
United Kingdom	577.4	640.0	646.5	12.5	19.3	27.9
Central Europe	1042.1	893.2	1110.4	-4.8	3.3	9.2
Canada	427.5	597.9	602.3	6.0	8.6	35.1
Japan	1091.4	1264.8	1168.3	6.0	8.6	14.6
Former Soviet Union	3605.4	2489.4	2764.3	0.0	2.7	-26.9
Pacific OECD	292.0	449.7	446.1	-7.0	-4.1	31.9
United States	4890.8	6410.1	6500.0	-27.3	-23.8	6.8
Brazil	214.0	567.4	838.2	-	-	-
China	2495.7	5038.3	6491.2	-	-	-
India	616.1	1764.9	2934.5	-	-	-
Mexico	309.0	572.4	733.7	-	-	-
South Korea	253.7	658.7	853.0	-	-	-

Sources: Netherlands Environment Assessment Agency (Van Vuuren et al., 2006), EU (1999), UNFCCC (1997); own calculations

[63] Note that the region Pacific OECD primarily consists of Australia (target of -8% vs. 1990) and New Zealand (target of 0% vs. 1990), which explains the aggregate target of -7% compared to 1990 levels.

Table 25: Allocation factors for various regions in 2005 and 2020

	Allocation factors in 2005	Allocation factors in 2020
Austria	0.940	0.752
Belgium	1.042	0.834
Denmark	0.850	0.680
Finland	0.980	0.784
France	0.995	0.796
Germany	1.000	0.800
Greece	1.000	0.800
Ireland	0.970	0.776
Italy	1.074	0.859
Netherlands	1.030	0.824
Portugal	1.035	0.828
Spain	0.940	0.752
Sweden	1.000	0.938
United Kingdom	0.993	0.794
Central Europe	1.000	0.835
Canada	1.000	0.800
Japan	1.000	0.800
Former Soviet Union	1.496	1.269
Pacific OECD	1.000	0.800
United States	1.000	0.869

Table 26: Marginal abatement cost coefficients in 2020 (€2005)

Regions	Energy-intensive sectors (EIS)			Non-energy-intensive sectors (NEIS)		
	$\beta_{1,EIS,r}$	$\beta_{2,EIS,r}$	$\beta_{3,EIS,r}$	$\beta_{1,NEIS,r}$	$\beta_{2,NEIS,r}$	$\beta_{3,NEIS,r}$
Austria	21.1480	-3.3392	0.8094	11.4095	2.8620	-0.1012
Belgium	2.8430	-0.0984	0.0026	5.8176	0.1881	0.0176
Denmark	11.1840	-0.5817	0.0235	59.6656	-12.7515	5.7710
Finland	3.0710	-0.0566	0.0032	75.2956	-14.0624	1.5541
France	0.9439	-0.0078	0.0002	1.5191	0.0784	-0.0007
Germany	0.3668	-0.0017	0.0000	0.9417	0.0111	0.0000
Greece	1.8843	-0.0118	0.0005	30.8964	-1.6083	0.3375
Ireland	3.0683	-0.1585	0.0110	23.4662	-0.3972	0.2788
Italy	0.9413	0.0036	0.0001	2.5992	0.1511	-0.0005
Netherlands	0.8665	0.0393	-0.0004	10.9863	-0.4063	0.1088
Portugal	11.0386	-0.5740	0.0175	56.1921	-9.2007	2.4941
Spain	0.8090	-0.0097	0.0002	10.3924	-0.4192	0.0137
Sweden	7.7433	-0.2814	0.0102	12.5684	1.7070	0.3807
United Kingdom	0.4066	-0.0022	0.0000	1.4731	0.0244	-0.0001
Central Europe	0.1466	0.0001	0.0000	0.7554	0.0008	0.0000
Canada	0.2766	0.0007	0.0000	0.8316	0.0044	0.0001
Japan	0.2666	0.0023	0.0000	1.3130	0.0313	-0.0001
Former Soviet Union	0.0218	0.0002	0.0000	0.1075	0.0004	0.0000
Pacifc OECD	0.7244	-0.0094	0.0001	1.8636	-0.0315	0.0005
United States	0.0245	0.0000	0.0000	0.1453	0.0000	0.0000
Brazil	11.5525	-0.0631	0.0001	4.1163	0.0006	0.0004
China	0.0129	0.0000	0.0000	0.3052	-0.0004	0.0000
India	0.0960	-0.0001	0.0000	2.2685	-0.0346	0.0008
Mexico	0.0116	0.0191	-0.0001	0.3852	0.0204	-0.0001
South Korea	0.3405	-0.0011	0.0000	4.1598	-0.0027	0.0010

5.6.2 Algebraic model summary

This appendix provides an algebraic summary of the equilibrium conditions for a simple partial equilibrium model designed to investigate the economic implications of emissions allocation and emissions trading in a two-sector, multi-region framework. Emissions mitigation options are captured through marginal abatement cost functions that are differentiated by sectors and regions.

Cast as a planning problem, the model corresponds to a nonlinear program that seeks a cost-minimizing abatement scheme subject to initial emissions allocation and institutional restrictions for emissions trading between sectors and regions. The nonlinear optimization problem can be interpreted as a market equilibrium problem where prices and quantities are defined using duality theory. In this case, a system of (weak) inequalities and complementary slackness conditions replace the minimization operator yielding a so-called mixed complementarity problem (see e.g. Rutherford 1995).[64]

Two classes of conditions characterize the (competitive) equilibrium for the model: zero profit conditions and market clearance conditions. The former class determines activity levels (quantities) and the latter determines prices. The economic equilibrium features complementarity between equilibrium variables and equilibrium conditions: activities will be operated as long as they break even, positive market prices imply market clearance – otherwise commodities are in excess supply and the respective prices fall to zero.[65]

Numerically, the algebraic MCP formulation of the model is implemented in GAMS (Brooke et al. 1987) using PATH (Dirkse and Ferris 1995) as a solver. In the algebraic exposition of equilibrium conditions, *i* is used as an index for sectors and *r* as an index for regions. Table 27 explains the notations for variables and parameters.

[64] The MCP formulation provides a general format for economic equilibrium problems that may not be easily studied in an optimization context. Only if the complementarity problem is “integrable” (see Takayma and Judge (1971)), the solution corresponds to the first-order conditions for a (primal or dual) programming problem. Taxes, income effects, spillovers and other externalities, however, interfere with the skew symmetry property which characterizes first order conditions for nonlinear programs.

[65] In this context, the term „*mixed complementarity problem*“ (MCP) is straightforward: „*mixed*“ indicates that the mathematical formulation is based on weak inequalities that may include a mixture of equalities and inequalities; „*complementarity*“ refers to complementary slackness between system variables and system conditions.

Table 27: Variables and parameters

Variables: Activity levels	
D_{ir}	Emissions abatement by sector *i* in region *r*
MD_{ir}	Imports of emissions permits by sector *i* in region *r* from domestic market
XD_{ir}	Exports of emissions permits by sector *i* in region *r* to domestic market
M_{ir}	Imports of emissions permits by sector *i* in region *r* from international market
X_{ir}	Exports of emissions permits by sector *i* in region *r* to international market
$MCDM_{ir}$	Imports of Certified Emissions Reductions (CERs) by sector *i* in region *r* from CDM world market
$XCDM_{ir}$	Exports of CERs by sector *i* in region *r* to CDM world market
Variables: Price levels	
P_{ir}	Marginal abatement cost by sector *i* in region *r*
PD_r	Price of domestically tradable permits in region *r*
PFX	Price of internationally tradable permits
$PCDM$	Price of CERs from CDM world market
$PLIM_r$	Shadow price of CER import restriction
Parameters	
target_{ir}	Effective carbon emissions reduction requirement for sector *i* in region *r*
$a_{1,ir}, a_{2,ir}, a_{3,ir}$	Coefficients of marginal abatement cost function for sector *i* in region *r*
mlimit_{ir}	Upper limit on CER imports by sector *i* in region *r* from CDM world market (Suppplementarity criterion)

Zero profit conditions[66]

Abatement by sector *i* in region *r* ($\perp D_{ir}$):

$$a_{1,ir} \cdot D_{ir} + a_{2,ir} \cdot D_{ir}^2 + a_{3,ir} \cdot D_{ir}^3 \geq P_{ir}$$

Permit imports by sector *i* in region *r* from domestic market ($\perp MD_{ir}$):

$$PD_r \geq P_{ir}$$

Permit exports by sector *i* in region *r* to domestic market ($\perp XD_{ir}$):

$$P_{ir} \geq PD_r$$

Permit imports by sector *i* in region *r* from international market ($\perp M_{ir}$):

$$PFX \geq P_{ir}$$

Permit exports by sector *i* in region *r* to international market ($\perp X_{ir}$):

$$P_{ir} \geq PFX$$

CER imports by sector *i* in region *r* from CDM world market ($\perp MCDM_{ir}$):

$$PCDM + PLIM_r \geq P_{ir}$$

CER exports by sector i in region r to CDM world market ($\perp XCDM_{ir}$):

$$P_{ir} \geq PCDM$$

Market clearance conditions

Market clearance for abatement by sector *i* in region *r* ($\perp P_{ir}$):

$$D_{ir} + M_{ir} + MD_{ir} + MCDM_{ir} \geq \text{target}_{ir} + X_{ir} + XD_{ir} + XCDM_{ir}$$

Market clearance for domestically tradable permits ($\perp PD_r$):

$$\sum_i XD_{ir} \geq \sum_i MD_{ir}$$

Market clearance for internationally tradable permits ($\perp PFX$):

$$\sum_i X_{ir} \geq \sum_i M_{ir}$$

Market clearance for CERs ($\perp PCDM$):

$$\sum_i XCDM_{ir} \geq \sum_i MCDM_{ir}$$

CER import restriction for supplementarity ($\perp PLIM_r$):

$$\text{mlimit}_{ir} \geq \sum_i MCDM_{ir}$$

[66] The variable associated with each equilibrium condition is added in brackets and denoted with an orthogonality symbol ($\perp$).

5.6.3 Core simulation results

Table 28: Linking ETS in alternative trading regimes in 2020: Compliance costs by region, sector and scenario (in million €2005)

	NOTRADE			***ETS [EU]***			***ETS [EU⁺]***			***ETS [EU⁺⁺]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	358628.4	6471.7	352156.7	354300.8	2144.1	352156.7	355481.8	3325.1	352156.7
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	22431.5	253	22178.5	22555.7	377.2	22178.5
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	2977.8	572.6	2405.2	3318.9	913.7	2405.2
Former Soviet Union	0	0	0	0	0	0	-2411.9	-2411.9	0	-4273	-4273	0
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	8704.7	375.1	8329.6
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2220.1	2220	0.1
	NOTRADE			***PARALLEL [EU]***			***PARALLEL [EU⁺]***			***PARALLEL [EU⁺⁺]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	80639.2	6471.7	74167.5	29316.8	2144.1	27172.7	21205.6	3325.1	17880.5
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	6760.2	253	6507.2	4665.6	377.2	4288.4
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	2252.8	572.6	1680.2	2096.6	913.7	1182.9
Former Soviet Union	0	0	0	0	0	0	-26513.8	-2411.9	-24101.9	-17816.6	-4273	-13543.6
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	2912.5	375.1	2537.4
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	-1257.3	2220	-3477.3
	NOTRADE			***JOINT [EU]***			***JOINT [EU⁺]***			***JOINT [EU⁺⁺]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	32393.8	-2540.6	34934.4	13255.7	4898.2	8357.5	12060.7	4546.9	7513.8
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	2530	517.8	2012.2	2299.6	489.8	1809.8
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	2024.1	1435.6	588.5	1840.2	1308.2	532
Former Soviet Union	0	0	0	0	0	0	-13099.3	-7802.1	-5297.2	-11537	-6856.5	-4680.5
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	1602.2	517.3	1084.9
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1686.7	2216	-529.3

Table 29: Linking ETS with alternative CDM options in 2020: Compliance costs by region, sector and scenario (in million €2005)

	ETS_CDM [EU]			***ETS_CDM [EU^{+}]***			***ETS_CDM [EU^{++}]***			***ETS_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	354110.7	1954	352156.7	353035.8	879.1	352156.7	353952	1795.3	352156.7	354722.9	353035.8	353952
Canada	7572.4	4960.9	2611.5	22285.9	107.4	22178.5	22392.5	214	22178.5	7572.4	22285.9	22392.5
Japan	5590.5	4412	1178.5	2635.3	230.1	2405.2	2881.6	476.4	2405.2	5590.5	2635.3	2881.6
Former Soviet Union	0	0	0	-859.1	-859.1	0	-1943.8	-1943.8	0	0	-859.1	-1943.8
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	8528.4	198.8	8329.6	3213.8	3213.8	8528.4
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1462.6	1462.5	0.1	2002.7	2002.7	1462.6
	PARALLEL_CDM [EU]			***PARALLEL_CDM [EU^{+}]***			***PARALLEL_CDM [EU^{++}]***			***PARALLEL_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.5	3595.3	5543.2	5091.5	2100.2	2991.3	6646.5	2695.8	3950.7	8723.2	5091.5	6646.5
Canada	7572.4	4960.9	2611.5	970.1	248.1	722	1265.8	312.6	953.2	7572.4	970.1	1265.8
Japan	5590.5	4412	1178.5	778.5	560.4	218.1	1014.9	728.6	286.3	5590.5	778.5	1014.9
Former Soviet Union	0	0	0	-4035.6	-2351.1	-1684.5	-5498.7	-3222.7	-2276	0	-4035.6	-5498.7
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	872.2	301.9	570.3	3213.8	3213.8	872.2
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1846.8	1983.2	-136.4	2002.7	2002.7	1846.8
	JOINT_CDM [EU]			***JOINT_CDM [EU^{+}]***			***JOINT_CDM [EU^{++}]***			***JOINT_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.5	3595.3	5543.2	5091.5	2100.2	2991.3	6646.5	2695.8	3950.7	10279.7	5091.5	6646.5
Canada	7572.4	4960.9	2611.5	970.1	248.1	722	1265.8	312.6	953.2	7572.4	970.1	1265.8
Japan	5590.5	4412	1178.5	778.5	560.4	218.1	1014.9	728.6	286.3	5590.5	778.5	1014.9
Former Soviet Union	0	0	0	-4035.6	-2351.1	-1684.5	-5498.7	-3222.7	-2276	0	-4035.6	-5498.7
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	872.2	301.9	570.3	3213.8	3213.8	872.2
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1846.8	1983.2	-136.4	2002.7	2002.7	1846.8

5.6.4 Sensitivity analyses: Simulation results

Table 30: Trading regimes for stricter allowance allocation in 2020: Compliance costs by region, sector and scenario (in million €2005)

	NOTRADE			***ETS [EU]***			***ETS [EU^{+}]***			***ETS [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	144701.8	13330.3	131371.5	138375.5	7004	131371.5	138120.8	6749.3	131371.5
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	12843	873.6	11969.4	12813.6	844.2	11969.4
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	2115.3	2115.3	0	2028.6	2028.6	0
Former Soviet Union	0	0	0	0	0	0	-6992.2	-6992.2	0	-6626.9	-6626.9	0
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	4079.2	820.7	3258.5
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2245.9	2245.8	0.1
	NOTRADE			***PARALLEL [EU]***			***PARALLEL [EU^{+}]***			***PARALLEL [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	44761.4	13330.3	31431.1	14174.2	7004	7170.2	12470.2	6749.3	5720.9
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	2877.6	873.6	2004	2440.9	844.2	1596.7
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	1739.6	2115.3	-375.7	1750.3	2028.6	-278.3
Former Soviet Union	0	0	0	0	0	0	-13977	-6992.2	-6984.8	-11930.6	-6626.9	-5303.7
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	1666.3	820.7	845.6
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1580.5	2245.8	-665.3
	NOTRADE			***JOINT [EU]***			***JOINT [EU^{+}]***			***JOINT [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	32393.6	10619.2	21774.4	13255.6	7540.4	5715.2	12060.8	6910.4	5150.4
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	2529.9	934.8	1595.1	2299.5	862.8	1436.7
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	2024.1	2302	-277.9	1840.3	2083.3	-243
Former Soviet Union	0	0	0	0	0	0	-13099.3	-7802.1	-5297.2	-11537	-6856.5	-4680.5
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	1602.2	840.7	761.5
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1686.7	2216	-529.3

Table 31: CDM options for stricter allowance allocation in 2020: Compliance costs by region, sector and scenario (in million €2005)

	ETS_CDM [EU]			***ETS_CDM [EU^{+}]***			***ETS_CDM [EU^{++}]***			***ETS_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	135038.3	3666.8	131371.5	133787.7	2416.2	131371.5	134861.3	3489.8	131371.5	138346.4	133787.7	134861.3
Canada	7572.4	4960.9	2611.5	12285.9	316.5	11969.4	12421.5	452.1	11969.4	7572.4	12285.9	12421.5
Japan	5590.5	4412	1178.5	685.5	685.5	0	1000.9	1000.9	0	5590.5	685.5	1000.9
Former Soviet Union	0	0	0	-1813.1	-1813.1	0	-2801.3	-2801.3	0	0	-1813.1	-2801.3
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3675.1	416.6	3258.5	3213.8	3213.8	3675.1
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1842.2	1842.1	0.1	2002.7	2002.7	1842.2
	PARALLEL_CDM [EU]			***PARALLEL_CDM [EU^{+}]***			***PARALLEL_CDM [EU^{++}]***			***PARALLEL_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.4	5318.4	3820	5091.4	3016.1	2075.3	6646.6	3912.4	2734.2	10425.5	5091.4	6646.6
Canada	7572.4	4960.9	2611.5	970.1	392.7	577.4	1265.7	504.6	761.1	7572.4	970.1	1265.7
Japan	5590.5	4412	1178.5	778.6	860.8	-82.2	1014.8	1127.5	-112.7	5590.5	778.6	1014.8
Former Soviet Union	0	0	0	-4035.6	-2351.1	-1684.5	-5498.7	-3222.7	-2276	0	-4035.6	-5498.7
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	872.2	468.4	403.8	3213.8	3213.8	872.2
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1846.8	1983.2	-136.4	2002.7	2002.7	1846.8
	JOINT_CDM [EU]			***JOINT_CDM [EU^{+}]***			***JOINT_CDM [EU^{++}]***			***JOINT_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.4	5318.4	3820	5091.4	3016.1	2075.3	6646.6	3912.4	2734.2	10279.6	5091.4	6646.6
Canada	7572.4	4960.9	2611.5	970.1	392.7	577.4	1265.7	504.6	761.1	7572.4	970.1	1265.7
Japan	5590.5	4412	1178.5	778.6	860.8	-82.2	1014.8	1127.5	-112.7	5590.5	778.6	1014.8
Former Soviet Union	0	0	0	-4035.6	-2351.1	-1684.5	-5498.7	-3222.7	-2276	0	-4035.6	-5498.7
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	872.2	468.4	403.8	3213.8	3213.8	872.2
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1846.8	1983.2	-136.4	2002.7	2002.7	1846.8

Table 32: Trading regimes in the absence of "Hot Air" in 2020: Compliance costs by region, sector and scenario (in million €2005)

	NOTRADE			***ETS [EU]***			***ETS [EU^{+}]***			***ETS [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	358628.4	6471.7	352156.7	357666.7	5510	352156.7	356966.1	4809.4	352156.7
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	22737.6	559.1	22178.5	22689.4	510.9	22178.5
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	4090.6	1685.4	2405.2	3807.7	1402.5	2405.2
Former Soviet Union	0	0	0	0	0	0	-2742.4	-2742.4	0	-1893.8	-1893.8	0
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	8876.4	546.8	8329.6
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2095.5	2095.4	0.1
	NOTRADE			***PARALLEL [EU]***			***PARALLEL [EU^{+}]***			***PARALLEL [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	80639.2	6471.7	74167.5	52497.3	5510	46987.3	32816.7	4809.4	28007.3
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	11908.5	559.1	11349.4	7218	510.9	6707.1
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	4046.2	1685.4	2360.8	3122.9	1402.5	1720.4
Former Soviet Union	0	0	0	0	0	0	-27339.8	-2742.4	-24597.4	-9764.3	-1893.8	-7870.5
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	4362.8	546.8	3816
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	-7665.8	2095.4	-9761.2
	NOTRADE			***JOINT [EU]***			***JOINT [EU^{+}]***			***JOINT [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU-27	54747.1	39216.5	15530.6	32393.8	-2540.6	34934.4	25739	6200.7	19538.3	18269.3	6057.5	12211.8
Canada	7572.4	4960.9	2611.5	7572.4	4960.9	2611.5	5102.1	418.3	4683.8	3515.9	580.9	2935
Japan	5590.5	4412	1178.5	5590.5	4412	1178.5	4060.4	2782.4	1278	2810.2	1971.4	838.8
Former Soviet Union	0	0	0	0	0	0	-12492.3	-8680	-3812.3	-5341.6	-3814.5	-1527.1
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	3213.8	2393.4	820.4	2402.7	646.9	1755.8
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	2002.7	1725.3	277.4	-1377.7	122.7	-1500.4

Table 33: CDM options in the absence of "Hot Air" in 2020: Compliance costs by region, sector and scenario (in million €2005)

	ETS_CDM [EU]			***ETS_CDM [EU^{+}]***			***ETS_CDM [EU^{++}]***			***ETS_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	354110.7	1954	352156.7	354219.8	2063.1	352156.7	354783.4	2626.7	352156.7	354722.9	354219.8	354783.4
Canada	7572.4	4960.9	2611.5	22422.5	244	22178.5	22483.8	305.3	22178.5	7572.4	22422.5	22483.8
Japan	5590.5	4412	1178.5	2955.3	550.1	2405.2	3114	708.8	2405.2	5590.5	2955.3	3114
Former Soviet Union	0	0	0	-322.7	-322.7	0	-516.3	-516.3	0	0	-322.7	-516.3
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	8623.5	293.9	8329.6	3213.8	3213.8	8623.5
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1950.3	1950.2	0.1	2002.7	2002.7	1950.3
	PARALLEL_CDM [EU]			***PARALLEL_CDM [EU^{+}]***			***PARALLEL_CDM [EU^{++}]***			***PARALLEL_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.5	3595.3	5543.2	9483.3	3713.8	5769.5	9869.2	3844.4	6024.8	8723.2	9483.3	9869.2
Canada	7572.4	4960.9	2611.5	1805.9	415.1	1390.8	1879.6	427.4	1452.2	7572.4	1805.9	1879.6
Japan	5590.5	4412	1178.5	1446.1	1033	413.1	1505	1074.3	430.7	5590.5	1446.1	1505
Former Soviet Union	0	0	0	-1411.1	-1047.6	-363.5	-1523.6	-1128.8	-394.8	0	-1411.1	-1523.6
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	1305.9	435.8	870.1	3213.8	3213.8	1305.9
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1977.2	2308.9	-331.7	2002.7	2002.7	1977.2
	JOINT_CDM [EU]			***JOINT_CDM [EU^{+}]***			***JOINT_CDM [EU^{++}]***			***JOINT_SUP***		
										[EU]	***[EU^{+}]***	***[EU^{++}]***
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***TOTAL***	***TOTAL***
EU-27	9138.5	3595.3	5543.2	9483.3	3713.8	5769.5	9869.2	3844.4	6024.8	10279.7	9483.3	9869.2
Canada	7572.4	4960.9	2611.5	1805.9	415.1	1390.8	1879.6	427.4	1452.2	7572.4	1805.9	1879.6
Japan	5590.5	4412	1178.5	1446.1	1033	413.1	1505	1074.3	430.7	5590.5	1446.1	1505
Former Soviet Union	0	0	0	-1411.1	-1047.6	-363.5	-1523.6	-1128.8	-394.8	0	-1411.1	-1523.6
Pacific OECD	3213.8	2393.4	820.4	3213.8	2393.4	820.4	1305.9	435.8	870.1	3213.8	3213.8	1305.9
United States	2002.7	1725.3	277.4	2002.7	1725.3	277.4	1977.2	2308.9	-331.7	2002.7	2002.7	1977.2

6 Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis [67]

Political measures to combat climate change are increasingly designed in the context of economic efficiency and international competitiveness. As a prominent example, the European Union is simultaneously pursuing ambitious emissions reduction targets to limit global warming to two degrees Celsius and aiming to become the most competitive economy of the world (EU, 2007, 2000). In order to increase cost efficiency of EU climate policy, the European Council has recently proposed to link Europe's central climate policy instrument – the EU Emissions Trading Scheme (EU ETS) – to compatible mandatory schemes in third countries (EU, 2007).

As laid out in the previous chapter, also non-EU countries are currently discussing the set up of domestic ETS at the national and regional level with the intention of linking up to the European scheme. In October 2007, the International Carbon Action Partnership (ICAP) was established as an intergovernmental expert forum to discuss relevant questions on the design, compatibility and potential linkage of regional carbon markets (ICAP, 2007). Thus, not only parties having ratified the Kyoto Protocol – such as Canada, Japan, Australia and the Russian Federation – may have incentives to join the EU ETS. Also Russia could benefit from setting up a domestic emissions trading system in order to be linked to the EU ETS and exploit a larger market for the sale of emissions permits from low-cost domestic abatement options (Böhringer et al., 2007). Furthermore, linking the EU ETS to the United States, which have so far not ratified the Kyoto-Protocol, could be considered as a first step in integrating this region into an international climate policy regime.

Reflecting current political priorities within and beyond the EU, this paper presents an efficiency and international trade analysis of future supra-European emissions trading schemes. Previous quantitative economic analyses have focused on efficiency aspects (e.g. Fischer, 2006 or Böhringer et al., 2005) and competitiveness implications of the current European trading scheme (Kemfert et al., 2005; Klepper and Peterson, 2004; Peterson 2006,

[67] This chapter is based on the paper: Alexeeva-Talebi, V. and N. Anger (2007): "Developing Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis", *ZEW Discussion Paper* No. 07-038, Mannheim. The manuscript was submitted to and is currently under review for the journal *Applied*

2006a) in applied partial and general equilibrium frameworks. In a first economic impact assessment of linking the EU ETS to emerging schemes outside Europe in the presence of a post-Kyoto agreement, Anger (2008) shows that the carbon-market benefits of integrating industry-specific ETS are limited. Further contributions examine economic and institutional aspects of linking the EU ETS internationally in a qualitative manner only (e.g. Kruger et al., 2007; Sterk et al, 2006). None of the previous studies has investigated social welfare and international trade implications of linking the EU ETS to emerging schemes outside Europe.

Against this background, the contribution of this paper is threefold: employing both economic theory and a large-scale computable general equilibrium model of the global economy, we (i) analytically derive the efficiency aspects of integrating emissions trading schemes from a partial market perspective, (ii) numerically analyze the aggregate welfare impacts of linking the EU ETS and (iii) explicitly assess the economy-wide and sectoral trade-based competitiveness effects of developing supra-European emissions trading schemes in the year 2020. The article is structured as follows: section 6.1 lays out the theoretical background of our analysis. In section 6.2, we present the numerical framework underlying our quantitative impact assessment. Section 6.3 introduces policy scenarios of linking the EU ETS internationally. Section 6.4 summarizes our quantitative simulation results. In section 6.5, we conclude.

6.1 Theoretical background

In this section, we present a simple analytical model of the emissions market in order to lay out the theoretical background for our numerical analysis of linking the European ETS. For this purpose, we first analyze the general efficiency aspects of international emissions trading and subsequently assess the emissions market implications of linking alternative trading systems.

Following the stylized framework of Anger (2008), R regions are assumed ($r=1,...,R$) to commit to individual emissions targets (e.g. targets under the Kyoto Protocol), yielding an absolute emissions budget $\overline{E}_r$ for each region. Abatement costs of those sectors covered by a domestic emissions trading scheme (in the following referred to as *ETS* sectors) and the remaining non-covered sectors (in the following referred to as *NETS* sectors) in each region

Economics. As the corresponding author of the manuscript, I contributed to all sections of the chapter, including the theoretical background and the numerical simulation analysis.

are denoted by $AC_r^{ETS}(e)$ and $AC_r^{NETS}(e)$, respectively. Abatement cost functions are decreasing, convex and differentiable in emissions e. Total abatement costs $AC_r(E_r)$ are the sum of the sectoral costs $AC_r^{ETS}(e_r^{ETS})$ and $AC_r^{NETS}(e_r^{NETS})$.

For regions with binding emissions targets (such as Annex B parties of the Kyoto Protocol) cost minimization with respect to e_r^{ETS} and e_r^{NETS} yields the following first-order condition:

$$\sigma = -\frac{\partial AC_r^{ETS}}{\partial e_r^{ETS}} = -\frac{\partial AC_r^{NETS}}{\partial e_r^{NETS}} = -\frac{\partial AC_r}{\partial (e_r^{ETS} + e_r^{NETS})} \tag{1}$$

For each region and sector, this cost-efficient solution implies that marginal abatement costs equal the permit price σ and are thus equalized across all emissions sources. Optimal emissions can then be derived as E_r^*, $e_r^{ETS^*}$, $e_r^{NETS^*}$, where $E_r^* = e_r^{ETS^*} + e_r^{NETS^*}$. The difference between the total emissions budget $\overline{E}_r$ and aggregate optimal emissions E_r^* yields the optimal total trade volume in emissions permits.

6.1.1 An international emissions trading scheme

We now introduce an international emissions trading scheme consisting of two regions, 1 and 2, within the presented framework. To reflect the key features of the European ETS, we assume that interregional trading of emissions permits is feasible only for a segment of each economy, i.e. only for the *ETS* sectors covered by the trading system. We denote $\overline{e_r^{ETS}}$ as the regional allocation of permits to the respective *ETS* sectors. For both regions we assume linear marginal abatement costs $MAC_1^{ETS}(e_1^{ETS})$ and $MAC_2^{ETS}(e_2^{ETS})$ depending on regional emissions levels, with region 1 having a steeper marginal abatement costs curve than region 2. Finally, both regions are assumed to have equal maximum emissions levels $e_{r,\max}^{ETS}$ and equal regional emissions budgets for the covered *ETS* sectors $(\overline{e_1^{ETS}}, \overline{e_2^{ETS}})$ which amounts to 50 percent of the maximum emission level, respectively. Figure 6 illustrates the efficiency implications from trading emissions in terms of compliance costs for *ETS* sectors given their permit allocation.

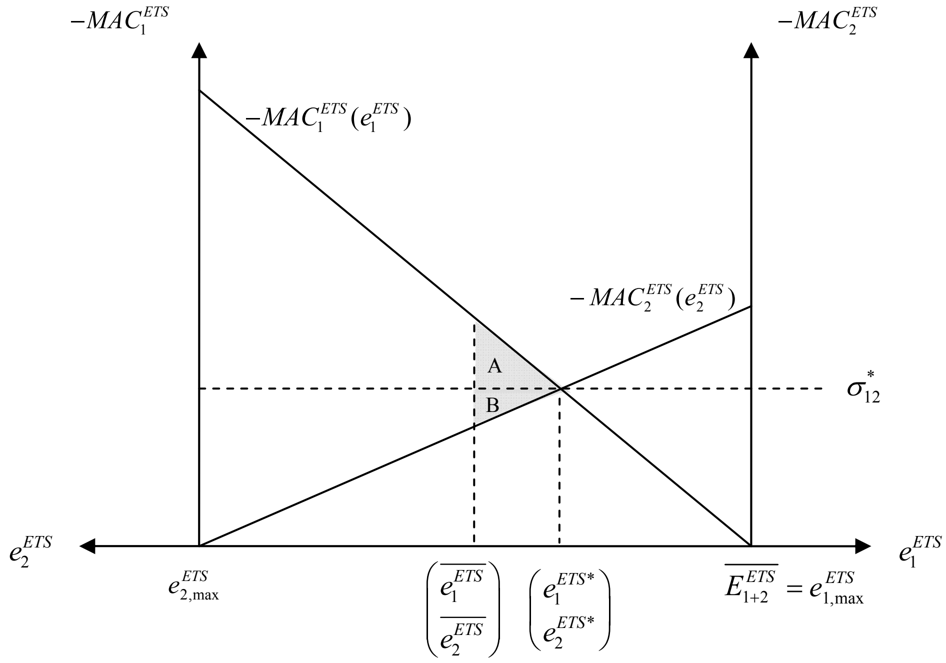

Figure 6: Sectoral efficiency gains in an international emissions trading scheme

In the figure, the initial regional allocation of emissions permits to the covered *ETS* sectors $(\overline{e_1^{ETS}}, \overline{e_2^{ETS}})$, which translate into a total emissions ceiling $\overline{E_{1+2}^{ETS}}$, imply economically inefficient emissions levels of the two regions. This is due to their differing marginal abatement costs. Once participating in international emissions trading, the high-cost (low-cost) region 1 (2) imports (exports) emissions permits from (to) the other region, thereby increasing (reducing) its emissions. The resulting international permit price σ_{12}^* equalizes marginal abatement costs and yields the respective optimal emissions level $\left(e_1^{ETS*}, e_2^{ETS*}\right)$. As a consequence, international trading activities yield a Pareto-improvement which generates efficiency gains both for region 1 – due to avoided abatement costs exceeding permit import costs (equal to area A) – and for region 2 – due to larger permit export revenues than associated abatement costs (equal to area B).

6.1.2 Linking of alternative trading schemes

We extend the bilateral perspective of Figure 6 by introducing an additional region that may be linked to the joint trading scheme of region 1 and 2. The sectors covered by the joint scheme commit to a total emissions ceiling $\overline{E_{1+2}^{ETS}}$ featuring an aggregate marginal abatement cost function $MAC_{1+2}^{ETS}(E_{1+2}^{ETS})$. We distinguish between two linking candidates: a high-cost region (3) with marginal abatement costs $MAC_3^{ETS}(e_3^{ETS})$ and a low-cost region (4) with marginal abatement costs $MAC_4^{ETS}(e_4^{ETS})$. Both regions are assumed to exhibit the same maximum amount of emissions as the joint scheme and also allocate only half of their maximum emissions level as emissions permits $\overline{e_3^{ETS}}$ and $\overline{e_4^{ETS}}$ to their *ETS* sectors. Figure 7 illustrates the efficiency aspects of linking an additional region to the existing, joint trading scheme of regions 1 and 2.

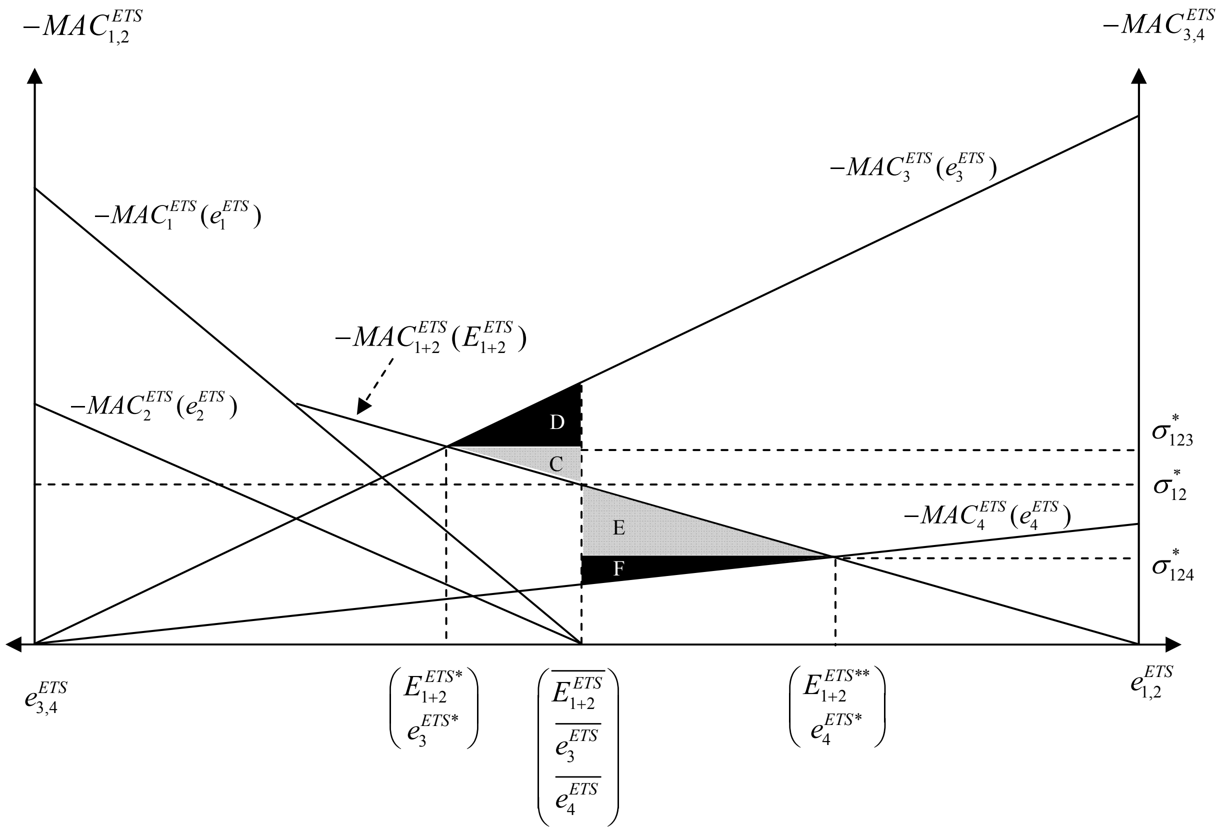

Figure 7: Additional efficiency gains from linking emissions trading schemes

In the case of linking high-cost region 3 to the existing trading system, the initial allocation of emissions permits $\overline{E_{1+2}^{ETS}}$ and $\overline{e_3^{ETS}}$ to the covered *ETS* sectors implies once again economically inefficient regional emissions levels. When participating in international emissions trading, the high-cost region 3 will however import permits from the lower-cost existing joint scheme. This yields an increased international permit price of σ_{123}^* (as compared to σ_{12}^*) and optimal emissions levels $(E_{1+2}^{ETS*}, e_3^{ETS*})$ with equalized marginal abatement costs. Compared to the initial permit allocation, in the new equilibrium region 3 increases its emissions, while the regions in the existing scheme reduce pollution by the same amount. Thereby, emissions trading activities induce efficiency gains for both the existing joint scheme (equal to area C) and region 3 (equal to area D).

In contrast, linking to low-cost region 4 with an initial permit allocation $\overline{e_4^{ETS}}$ implies that this region will export permits to the higher-cost joint scheme of regions 1 and 2. These trading activities yield a decreased international permit price of σ_{124}^{*}, optimal emissions levels ($E_{1+2}^{ETS**}, e_4^{ETS*}$) with equalized marginal abatement costs and reduced (increased) emissions of region 4 (the joint scheme). Thus, this linking strategy also generates efficiency gains for both the original scheme (equal to area E) and region 4 (equal to area F). To sum up, for the existing trading scheme linking to a high-cost or low-cost region implies positive incentives of a different magnitude – illustrated by the two areas C and E. In our case, the option to link to a low-cost candidate appears to be more preferable for the joint scheme, as the prospects of avoiding abatement costs by permit imports dominate the potential net benefits from exporting permits. Clearly, these incentives vary with the marginal abatement costs of the existing scheme and the respective linking candidates.

Our stylized partial market analysis suggests that – independently of the cost characteristics of a region to be linked with an existing scheme – the integration of trading systems yields economic efficiency gains for all participating regions. The reason is an increased where-flexibility of regional emissions abatement through an international linkage which allows emissions reductions to take place at the least-cost geographic location (Nordhaus and Boyer, 1999). Our stylized theoretical framework deliberately abstracts from real-world conditions regarding the regional heterogeneity of emissions levels, permit allocation and marginal abatement costs. In the next section we therefore present a numerical economic assessment of linking emissions trading schemes based on empirical data. Our applied general equilibrium model framework further enables us to analyze the associated indirect economic impacts that surpass the emissions market, affecting macroeconomic variables such as domestic production and international trade flows.

6.2 Numerical model framework

In the following, we present the quantitative framework of our efficiency and international trade analysis. We first introduce the modeling approach and will then briefly discuss prerequisites and inputs for our policy assessment.

6.2.1 Modelling approach

For our numerical analysis, we build on the *PACE* model (*Policy Assessment based on Computable Equilibrium*), a large-scale CGE model of international energy use and global trade (for details and an algebraic formulation of the core model see Böhringer and Lange, 2005). The model reflects the key features of the European ETS and emerging non-EU trading schemes from a single country perspective: EU Member States and countries with domestic ETS outside Europe (linking candidates) are committed to specific carbon emissions constraints $\overline{E}_r$ which are agreed upon (e.g. under the Kyoto Protocol).[68] Each of these countries must specify a cap $\overline{e_r^{ETS}}$ and the allocation rule for free emissions allowances to energy-intensive installations in six downstream sectors that are eligible for international emissions trading (electricity, oil refineries, iron and steel, non-ferrous metals, mineral industries and paper and pulp production). Assuming that the EU and non-EU emissions trading systems cover only energy-intensive industries implies that complementary domestic abatement policies are necessary for the non-covered sectors in order to comply with the remaining national emissions budget $\left(\overline{E}_r - \overline{e_r^{ETS}}\right)$. Figure 8 provides a diagrammatic structure of the generic open-economy model.

[68] The issue of stability of international environmental agreements goes beyond the scope of our analysis. The game theoretical extension of integrated assessment models has been recently proposed by Finus and Eyckmans (2006).

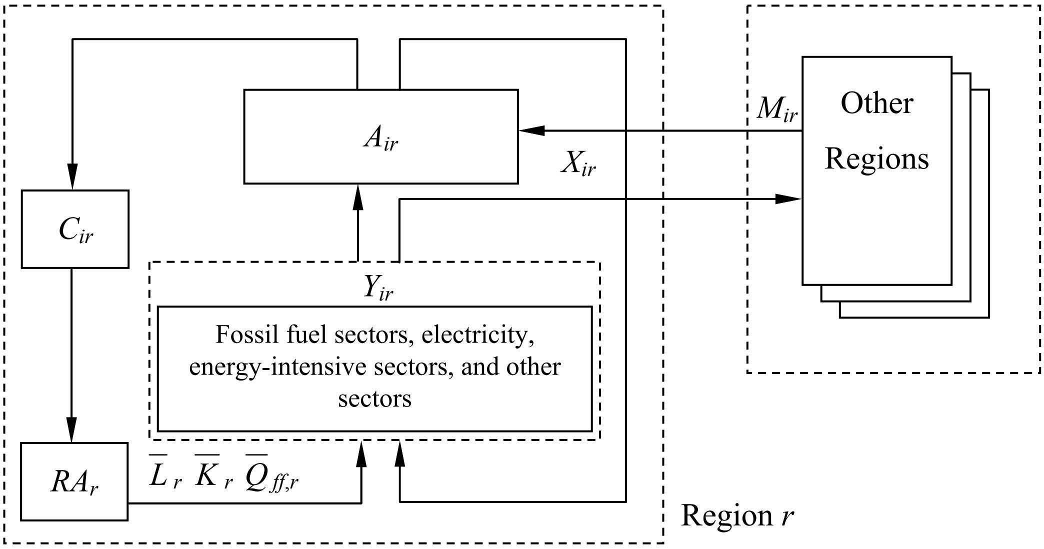

Figure 8: Diagrammatic overview of the model structure

A representative agent RA_r in each region *r* is endowed with three primary factors: labour $\overline{L}_r$, capital $\overline{K}_r$, and fossil-fuel resources $\overline{Q}_{ff,r}$ (used for fossil fuel production). The representative agent maximizes utility from consumption of a composite good C_r which combines demands for energy and non-energy commodities at a constant-elasticity-of-substitution (CES). Production Y_{ir} of commodities *i* in region *r* is captured by nested separable CES functions that describe the price-dependent use of capital, labour, energy and material in production. Carbon emissions are linked in fixed proportions to the emissions-relevant use of fossil fuels through carbon coefficients which are differentiated by the specific carbon content of fuels. Carbon abatement, thus, can take place by fuel switching or energy savings in production and final consumption.

In order to conduct an international trade analysis of linking the EU Emissions Trading Scheme, we adapt the core PACE model by explicitly modelling export flows and prices. The modelling of international trade is based on the Armington approach of product heterogeneity (Armington, 1969), so that domestic and foreign goods of the same variety are distinguished by their origin. All goods used on the domestic market in intermediate and final demand correspond to a CES composite A_{ir} that combines the domestically produced variety Y_{ir} and imports M_{ir} of the same variety from other regions. Domestic production Y_{ir} either enters the formation of the Armington good A_{ir} or is exported (X_{ir}) to other regions. A balance of payment constraint, which is warranted through flexible exchange rates, incorporates the benchmark trade deficit or surplus.

The model is based on consistent accounts of national production and consumption, trade and energy flows for 2001 as provided by the GTAP 6 database (Dimaranan and McDougall, 2006). The forward calibration of the 2001 economies to the target year 2020 is based on energy trends for EU Member States (EU, 2003) and on international energy projections for non-European economies (US Department of Energy, 2005). A description of model regions and sectors can be found in Table 34 and Table 35 (all tables of this chapter are compiled in Appendix 6.6).

6.2.2 Prerequisites for the quantitative analysis

In the following, we present the set of relevant inputs for our numerical analysis. We include data on emissions reduction targets, allocation of emissions allowances to the sectors covered by emissions trading schemes, CDM transaction costs and investment risk indicators.

National emissions reduction targets

In order to analyze future climate policy scenarios we first have to assume regional emissions reduction commitments for the year 2020. Motivated by its ambitious current climate policy goals, the EU is expected to commit to a 30 percent emissions reduction versus 1990 levels in 2020 (EU, 2007a). As for the less ambitious EU target under the Kyoto Protocol (UNFCCC, 1997) the resulting aggregate EU commitment of effectively 32.5 percent versus business-as-usual emissions levels implies very heterogeneous effective reduction targets for old and new EU Member States in 2020 (37.4 and 10.7 percent, respectively).

Given the leadership role of current European climate policy, the non-EU linking candidates are assumed to commit to less stringent emissions targets. Here, it is reasonable to differentiate between Canada and Japan one the one hand, and Australia and United States one the other hand: Having ratified the Kyoto Protocol in 2002, Canada and Japan are assumed to effectively reduce 25 percent versus business-as-usual emissions levels in 2020, while the recent ratifier Australia and the non-ratifier United States commit to an effective reduction target of 20 percent.[69] While having received excess emissions permits under the Kyoto Protocol, we assume Russia to hold its emissions constant under a post-Kyoto

[69] At the Vienna Climate Change Talks 2007, the Parties to the Kyoto Protocol officially recognized that preventing the threats of climate change would entail emission reductions in the range of 25-40% below 1990 levels by industrialized countries (UNFCCC, 2007a). As these talks had a rather indicative character for post-Kyoto climate policy, we assume less stringent and – from our perspective – more realistic *effective* reduction requirements for our analysis.

agreement in 2020, so that the phenomenon of "Hot Air" is no longer existent.[70] The resulting climate policy targets are summarized in Table 36.

Allocation of emissions allowances

A central input for our policy assessment is the allocation of emissions allowances for EU Member States and linking candidates, which specifies an overall cap on emissions for those installations covered by the respective trading schemes. Here, we assume that the EU continues its predominant grandfathering method (i.e. the free allocation of allowances) to the covered installations in 2020. Numerically, emissions allocation can be described by so-called allocation factors, i.e. the fraction of baseline emissions that are freely allocated as allowances. In order to derive allocation factors for EU Member States in 2020 we build on empirical allocation data for the second trading period of the EU ETS (2008 to 2012) – as published in the National Allocation Plan of each Member State – and on recent emissions projections for 2010 (EU, 2007c).

In consistence with our national climate policy targets in 2020, we assume EU leadership also regarding the allocation of emissions allowances. For the future trading period in 2020, the EU's relative allowance allocation is decreased by 30 percent as compared to the second trading period.[71] This yields an allocation factor of 0.60 and 0.81 (i.e. an emissions reduction requirement for covered sectors of 40 and 19 percent versus business-as-usual) for old and new EU Member States, respectively. In contrast, non-EU regions exhibit a less stringent allowance allocation to their covered sectors than the EU: Kyoto ratifiers Japan and Canada implement an allocation factor of 0.85, while the recent ratifier Australia and the non-ratifier United States allocate emissions allowances based on a factor of 0.90 in 2020. For Russia we assume an allocation factor equal to one in 2020, consistently implying no allocation of excess permits to installations covered by a Russian ETS.[72] Table 37 presents the resulting allocation factors for the EU and all linking candidates.

[70] The phenomenon of excess emissions permits (or "Hot Air") arises when business as-usual emissions of a region are lower than the target emissions level committed to.

[71] Two limitations apply here: Due to lacking information for Bulgaria and Romania, for these countries we start from an allocation factor equal to one in the second trading period. Moreover, as for new EU Member States the 30 percent decrease of relative allowance allocation implies an emissions reduction of the covered sectors that is larger than the national reduction requirement, for this aggregate region a minimal allocation factor of 0.81 was chosen. We assess the role of allowance allocation in greater detail by a sensitivity analysis in section 6.4.4

[72] We also abstract from "Hot Air" in the context of allowance allocation, as the allocation of excess permits would imply an indirect subsidy for Russian installations (the allocated permits could be directly exported to other ETS regions). It is not unambiguous if such an ETS design may prevail or even be linked to an EU scheme.

The Clean Development Mechanism

The Kyoto Protocol enables industrialized countries (as listed in Annex B of the agreement) to undertake project-based emissions reductions in developing countries via the Clean Development Mechanism (CDM). By the amending directive linking the EU ETS with the Kyoto Protocol's project-based mechanisms, the EU grants also ETS companies access to low-cost emissions reductions via the CDM and use the associated credits as a substitute for EU allowances (EU, 2004). The potential economic benefits of the CDM may however be substantially reduced by transaction costs and investment risk associated with abatement projects in developing countries. We cover constant transaction costs by an absolute premium on the marginal abatement costs of CDM host countries, amounting to 1 US\$/tCO_2.[73] Following Böhringer and Löschel (2008), host-country-specific investment risk for CDM projects is derived by regional bond-yield spreads between long-term government bonds of the respective developing country and the United States (as a risk-free reference region) and is based on the IMF data (IMF, 2000).

6.3 Policy scenarios

In order to assess the competitiveness impacts of linking the EU ETS to emerging schemes outside Europe, we introduce climate policy scenarios for the year 2020. Across all scenarios, the regulation stringency is represented by the underlying regional emissions reduction targets and the respective allowance allocation as presented in the previous section.

An important characteristic of the EU ETS is the exclusive coverage of energy-intensive installations in six downstream sectors (electricity, oil refineries, iron and steel, non-ferrous metals, mineral industries and paper and pulp production). As the EU system is expected to serve as a "blueprint" for emerging ETS outside Europe, we assume that the non-EU linking candidates also restrict emissions trading to energy-intensive industries. Within each emissions trading scheme, the covered (*ETS*) sectors are thus allocated tradable allowances, while the remaining (*NETS*) industries have to be regulated via domestic abatement measures (here: unilateral carbon taxation) in order to meet the national emissions reduction targets in 2020.[74] In our analysis, emissions trading at the installation level is thus approximated by

[73] The magnitude of transaction costs is consistent with recent estimations (Michaelowa and Jotzo, 2005).
[74] Note that for the emissions trading schemes of all linking candidates we assume an identical sectoral coverage to the EU ETS, as well as the regulation of CO_2 as the only greenhouse gas.

sectoral trading activities. All regions that have not (yet) linked up to the EU ETS are assumed to having introduced a domestic emissions trading scheme.

Table 38 presents the set of policy scenarios of our analysis, showing the corresponding constellations of linking the EU ETS internationally. As a reference case, scenario *EU* represents the current EU trading scheme, while all non-EU linking candidates fulfill their emissions reduction commitment by a domestic ETS. Scenario EU^{+} indicates the potential linkage of the current EU ETS to emerging schemes in two countries that have ratified the Kyoto Protocol, namely Japan and Canada. Scenario EU^{++} assumes that the Kyoto-ratifier Russia is joining the system of the EU-27, Canada and Japan. Finally, the most optimistic scenario EU^{+++} implies linking the EU ETS also to emerging trading schemes in Australia, which has recently ratified the Kyoto-Protocol, and the non-ratifying Annex B country United States.

Representing the EU's directive linking the European ETS with the Kyoto Protocol's project-based mechanisms, we consider CDM access for European ETS sectors (denoting this scenario as *EU_CDM*) and adopt it for all linking candidates. By concentrating on private CDM investments only, we abstract from government CDM activities as facilitated under the Kyoto Protocol.[75]

Table 38 shows that for all regional scenarios alike five central developing countries are assumed to host CDM projects, representing major suppliers on the CDM carbon market (UNFCCC, 2007). As described in the previous section, our CDM representation considers transaction costs and investment risk as central barriers to CDM investments. In our subsequent comparative-static analysis we measure the macroeconomic impacts of climate policy in 2020 relative to the benchmark situation – usually termed *Business-as-Usual* (BaU) – where no emissions regulation is imposed.

6.4 Simulation results

This section presents the simulation results of our model-based assessment of the macroeconomic and competitiveness impacts of linking the EU ETS internationally. The corresponding quantitative simulation results are presented in Table 39 and Table 40. We begin our analysis by reporting the effects of linking the EU ETS on the market for emissions

[75] For a macroeconomic impact assessment of government CDM under the Kyoto Protocol see Anger et al. (2007).

permits (section 6.4.1) and the associated macroeconomic impacts (section 6.4.2), before addressing the competitiveness effects of linking the European trading scheme (section 6.4.3). Finally, we present a sensitivity analysis with respect to the assumed allowance allocation (section 6.4.4).

6.4.1 Impacts on the emissions market

Our partial market analysis in section 6.1 suggested that a region's (export or import) position on the emissions market is determined by the level of marginal abatement costs in the covered sectors prior to linking. On a competitive emissions market, this level equals the regional carbon permit price. Regions with relatively low-cost abatement options will increase their emissions reductions in order to export permits to regions with relatively high marginal abatement costs, which in turn will decrease emissions abatement. The quantified effects of linking the EU ETS on the market for emissions permits are presented in Figure 9.

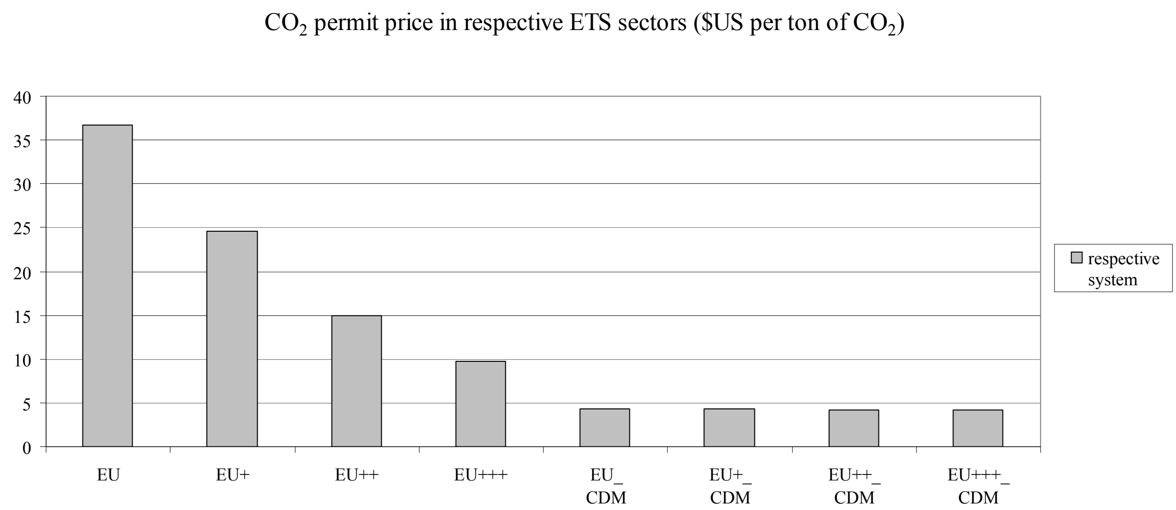

Figure 9: CO_2 permit price within linked schemes by scenario

It first shows that the EU permit price resulting from a non-linked European emissions trading scheme in 2020 (scenario *EU*) amounts to roughly 37 US$ per ton CO_2. This price originates from the EU allowance allocation implying emissions reduction requirements for EU ETS sectors of 40 and 19 percent in old and new EU Member States, respectively (see again section 6.2.2). The figure further illustrates that from an EU perspective, linking the EU ETS to Canada and Japan (yielding scenario EU^+) decreases the international CO_2 value in the covered sectors to 25 US$. Despite of the relatively high-cost abatement options of Canada and Japan, the relatively generous allowance allocation in both countries (allocation factors equal to 0.85) implies that sectors in these regions exhibit relatively low marginal abatement cost *levels* as compared to the EU.[76] This is underlined by the low carbon price levels in the domestic ETS of Canada and Japan prior to linking (11 and 4 US$ per ton CO_2) and causes the international allowance price to drop. Within the linked trading scheme, Japan and Canada are thus exporting carbon permits to the EU while the EU imports permits, thereby decreasing its domestic emissions reductions (see Table 39). A further integration of Russia (scenario EU^{++}) increases the where-flexibility of emissions abatement and puts more downward pressure on the allowance price, which falls to 15 US$. As we abstract from the allocation of potential excess emissions permits to the covered Russian installations, this lower permit price only originates from relatively low-cost abatement options of permit-exporting Russian *ETS* sectors. Table 39 shows that Russian emissions reductions are consequently boosted by linking up to the EU trading scheme, while EU economies reduce their abatement efforts. Linking the EU ETS also to Australia and the non-ratifier United States (scenario EU^{+++}) induces an additional permit price fall to 10 US$ per ton CO_2. This effect is in particular due to the relatively low-cost abatement options in the Unites States and the generous assignation of allowances in both countries (allocation factor equal to 0.90): carbon permit prices in the domestic ETS of Australia and the Unites States prior to linking amount to 5 $US and 7 $US per ton CO_2, respectively. The associated permit supply from these countries further decreases the international permit price.

In the absence of CDM access, the carbon-market impacts of linking the EU ETS are thus driven by marginal abatement costs levels of the linking participants. Our results indicate that the initial EU permit price can be lowered both by linking to candidates with lower-cost abatement options (especially Russia and the United States) and less stringent allowance allocations (Canada, Japan and Australia). Note that regardless of the regional linking constellation the EU represents an importer of emissions allowances, while all non-EU regions are exporting carbon permits. This unambiguous pattern of permit trade serves as the background for our interpretation of the welfare and production impacts of linking emissions trading schemes.

Across all linking scenarios, allowing the covered *ETS* sectors to import low-cost emissions reductions from developing countries via the CDM substantially lowers the international CO_2

[76] For comprehensive assessments of marginal abatement costs across OECD countries see Klepper and Peterson (2006a) or Criqui et al. (1999).

value. The maximum price in this case amounts to 4.3 US$ in a non-linked European system, while the most integrated scheme including Australia and the United States generates only a slightly lower value of 4.2 US$. Figure 9 thus implies that establishing CDM access for *ETS* sectors levels out the permit price differences between alternative linking strategies.

6.4.2 Macroeconomic impacts

From a general equilibrium perspective, the economic effects of climate change policies surpass the emissions market. Carbon abatement policies induce adjustments of production and consumption patterns towards less carbon intensity and associated energy use. Abstracting from investment changes, this restriction of domestic production patterns decreases real income and macroeconomic consumption, thereby generating welfare losses from a cost-effectiveness perspective (Böhringer and Löschel, 2002).[77] In the following, we assess these efficiency implications at the macroeconomic level in terms of social welfare. The welfare indicator captures not only efficiency gains on the emissions market originating from net revenues (for permit exporters) or reduced abatement costs (for permit importers), but also represents the macroeconomic consumption and real income changes originating from the corresponding impacts on domestic production. This is particularly relevant as increased (decreased) abatement efforts in order to export (import) emissions permits within the linked scheme will affect domestic production levels negatively (positively).

For the EU-27 region, Table 39 first reports negative production and welfare impacts of emissions regulation in non-linked domestic emissions trading schemes which amount to roughly 1.4 and 0.7 percent, respectively (scenario *EU*). Gradual integration of non-EU trading schemes (i.e. by moving from *EU* to EU^{+++}) slightly reduces EU production and welfare losses due to an increased where-flexibility of emissions abatement. As permit importers, the European ETS sectors reduce abatement levels and costs, thereby increasing output and reducing output prices for energy-intensive goods. On their part, the non-covered *NETS* sectors slightly increase production levels due a reduced overall consumption price level and the associated increased demand. However, the beneficial impacts of an international linkage are rather limited for the EU, as the associated efficiency gains

[77] Our cost-effectiveness analysis quantifies adjustment costs of environmental regulation as compared to an unconstrained business-as-usual situation. The deliberate neglect of economic benefits from controlling global warming implies that the macroeconomic effects resulting from the imposition of emissions constraints on the respective economies will necessarily be negative. Welfare changes are expressed by the Hicksian Equivalent Variation (HEV) measuring the change in real income which is necessary to make the economy under regulation as well off as under BaU.

exclusively apply to sectors covered by the EU ETS – the remaining industries cannot benefit from the increased where-flexibility. Moreover, energy-intensive goods make up a relatively small fraction of the consumption bundle of EU households (less then 10 percent), which limits the associated welfare improvements via lower output prices.

For non-EU countries, the macroeconomic impacts from linking to the EU ETS are reported in Table 39. Note that for those non-EU regions which are not (yet) involved in linked emissions trading schemes we assume compliance with the national emissions reduction targets (see again Table 36) by means of domestic emissions trading schemes and complementary regulation of the respective non-covered sectors. Table 39 suggests that production impacts for non-EU regions from linking up to the EU ETS are rather heterogeneous. While Japan, Russia and the United States face losses in total domestic production by linking up, Canada and Australia increase their overall production levels by integrating with the EU ETS. Since the covered *ETS* sectors in all non-EU regions act as permit exporters on the unified carbon market, these industries homogenously increase emissions reductions, thereby decreasing energy use and output. However, this negative production effect can be antagonized by production increases of the non-covered *NETS* sectors: in Canada and Australia, this sectoral substitution effect outweighs the production losses in *ETS* industries. Moreover, we find that (positive and negative) non-EU production effects are counteracted when the linked trading scheme is further extended by additional regions, as both the permit price and the incentives for emissions abatement decrease.

Table 39 shows that non-EU welfare impacts are homogeneous across regions: welfare losses from emissions regulation are diminished by linking up to the European trading system. As suggested by our theoretical analysis in section 6.1, this result reflects the efficiency gains of increased where-flexibility in international emissions trading: the net revenues from permit exports to the EU ETS induce a welfare improvement for non-EU regions via higher income levels. These positive impacts outweigh the increased production losses in most non-EU regions as described above. However, welfare losses of non-EU regions generally rise when the linked trading scheme is further extended by additional regions. The higher degree of competition on the supply side of the carbon permit market caused by a further extension of the linked trading scheme decreases the permit price and reduces the initial welfare gains of non-EU regions – as opposed to the beneficial effects for the permit-demanding EU economies.

Table 39 finally implies that CDM access (i) does not substantially affect overall production and welfare impacts for EU and non-EU regions and (ii) keeps the regional macroeconomic impacts rather constant across linking scenarios. Clearly, the access to low-cost emissions abatement in developing countries for only a part of the economy (i.e. the covered sectors) cannot induce substantial efficiency improvements. Moreover, the inflow of low-cost emissions permits from developing countries into each domestic trading system induces comparably low levels of marginal abatement costs in *ETS* sectors, thus limiting the benefits from linking ETS.

6.4.3 Effects on international competitiveness

Policy-induced carbon restrictions affect import and export activities by increasing the costs of domestic production and decreasing macroeconomic consumption. Carbon restrictions may also generate indirect effects on international trade in large open economies, which are most dominant on fossil fuel markets: a decreased demand for fossil fuels due to globally relevant carbon constraints leads to a decreasing international fossil fuel price, which benefits energy importing regions and causes losses for energy exporters via lower revenues (Böhringer and Rutherford, 2002a). In the following we assess the trade-based competitiveness effects of linking emissions trading schemes at the national and sectoral level.

Focusing first on the EU-27 region, Figure 10 (a) illustrates economy-wide competitiveness effects as measured by changes in the terms of trade (ToT), i.e. the ratio between export and import prices, across policy scenarios (all numerical results are reported in Table 40). In a non-linked EU trading scheme (scenario *EU*), the EU faces a ToT loss of more than 2 percent due to more ambitious national emissions reduction targets and stricter allowance allocation within the EU ETS as compared to regulations in non-EU regions. Figure 10 (c) and (d) decompose these national competitiveness effects for the EU at the sectoral level using two well-known indicators: Revealed Comparative Advantage (RCA) and Relative World Trade Shares (RWS).[78] It shows that in the absence of linking, the European *ETS* sectors face competitiveness losses both vis-à-vis the non-covered EU industries (the RCA indicator amounting to -2.1 percent) and vis-à-vis less stringent regulated *ETS* sectors in non-EU regions (the RWS indicator amounting to -1.4 percent). The ambitious EU ETS allocation has

[78] Here, the RCA indicator relates the ratio of a region's exports in a specific sector over the region's imports of this sector to the ratio of exports over imports in all sectors of this region. The RWS indicator relates the ratio of a region's exports in a specific sector over the world's exports in this sector to the ratio of a region's exports in all sectors over the world's total exports.

negative consequences for energy use in domestic production of European *ETS* sectors and thus for their export performance.

Linking the EU ETS internationally (i.e. moving from *EU* to EU^{+++}) improves both national competitiveness for the EU-27 region and sectoral competitiveness of European *ETS* sectors. The decreased abatement levels (and costs) due to a lower carbon price make production and exports of European *ETS* sectors relatively cheaper than imports to those sectors from non-EU regions. Remarkably, the initial losses of European *ETS* sectors turn into competitiveness gains both vis-à-vis non-covered EU industries and comparable sectors in non-EU regions by an increased linkage to non-EU trading schemes (positive RCA and RWS indicators). Here, linking to Russia yields the largest economy-wide and sectoral competitiveness improvements: the access to low-cost abatement options of this region reduces economic adjustment costs and adverse production and export impacts. On the contrary, sectoral competitiveness of the non-covered *NETS* industries within the EU is substantially deteriorated by linking the EU emissions trading scheme internationally. Integrating the EU ETS with emerging schemes outside Europe thus shifts export performance from the non-covered to the covered EU industries, as only the latter may benefit from increased where-flexibility and a lower allowance price.

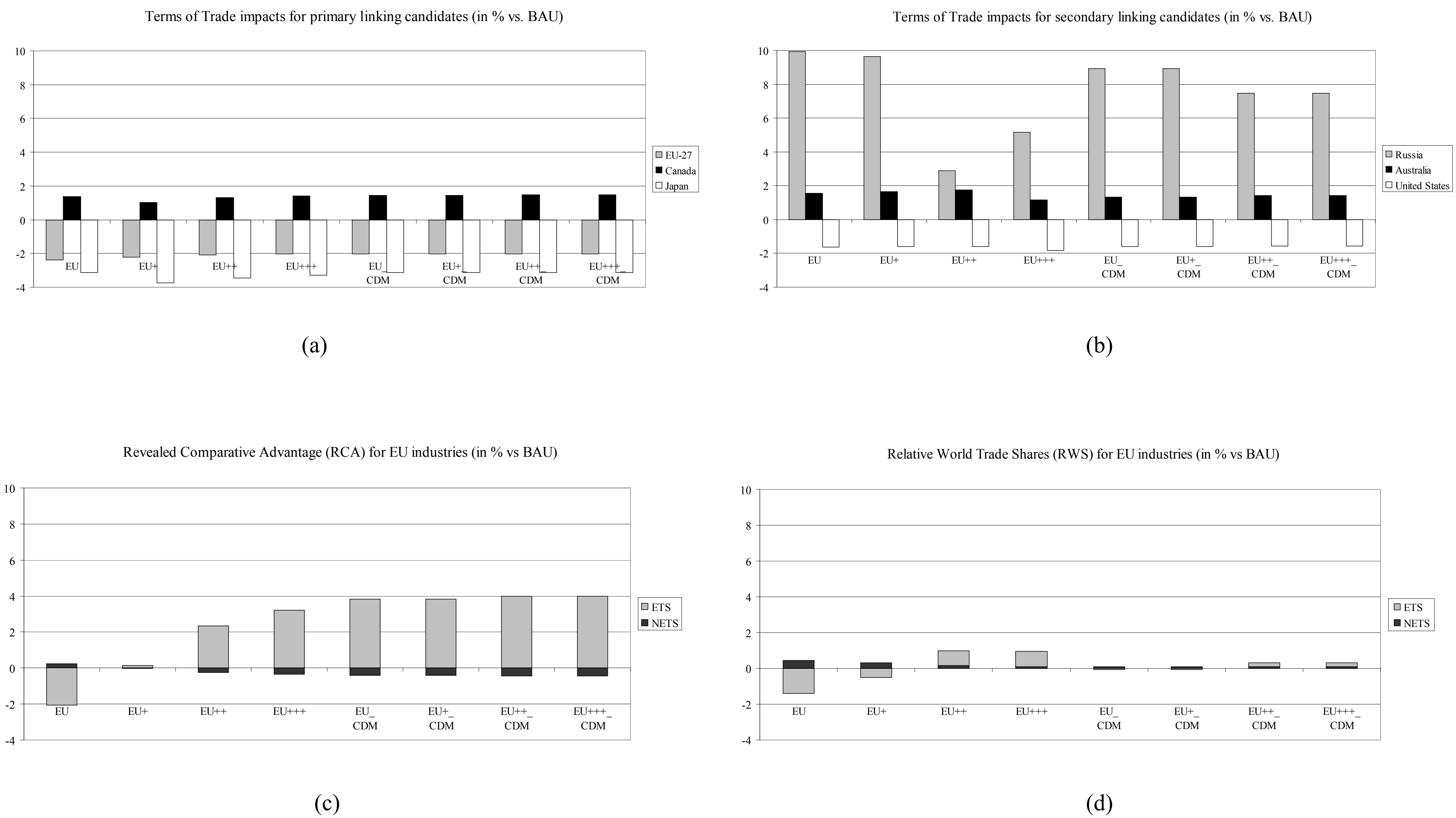

Figure 10: Economy-wide and sectoral competitiveness indicators by region, sector and scenario

Figure 10 (a) and (b) also summarize the national competitiveness impacts for non-EU regions across policy scenarios. The figures first show that in non-linked domestic emissions trading schemes (scenario *EU*), the less ambitious emissions regulations in non-EU regions (as compared to EU regulation) lead to economy-wide competitiveness gains for all non-EU countries (except of Australia and the US). Non-EU production and export performance is affected less negatively especially in the case of the Russian Federation, which effectively imposes no carbon constraint on the economy and benefits in terms of international competitiveness. This leads to competitiveness gains for Russia despite of a decreased international fossil fuel price (caused by a reduced demand for emissions and energy use in the remaining, carbon-constrained world regions) that harms the exporting fossil fuel sectors.

Figure 10 (a) and (b) show that linking to the EU ETS induces homogeneous competitiveness impacts for non-EU economies: all regions face substantial losses in economy-wide competitiveness by linking up. These results relate inversely to the economy-wide competitiveness for the EU and the non-EU welfare impacts – and are clearly driven by the fact that all non-EU regions act as permit exporters within a joint ETS: the increased emissions reductions of non-EU regions by linking up lead to decreased energy use, production levels in *ETS* sectors and export performance.

The negative competitiveness impacts are attenuated when the linked trading scheme is further extended by competing permit-exporting regions, which drives down emissions reductions and the associated ToT losses. These effects can most clearly be seen at the permit-exporting Russian Federation, whose initial competitiveness gain of almost 10 percent is reduced to less than 3 percent by linking up to the EU scheme – before rising again to more than 5 percent through the further integration of Australia and the United States within the EU ETS. The corresponding Russian emissions reductions rise from 0 to almost 11 percent by linking up, but fall to less than 8 percent by a further linkage of Australia and the USA.

When allowing for CDM access for the covered sectors of the respective trading systems, the economy-wide competitiveness effects across scenarios are largely leveled out for the EU-27 and non-EU regions – except for Russia, which still faces a moderate ToT decrease by linking up to the EU ETS. Clearly the access to low-cost carbon abatement in developing countries also balances emissions reductions of the linked regions across scenarios, thereby limiting the corresponding effects on domestic production and export performance. From a European perspective, CDM access for the permit-importing ETS sectors serves as a flexibility mechanism that improves their competitiveness vis-à-vis NETS sectors, which are not able to improve their ability to compete as they are excluded from the low-cost abatement options in developing countries.

6.4.4 Sensitivity analysis: Stricter allowance allocation

The allocation of emissions permits to the covered sectors in future trading schemes is a crucial determinant for our simulation results. As future permit allocation is clearly associated with considerable uncertainty, we conduct a sensitivity analysis with respect to the stringency of allowance allocation. In contrast to the empirically motivated allocation factors (see section 6.2.2) we now assume that sectors covered by a domestic trading system account for the entire national emission reduction requirement.[79] The associated simulation results are presented in Table 41 and Table 42. We find that the qualitative impacts of linking the EU ETS are generally robust to the stringency of allowance allocation: linking ETS diminishes the welfare losses from emissions regulation for all regions. While EU Member States improve their terms of trade by integrating with emerging ETS, all linking candidates (except of Canada) loose competitiveness by linking up. However, our quantitative results show that the magnitude of efficiency and international trade effects is drastically increased by a stricter allowance allocation. Based on our results for a stricter allowance allocation, we conclude that a more efficient design of domestic ETS can boost the overall prospects for establishing supra-European emissions trading schemes. In particular, linking ETS diminishes the negative welfare impacts for the EU and non-EU regions to a much larger extent, thereby increasing the attractiveness of the linking process for all countries.

6.5 Conclusions

In this paper we have presented an efficiency and international trade analysis of developing supra-European emissions trading schemes. A stylized partial-market model suggested that – independently of the marginal abatement costs of a region to be linked with an existing scheme – the integration of trading systems yields economic efficiency gains for all participating regions. We have subsequently analyzed the macroeconomic and trade-based

[79] Two limitations apply here: The EU-15 region is assigned a minimal allocation factor equal to 0.3 in order to keep the computational problem tractable. Moreover, the EU-12 allocation factor remains unchanged as compared to the original allocation, as it already implied that *ETS* sectors account for the entire national reduction requirement.

competitiveness impacts of linking the EU ETS employing a large-scale computable general equilibrium (CGE) model of the global economy.

Based on empirical allowance allocation of the EU ETS, our quantitative analysis indicates an unambiguous pattern of international permit trade: regardless of the regional linking constellation the EU represents an importer of emissions allowances, while all non-EU regions are exporting carbon permits to Europe. This originates from a leadership of the EU in terms of a relatively stringent allowance allocation within the EU ETS. Moreover, the CGE analysis confirms our theoretical findings regarding economic efficiency: by decreasing the international permit price, linking emissions trading schemes reduces welfare costs from emissions regulation for both EU Member States and non-EU regions. Here, the role of the EU as permit importer simultaneously leads to relative EU welfare and production gains, as abatement costs and levels are reduced at the same time. For all non-EU regions, the net revenues from permit sales outweigh the partly negative production impacts, which are caused by increasing emissions abatement when linking up to the European trading system.

Regarding international trade impacts our quantitative assessment suggests however opposite incentives of linking ETS: EU Member States clearly improve their terms of trade by integrating with emerging ETS outside Europe. Decomposing these international trade effects at the sectoral level shows that only those sectors covered by the EU ETS benefit substantially from an increased integration of non-EU ETS, both versus non-covered industries within the EU and comparable ETS sectors in non-EU regions. On the contrary, all non-EU regions face substantial losses in economy-wide competitiveness by linking up to the European scheme. These opposite results are clearly driven by the mutual roles of EU and non-EU regions as permit importers and exporters within the linked emissions trading systems. The disadvantageous non-EU competitiveness impacts may however be attenuated when the linked ETS is further extended by additional non-EU regions.

Allowing for permit imports from outside the linked schemes via the Clean Development Mechanism largely neutralizes the macroeconomic impacts of linking ETS. The reason are equally low levels of marginal abatement costs in the covered sectors of the respective ETS induced by the inflow of low-cost emissions permits from developing countries. However, the access to low-cost emissions abatement for only a part of the economy (i.e. the covered sectors) can substantially alter the sectoral competitiveness implications of linking emissions trading schemes.

We conclude that EU Member States have strong incentives to integrate emerging emissions trading schemes with the European ETS both in terms of economic efficiency and international trade. For non-EU linking candidates, the efficiency improvements by linking up go however at the expense of their ability to compete. For these regions, the attractiveness of developing supra-European ETS thus comes down to a matter of priorities for social welfare or international competitiveness.

The previous two chapters have analyzed the carbon-market and macroeconomic impacts of linking emissions trading schemes in greater detail. Against this background, the following chapter investigates the economic implications of integrating a novel carbon abatement option in international emissions trading: reduced emissions from tropical deforestation.

6.6 Appendix: List of tables

Table 34: PACE model regions

Annex B regions	Non-Annex B regions
EU-15 (Old EU Member States)	China (including Hong Kong)
EU-12 (New EU Member States)	India
Canada	Brazil
Japan	Mexico
Russian Federation	Korea
Australia	Rest of World
United States	

Table 35: PACE model sectors

ETS sectors	NETS sectors	Other sectors
Refined oil products	Rest of Industry (Other manufactures and services)	Coal
Electricity		Crude oil
Iron and steel industry		Natural gas
Paper products and publishing		
Non-ferrous metals		
Mineral products		

Table 36: Baseline emissions and reduction requirements of ratifying Annex-B countries

	Baseline CO_2 Emissions (Mt of CO_2)			Emissions reduction target (% vs. 1990)		Emissions reduction target (% vs. BAU)	
Region \ Year	1990	2010	2020	2010	2020	2010	2020
EU-15	3082.1	3204.7	3443.9	8.0	30.0	11.5	37.4
EU-12	964.6	691.4	756.5	8.0	30.0	-28.4	10.7
EU-27	4046.7	3896.1	4200.4	8.0	30.0	4.4	32.5
Canada	473.0	681.0	757.0	6.0	-20.0	34.7	25.0
Japan	990.0	1211.0	1240	6.0	6.0	23.2	25.0
Russian Fed.	2347.0	1732.0	1971.0	0.0	16.0	-35.5	0.0
Australia	294.0	520.0	582.0	-8.0	-58.4	38.9	20.0
United States	4989.0	6561.0	7461.0	7.0	-19.6	29.3	20.0

Sources: EU (2003): *European Energy and Transport Trends to 2030;* US Department of Energy (2005): *International Energy Outlook;* own calculations

Table 37: Allocation factor by region in 2020

Region	Empirical allocation	Stringent allocation
Austria	0.569	–
Belgium	0.660	–
Germany	0.613	–
Denmark	0.526	–
Spain	0.485	–
France	0.635	–
Finland	0.700	–
Greece	0.565	–
Ireland	0.525	–
Italy	0.594	–
Netherlands	0.625	–
Portugal	0.587	–
Sweden	0.693	–
United Kingdom	0.630	–
Czech Republic	0.578	–
Estonia	0.451	–
Hungary	0.621	–
Lithuania	0.667	–
Latvia	0.515	–
Poland	0.583	–
Slovenia	0.544	–
Slovakia	0.650	–
Cyprus	0.617	–
Malta	0.698	–
Bulgaria	0.700	–
Romania	0.700	–
EU-15	0.601	0.300
EU-12	0.810	0.810
Japan	0.850	0.508
Canada	0.850	0.348
Russian Federation	1.000	1.000
United States	0.900	0.590
Australia	0.900	0.707

Source: EU (2007c), own calculations

Table 38: Policy scenarios in 2020 and CDM host countries

<table>
<tr><th>Regional scenario</th><th>Regions participating in emissions trading</th><th>CDM regions</th></tr>
<tr><td>EU</td><td>EU-27</td><td rowspan="4">China
India
Brazil
Mexico
Korea
Rest of World</td></tr>
<tr><td>EU^{+}</td><td>EU-27
Canada
Japan</td></tr>
<tr><td>EU^{++}</td><td>EU-27
Canada
Japan
Russian Federation</td></tr>
<tr><td>EU^{+++}</td><td>EU-27
Canada
Japan
Russian Federation
Australia
United States</td></tr>
</table>

Table 39: Core allowance allocation – Environmental and macroeconomic indicators in 2020

Region \ Scenario	*EU*	EU^{+}	EU^{++}	EU^{+++}	*EU_CDM*	EU^{+}_CDM	EU^{++}_CDM	EU^{+++}_CDM
	Carbon emissions reduction (in % vs. BaU)							
EU-27	-33.28	-30.83	-28.01	-25.95	-23.22	-23.22	-23.14	-23.14
Canada	-25.00	-29.27	-26.62	-24.55	-22.12	-22.12	-22.05	-22.05
Japan	-25.00	-32.75	-30.14	-28.04	-25.00	-25.10	-25.02	-25.02
Russian Fed.	0.00	0.00	-10.63	-7.71	0.00	0.00	-3.62	-3.62
Australia	-20.00	-20.00	-20.00	-25.57	-19.23	-19.23	-19.03	-19.03
United States	-20.00	-20.00	-20.00	-22.17	-18.42	-18.41	-18.32	-18.32
	CO2 value in ETS sectors (in $US per ton of CO_2)							
EU-27	36.69	24.6	14.96	9.74	4.27	4.27	4.20	4.20
Canada	10.72	24.6	14.96	9.74	4.27	4.27	4.20	4.20
Japan	4.36	24.6	14.96	9.74	4.13	4.27	4.20	4.20
Russian Fed.	1.56	1.50	14.96	9.74	0.99	0.99	4.20	4.20
Australia	5.11	5.16	5.26	9.74	4.27	4.27	4.20	4.20
United States	6.45	6.53	6.53	9.74	4.27	4.27	4.20	4.20
	Production impact (in % vs. BaU)							
EU-27	-1.44	-1.41	-1.39	-1.37	-1.36	-1.36	-1.36	-1.36
Canada	-0.74	-0.66	-0.70	-0.73	-0.72	-0.72	-0.72	-0.72
Japan	-1.00	-1.03	-1.02	-1.01	-0.99	-0.99	-0.99	-0.99
Russian Fed.	0.73	0.74	0.31	0.46	0.77	0.77	0.65	0.65
Australia	-1.20	-1.19	-1.19	-1.14	-1.21	-1.21	-1.21	-1.21
United States	-0.43	-0.43	-0.42	-0.44	-0.41	-0.41	-0.41	-0.41
	Welfare impact (in % of HEV)							
EU-27	-0.67	-0.67	-0.66	-0.64	-0.62	-0.62	-0.62	-0.62
Canada	-0.59	-0.54	-0.58	-0.59	-0.60	-0.60	-0.60	-0.60
Japan	-0.42	-0.39	-0.41	-0.42	-0.42	-0.42	-0.42	-0.42
Russian Fed.	-1.42	-1.42	-0.88	-1.14	-1.45	-1.45	-1.37	-1.37
Australia	-1.25	-1.25	-1.25	-1.22	-1.23	-1.23	-1.24	-1.24
United States	-0.17	-0.17	-0.17	-0.16	-0.17	-0.17	-0.17	-0.17

Table 40: Core allowance allocation – Economy-wide and sectoral competitiveness indicators in 2020

Scenario / Region	***EU***		***EU^{+}***		***EU^{++}***		***EU^{+++}***		***EU_CDM***		***EU^{+}_CDM***		***EU^{++}_CDM***		***EU^{+++}_CDM***	
	Terms of Trade impact (in % vs. BaU)															
EU-27	-2.38		-2.21		-2.09		-2.03		-2.03		-2.03		-2.03		-2.03	
Canada	1.37		1.02		1.3		1.4		1.46		1.46		1.48		1.48	
Japan	-3.11		-3.75		-3.45		-3.29		-3.14		-3.14		-3.14		-3.14	
Russian Fed.	9.94		9.63		2.88		5.15		8.92		8.92		7.47		7.47	
Australia	1.57		1.65		1.75		1.18		1.33		1.33		1.41		1.41	
United States	-1.62		-1.61		-1.61		-1.81		-1.60		-1.60		-1.58		-1.58	
	Revealed Comparative Advantage – RCA (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	-2.05	0.24	0.14	-0.01	2.35	-0.25	3.20	-0.35	3.83	-0.41	3.83	-0.41	4.00	-0.43	4.00	-0.43
Canada	0.14	0.04	-5.73	0.89	-2.08	0.35	0.33	0.00	1.32	-0.11	1.32	-0.11	1.46	-0.14	1.46	-0.14
Japan	13.95	-0.94	7.92	-0.54	10.87	-0.74	11.83	-0.8	12.17	-0.82	12.13	-0.82	12.47	-0.84	12.47	-0.84
Russian Fed.	-1.19	0.14	-2.16	0.60	-19.63	8.93	-14.46	6.35	-4.16	1.65	-4.16	1.65	-8.51	3.62	-8.51	3.62
Australia	6.17	-0.36	5.96	-0.33	6.22	-0.44	-1.71	1.21	5.56	-0.25	5.57	-0.26	6.04	-0.36	6.04	-0.36
United States	1.55	-0.17	1.78	-0.19	0.9	-0.12	-1.29	0.05	-0.17	-0.04	-0.17	-0.04	-0.01	-0.05	-0.01	-0.05
	Relative World Trade Shares – RWS (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	-1.39	0.44	-0.52	0.31	0.85	0.15	0.83	0.11	-0.05	0.09	-0.05	0.09	0.23	0.08	0.23	0.08
Canada	66.22	-0.18	60.63	0.36	64.44	-0.03	66.06	-0.26	64.81	-0.31	64.81	-0.31	65.24	-0.33	65.24	-0.33
Japan	68.98	-0.39	64.55	-0.20	66.98	-0.33	66.77	-0.35	65.09	-0.35	65.06	-0.35	65.61	-0.37	65.61	-0.37
Russian Fed.	67.43	-0.29	66.24	0.11	50.47	7.23	54.8	5.06	62.23	1.04	62.23	1.04	58.68	2.74	58.68	2.74
Australia	65.06	0.08	64.7	0.07	65.79	-0.08	56.26	1.36	62.41	0.11	62.42	0.11	63.30	0.00	63.3	0.00
United States	63.96	-0.16	63.74	-0.18	63.25	-0.17	61.21	-0.11	60.03	-0.13	60.04	-0.13	60.37	-0.14	60.37	-0.14

Table 41: Stricter allowance allocation – Environmental and macroeconomic indicators in 2020

Scenario / Region	*EU*	*EU⁺*	*EU⁺⁺*	*EU⁺⁺⁺*	*EU_CDM*	*EU⁺_CDM*	*EU⁺⁺_CDM*	*EU⁺⁺⁺_CDM*
	Carbon emissions reduction (in % vs. BaU)							
EU-27	-33.28	-33.51	-25.90	-24.01	-9.23	-9.23	-9.10	-9.10
Canada	-25.00	-22.56	-17.01	-15.47	-3.70	-3.70	-3.58	-3.58
Japan	-27.31	-28.31	-21.25	-19.54	-5.18	-5.18	-5.06	-5.06
Russian Fed.	0.00	0.00	-27.23	-25.00	0.00	0.00	-6.22	-6.22
Australia	-20.42	-20.42	-20.36	-37.16	-9.64	-9.64	-9.33	-9.33
United States	-20.00	-20.00	-20.00	-20.98	-5.90	-5.90	-5.75	-5.75
	CO2 value in ETS sectors (in $US per ton of CO_2)							
EU-27	207.29	212.16	95.60	77.61	8.15	8.15	8.00	8.00
Canada	301.89	212.16	95.60	77.61	8.15	8.15	8.00	8.00
Japan	189.84	212.16	95.60	77.61	8.15	8.15	8.00	8.00
Russian Fed.	4.53	4.55	95.60	77.61	1.69	1.69	8.00	8.00
Australia	24.50	24.45	24.29	77.61	8.15	8.15	8.00	8.00
United States	70.37	69.85	68.11	77.61	8.15	8.15	8.00	8.00
	Production impact (in % vs. BaU)							
EU-27	-0.93	-0.93	-0.65	-0.58	-0.29	-0.29	-0.29	-0.29
Canada	0.07	0.02	-0.10	-0.17	-0.01	-0.01	-0.01	-0.01
Japan	-0.48	-0.51	-0.29	-0.26	-0.03	-0.03	-0.04	-0.04
Russian Fed.	-0.17	-0.16	-1.98	-1.69	0.05	0.05	-0.16	-0.16
Australia	0.35	0.35	0.38	0.53	0.22	0.22	0.22	0.22
United States	-0.32	-0.31	-0.27	-0.29	-0.02	-0.02	-0.02	-0.02
	Welfare impact (in % of HEV)							
EU-27	-0.74	-0.74	-0.60	-0.54	-0.08	-0.08	-0.08	-0.08
Canada	-1.43	-1.39	-1.01	-0.90	-0.17	-0.17	-0.17	-0.17
Japan	-0.23	-0.23	-0.20	-0.18	-0.03	-0.03	-0.02	-0.02
Russian Fed.	0.15	0.14	6.79	5.10	-0.15	-0.15	0.03	0.03
Australia	-0.52	-0.52	-0.52	0.26	-0.32	-0.32	-0.32	-0.32
United States	-0.23	-0.23	-0.23	-0.22	-0.07	-0.07	-0.07	-0.07

Table 42: Stricter allowance allocation – Economy-wide and sectoral competitiveness indicators in 2020

Scenario / Region	***EU***		***EU^{+}***		***EU^{++}***		***EU^{+++}***		***EU_CDM***		***EU^{+}_CDM***		***EU^{++}_CDM***		***EU^{+++}_CDM***	
	Terms of Trade impact (in % vs. BaU)															
EU-27	-2.28		-2.34		-0.88		-0.7		-0.54		-0.54		-0.54		-0.54	
Canada	-0.5		0.9		1.62		1.59		0.43		0.43		0.47		0.47	
Japan	-1.99		-2.41		-0.56		-0.34		0.06		0.06		0.05		0.05	
Russian Fed.	9.57		9.69		-30.6		-24.74		2.02		2.02		-0.59		-0.59	
Australia	4.06		4.07		4.13		-3.29		2.23		2.23		2.36		2.36	
United States	-0.31		-0.33		-0.35		-0.8		0.61		0.61		0.64		0.64	
	Revealed Comparative Advantage – RCA (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	-21.98	3.07	-22.57	3.17	-9.8	1.25	-7.46	0.94	0.39	-0.05	0.39	-0.05	0.65	-0.08	0.65	-0.08
Canada	-45.57	8.65	-34.62	5.98	-15.68	2.3	-10.73	1.45	-1.37	0.17	-1.37	0.17	-1.13	0.13	-1.13	0.13
Japan	-19.22	1.77	-21.93	2.06	-7.24	0.6	-3.98	0.32	0.92	-0.08	0.92	-0.08	1.37	-0.11	1.37	-0.11
Russian Fed.	20.26	-11.21	20.3	-11.22	-54.91	29.76	-48.71	24.9	1.03	-0.82	1.03	-0.82	-7.18	2.74	-7.18	2.74
Australia	-15.41	3.47	-15.58	3.52	-16.73	3.66	-53.65	14.31	-8.6	1.85	-8.6	1.85	-7.89	1.67	-7.89	1.67
United States	-0.3	0.1	-2.45	0.28	-9.04	0.86	-12.81	1.24	-0.97	0.09	-0.97	0.09	-0.73	0.07	-0.73	0.07
	Relative World Trade Shares – RWS (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	-2.89	1.77	-3.34	1.81	3.52	0.75	4.47	0.58	0	0.04	0	0.04	0.49	0.01	0.49	0.01
Canada	27.26	5.15	39.94	3.84	60.52	1.4	65.4	0.82	58.9	0.07	58.9	0.07	59.64	0.03	59.64	0.03
Japan	60.68	1.1	58.18	1.21	69.93	0.35	71.75	0.21	60.95	-0.07	60.95	-0.07	61.85	-0.1	61.85	-0.1
Russian Fed.	96.84	-10.29	96.73	-10.3	20.04	22.74	27.11	19.43	61.16	-0.81	61.16	-0.81	54.98	2.28	54.98	2.28
Australia	53.78	3.41	53.44	3.45	53.2	3.14	1.66	11.18	50.58	1.5	50.58	1.5	52.01	1.33	52.01	1.33
United States	79.67	0.22	77.38	0.31	69.61	0.36	66.42	0.44	59.44	0.01	59.44	0.01	60.03	0	60.03	0

7 Reducing Deforestation and Trading Emissions: Economic Implications for the post-Kyoto Carbon Market [80]

The 2007 assessment report of the Intergovernmental Panel on Climate Change (IPCC) reemphasized the urgency of combating climate change by stating that "continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century" (IPCC, 2007). As the primary causes of climate change the report highlights fossil fuel use and land use change, the latter accounting for roughly one fifth of total anthropogenic greenhouse gas emissions.

Assessing future strategies for solving the climate problem, Pacala and Socolow (2004) propose a set of options to reduce global carbon emissions within the next 50 years. One prominent option among the 15 proposed strategies is reducing tropical deforestation and the management of temperate and tropical forests. Emphasizing the importance of early international action for limiting global warming, also the Stern Review recently suggested emissions reductions from avoiding deforestation as a key element of cost-effective future climate policy (Stern, 2007). Forests play a twofold role in climate change by sequestering large quantities of carbon: while growing trees absorb carbon dioxide from the air and store carbon by the process of photosynthesis, forests can become a major emissions source when the stored carbon is released into the atmosphere by means of forest degradation and deforestation activities. Most commonly, the latter imply the logging or burning of rainforests for the production of wood and non-wood forest products or for agricultural land use. Recent studies estimate the net annual forest loss in Africa alone to amount to 4 million hectares, implying that the continuing decline of primary rainforest in tropical regions is a matter of growing concern (FAO, 2007).

Heal (1999) analyzes economic mechanisms through which goods and services provided by tropical forests and their biodiversity could be marketed. One discussed mechanism is the financial compensation for carbon sequestration services of forests under an international climate agreement, potentially generating incomes high enough to radically change the

[80] This chapter is based on the paper: Anger, N. and J. Sathaye (2008): "Reducing Deforestation and Trading Emissions: Economic Implications for the post-Kyoto Carbon Market", *Lawrence Berkeley National Laboratory Formal Report* LBNL-63746. The manuscript was submitted to and is currently under review for *The Energy*

incentives for forest conservation. Supported by the Coalition for Rainforest Nations, Papua New Guinea recently proposed to address reducing emissions from deforestation and degradation (REDD) within the international climate regime (UNFCCC, 2005). Whereas under the Kyoto Protocol only forestation and reforestation activities are eligible for crediting the associated carbon abatement, the proposal suggested that developing countries might commit to reducing emissions from deforestation – in exchange for receiving tradable carbon abatement credits and participating in international post-Kyoto emissions trading.

Over the last decades, the most important obstacle for the implementation of ambitious climate policies has been the associated mitigation costs. As a prominent example, the long drawn negotiations of the Kyoto Protocol eventually allowed business-as-usual emissions and imposed negligible compliance costs of regulation (Böhringer and Vogt, 2003). Thus, a viable and environmentally effective strategy for future climate policy has to be economically attractive at the same time. Against this background, the World Bank has proposed Forest Carbon Finance as an "ungrasped opportunity" of reducing global carbon emissions at low costs (Chomitz et al., 2007). As the marginal costs for reducing carbon by reducing tropical deforestation are expected to be far lower than emissions abatement options in industrialized countries, these countries could finance farmers in tropical regions for forest conservation rather than pursuing costly emissions abatement efforts at home. Given the low economic returns of agricultural land use in tropical rainforest regions, such incentive payments for avoiding deforestation could at the same time benefit the developing world. Moreover, they may pave the way for developing countries to actively take part in emissions reduction efforts within an international climate policy regime (Dutschke and Wolf, 2007).

The economic aspects of international emissions trading have been assessed in a number of previous quantitative studies on the Kyoto Protocol and the EU Emissions Trading Scheme (EU ETS). These studies employ both partial and general equilibrium models to illustrate the economic efficiency gains from "where flexibility" of carbon abatement, and highlight the welfare costs of restricting emissions trading to energy-intensive sectors of the economy (Weyant and Hill, 1999; Böhringer et al., 2005; Klepper and Peterson, 2006). Anger (2007) shows that parallel carbon trading within the EU ETS and among post-Kyoto governments yields considerable efficiency gains and increases the economic importance of project-based emissions reductions in developing countries via the Clean Development Mechanism (CDM). Criqui et al. (2006) study the impacts of "what flexibility" in greenhouse gas emissions

Journal. As the corresponding author of the manuscript, I contributed to all sections of the chapter except of section 7.1.1.

abatement by integrating an agricultural model within an energy-system framework, finding that multi-gas strategies decrease marginal abatement costs by 30 percent as compared to a CO_2-based policy. Regarding the role of deforestation in international climate policy, several studies assessed the relationship between tropical deforestation and climate change as well as the institutional aspects of including forestry activities in a post-Kyoto agreement (Moutinho and Schwartzman, 2005; Schlamadinger and Bird, 2007; Amano and Sedjo, 2006).

The quantitative economic literature assessing deforestation in the context of climate policy is comparably scant. Linking a forestry model to a climate-economy model, Sohngen and Mendelsohn (2003) analyze the role of forests in greenhouse gas mitigation, predicting forest sequestration to account for about one third of global carbon abatement within the next century. Tavoni et al. (2007) study the contribution of forestry management to long-term CO_2 stabilization policies, finding that increased forest sequestration could significantly lower the global costs of climate policy. These studies feature a strong integration of modeling frameworks and form an important scientific basis for the numerical analysis of interactions between forestry activities and future climate policy.

Against this background, the contribution of this paper is twofold: Linking a dynamic model of the forestry sector with an equilibrium model of the emissions market, we (i) explicitly study the implications of crediting abatement from reduced deforestation for the post-Kyoto carbon market. The emissions market model is calibrated to energy-system data, incorporates empirical allowance allocation and marginal abatement cost functions for reduced deforestation, and accounts for the institutional characteristics of the post-Kyoto carbon market: parallel emissions trading on the government level (representing a post-Kyoto climate agreement) and on the company level (representing the EU ETS and a future linkage to emerging non-EU schemes). Employing Monte-Carlo simulations of carbon stock changes in the forestry sector, we (ii) then analyze the emissions-market implications of uncertainties in transaction costs of forestry projects such as monitoring and verification costs, as well as uncertainties in the historical baseline against which reduced deforestation is measured.

The remainder of this paper is structured as follows. In Section 7.1 we present the numerical model framework for our quantitative analysis. Section 5.3 specifies illustrative scenarios of post-Kyoto climate policy in 2020. In Section 5.4 we present the simulation results, and in Section 5.5 we conclude.

7.1 Numerical model framework

For the quantitative assessment of reducing deforestation and trading emissions in 2020 we subsequently present our two numerical model frameworks: a dynamic model of the forestry sector and a static model of the world carbon market.

7.1.1 Modelling the forestry sector in tropical regions

In order to simulate the response of the forestry sector to changes in future carbon prices, we employ the dynamic partial equilibrium model *Generalized Comprehensive Mitigation Assessment Process* GCOMAP (Sathaye et al., 2005, 2006). The model analyzes the carbon benefits of forestation globally in ten regions and of reducing deforestation in four important tropical rainforest regions (FAO, 2007): Africa, South-East Asia, Central America and South America. It establishes a reference level of land use, absent carbon prices, for 2000 to 2100 before simulating the response of forest land users (i.e. farmers) to changes in prices of forest land and products, as well as prices emerging in carbon markets. The model's objective is to estimate the land area that land users would plant above the reference level, or prevent from being deforested, in response to carbon prices. As a result GCOMAP estimates net changes in carbon stocks while meeting the annual demand for timber and non-timber products.

In order to assess the role of institutional barriers for crediting carbon abatement from reducing deforestation we investigate the impact of transaction costs of forestry projects and programs (hereafter also referred to as projects) on the carbon-price response of the forestry sector (see Antinori and Sathaye, 2007). Such transaction costs may arise from project search, feasibility studies, as well as negotiation, monitoring and verification, regulatory approval, and insurance costs. Antinori and Sathaye (2007) analyze four data sets of forestry and energy projects including projects associated with the CDM and the Global Environmental Facility (GEF). In each data set, they find strong economies of scale. The forestry project sizes range from 58 thousand to as much as 22 million tons of CO_2 mitigated over their life and include both forestation and deforestation projects. Project lifetimes range from five to 100 years. The estimated transaction costs range from 0.05 US$ per ton of CO_2 for large projects to 1.22 US$ per ton of CO_2 for smaller ones. For this study, we conduct Monte-Carlo simulations of carbon stock changes resulting from a sequence of carbon prices in 2020 that are subject to the spread of transaction costs determined for the forestry sub-group of projects in the Antinori and Sathaye (2007) study.

Moreover, we analyze the implications of the baseline against which reduced deforestation is measured for the level of carbon abatement in the forestry sector. As in the case of transaction costs we employ Monte-Carlo simulations of carbon stock changes resulting from a sequence of carbon prices for an interval of deforestation baseline levels for the tropical rainforest region South America. Data for annual variation in deforestation rates was available only for the Brazilian Amazon from 1989 to 2006, and hence we use these variations to simulate the potential variation in deforested area for the baseyear (INPE, 2007).

7.1.2 Modelling the global carbon market

In order to quantitatively assess the emissions-market impacts of reducing deforestation we employ a numerical multi-country, two-sector partial equilibrium model of the global carbon market in 2020. For each region, the model incorporates calibrated marginal abatement cost functions for energy-intensive and non-energy-intensive sectors. Building on the modelling framework of Anger (2007), it represents parallel carbon markets for (i) companies covered by the EU ETS and emerging schemes outside Europe as well as (ii) post-Kyoto governments in 2020 and accounts for emissions reductions via the CDM. The objective of the model is to minimize compliance costs of carbon regulation by means of international emissions trading. An algebraic model summary is given in Anger (2007).

To generate marginal abatement cost (MAC) functions by region and sector we use data simulated by the well-known energy-system model POLES (Criqui et al., 1999), which explicitly covers energy technology options for emissions abatement in various world regions and sectors for the baseyear 2020. In the POLES simulations a sequence of carbon taxes (e.g. 0 to 100 US$ per ton of carbon) is imposed on the respective regions, resulting in associated sectoral emissions abatement. The coefficients for MAC functions in 2020 are estimated by an ordinary least squares (OLS) regression of tax levels (i.e. marginal abatement costs) on associated emissions abatement. Following Böhringer et al. (2005), in order to assure for functional flexibility a polynomial of third degree is chosen as the functional form of MAC functions.[81] For region *r* and sector *i* this results in the following equation (note that *EIS* and *NEIS* denote energy-intensive and non-energy-intensive sectors, respectively):

$$-MAC_{ir}(e_{ir}) = \beta_{1,ir}(e_{0ir} - e_{ir}) + \beta_{2,ir}(e_{0ir} - e_{ir})^2 + \beta_{3,ir}(e_{0ir} - e_{ir})^3 \qquad (1)$$

[81] We use the OLS approach as a standard estimation technique, which for our data yields parameter estimations with a high overall goodness-of-fit. Clearly alternative estimation approaches and functional forms could be chosen here.

with MAC_{ir} as marginal abatement cost in region r and sector $i \in \{EIS, NEIS\}$, $\beta_{1,ir}$, $\beta_{2,ir}$ and $\beta_{3,ir}$ as marginal abatement cost coefficients, e_{0ir} as baseline emissions level in 2020 and e_{ir} as emissions level after abatement. Table 45 in Appendix 7.5.1 shows the resulting least-square estimates of MAC coefficients by region and sector in 2020.[82]

MAC functions for reducing deforestation are generated by imposing a sequence of carbon prices (here: 0 to 100 US$ per ton of carbon) in four tropical rainforest regions with the GCOMAP model: Africa, South-East Asia, Central America and South America. This results in a sequence of regional net carbon stock changes and the corresponding carbon emissions reductions due to avoided deforestation. Based on these price-quantity pairs we are able to estimate the coefficients of regional MAC functions in 2020 by means of an OLS regression. Regarding transaction costs of forestry projects, we establish a triangular distribution of transaction costs with respect to the size of the project or program. Size is defined as the amount of carbon dioxide that is mitigated over the life of the project or program. We report the results for the 5th and 95th percentile values (implying high and low transaction costs) from the Monte-Carlo simulations of carbon stock changes for a sequence of carbon prices in 2020 and estimate the respective cost functions. Finally, these MAC coefficients are implemented into the carbon market model by covering tropical rainforest areas as explicit model regions. Within this linked model framework, tropical rainforest regions may export emissions reduction credits from reducing deforestation to industrialized model regions via the global carbon market. Table 46 in Appendix 7.5.1 presents the estimated marginal abatement cost coefficients for avoided deforestation (in the cases of high and low transaction costs) for the four tropical regions in 2020.

We incorporate three further inputs into the carbon market model: baseline emissions, emissions reduction commitments and allowance allocation associated with a potential post-Kyoto climate policy regime. The set of inputs is described in detail in Appendix 7.5.2.

7.2 Climate policy scenarios

The post-Koyto carbon market is expected to feature international emissions trading on two levels: (i) on the government level, as facilitated by the Kyoto Protocol and a potential post-

[82] The marginal abatement cost coefficients have the following units:
$\beta_{1,ir}$ [(€2005/tCO_2)/MtCO_2], $\beta_{2,ir}$ [(€2005/tCO_2)/(MtCO_2)^2] and $\beta_{3,ir}$ [(€2005/tCO_2)/(MtCO_2)^3].

Kyoto climate policy agreement and (ii) on the company level, as facilitated by the EU ETS and emerging schemes outside Europe. As the linked ETS are also expected to be restricted to energy-intensive industries, national Annex B governments may engage in country-level emissions trading as facilitated by a post-Kyoto agreement in order to represent their remaining, non-energy-intensive industries on the future carbon market (Anger, 2007).

In the following we specify scenarios of international emissions trading in the framework of a post-Kyoto agreement in 2020. The scenarios can be classified by two dimensions: the *regional* dimension distinguishes scenarios of countries participating in international emissions trading, whereas the *institutional* dimension lays out alternative designs of carbon regulation.

Table 43 presents our three regional scenarios: as a reference case, scenario EU represents EU ETS participants in 2020, i.e. current members of the European Union including the recently acceded countries Bulgaria and Romania.[83] Scenario EU^{+} indicates carbon trading among countries that have ratified the Kyoto Protocol relatively early: EU Member States, Japan, Canada and the Former Soviet Union. Scenario EU^{++} assumes that not only Kyoto ratifiers trade carbon emissions among each other, but also countries that have only recently or not yet ratified the Kyoto Protocol: Australia and the United States. For all regional scenarios alike five central developing countries are assumed to host CDM projects, representing major suppliers on the CDM carbon market (World Bank, 2006): China, India, Brazil, Mexico and South Korea.[84] Moreover, we include four tropical rainforest regions that are eligible for generating tradable offset credits for carbon abatement from reduced deforestation: Africa, South-East Asia, Central America and South America.

[83] Note that the region EU-27 is approximated by EU-15 Member States (excluding Luxemburg) and the POLES model region Central Europe, which essentially covers new Member States as well as Bulgaria and Romania.

[84] The present analysis focuses on the CDM as a project-based mechanism, as JI projects are hosted by Annex B parties who participate in international emissions trading. Abstracting from its project-based character, JI may therefore be represented by international emissions trading of the respective regions.

Table 43: Regional scenarios for 2020

<table>
<tr><th>Regional scenario</th><th>Regions participating in emissions trading</th><th>CDM regions</th><th>Tropical rainforest regions</th></tr>
<tr><td>EU</td><td>EU-27</td><td rowspan="3">Brazil
China
India
Mexico
South Korea</td><td rowspan="3">Africa
South-East Asia
Central America
South America</td></tr>
<tr><td>EU^{+}</td><td>EU-27
Japan
Canada
Former Soviet Union</td></tr>
<tr><td>EU^{++}</td><td>EU-27
Japan
Canada
Former Soviet Union
Pacific OECD
United States</td></tr>
</table>

Table 23 lists our institutional scenarios, which involve four cases. Scenario *Emissions Trading* denotes international emissions trading among industrialized regions on two levels. On the first level, it represents company-based emissions trading within linked EU and non-EU emissions trading schemes, assuming the sectoral emissions allocation in 2020 as laid out in Appendix 7.5.2. Here, we approximate emissions trading at the company level by trading at the sectoral level. Moreover, all regions that have not (yet) set up an emissions trading scheme are assumed to comply with their emissions reduction target by cost-efficient domestic emissions regulation, imposing a uniform carbon tax on their entire economy. On its second level, scenario *Emissions Trading* represents parallel government trading under a post-Kyoto Protocol, which for the sake of illustration only applies to the linked ETS regions. In such a setting of coexisting emissions trading regimes, a reasonable assumption is that no double regulation of energy-intensive industries covered by a national ETS takes place. As carbon trading among linked ETS is approximated by emissions trading among energy-intensive sectors (EIS), government trading only applies to the remaining, non-energy-intensive sectors (NEIS) of each region. These parallel government trading activities should be interpreted as national authorities *representing* their non-energy-intensive industries on the carbon market.[85]

[85] Here it is assumed that each ETS region has committed to a post-Kyoto agreement enabling government emissions trading.

Table 44: Institutional scenarios for 2020

Institutional scenario	**CO_2 regulation**		**International emissions trading**		**CDM access**	**REDD access**	**Forestry transact-ion costs**
	EIS	**NEIS**	**EIS with**	**NEIS with**	**EIS and NEIS**		
Emissions Trading	Permits	Permits	foreign EIS	foreign NEIS	No	No	-
CDM					Yes	No	-
Deforestation_highTC					Yes	Yes	high
Deforestation_lowTC					Yes	Yes	low

Considering the access to low-cost abatement options in developing countries, scenario *CDM* represents scenario *Emissions Trading* including the option of unlimited CDM offset credit imports by Annex B regions from undertaking CDM projects in non-Annex-B regions. In this setting, both companies covered by linked emissions trading schemes and post-Kyoto governments (i.e. all sectors of the economy) have access to CDM credits.[86]

The model considers the following barriers to CDM projects: first, it features transaction costs for the purchase of CDM credits of 0.5 US$ (1 US$) per ton of CO_2 for energy-intensive (non energy-intensive) sectors of developing countries.[87] Second, following Böhringer and Löschel (2008) country-specific investment risk for CDM projects, e.g. from country and project risks, is derived by region-specific bond-yield spreads between long-term government bonds of the respective developing country and the United States (as a risk-free reference region). It is assumed that investors are risk-neutral and discount the value of emissions reduction credits generated by CDM projects with the mean risk value of the respective host country. The underlying data stems from the International Monetary Fund's International Financial Statistics (IMF, 2000). Third, a CDM adaptation tax is incorporated amounting to two percent of CDM revenues as proposed under the Marrakech Accords (UNFCCC, 2002). CDM transaction costs, investment risk and the CDM tax enter the model via a premium on

[86] The amending directive linking the EU ETS with the Kyoto Protocol's project-based mechanisms grants European companies to generate emissions reductions via the CDM and use the associated credits as a substitute for EU allowances (EU, 2004).

[87] The magnitude of transaction costs is in line with recent estimates (see Michaelowa and Jotzo, 2005).

marginal abatement costs of CDM host countries, thereby increasing the international CDM credit price.[88]

Finally, the two scenarios *Deforestation_highTC* and *Deforestation_lowTC* represent scenario *CDM* including the access for all sectors of industrialized economies to carbon abatement options in tropical rainforest regions. These scenarios consider all institutional barriers to offset crediting as mentioned above. By reducing emissions from deforestation and degradation (REDD) the four tropical regions may export carbon-offset credits to Annex B regions. As noted in Sections 7.1.1 and 7.1.2, the two scenarios are distinguished by assuming high and low transaction costs of forestry projects, respectively. This is the most integrated climate policy scenario, facilitating not only CDM access but also international trading of offset credits from reduced deforestation on the carbon market.

In the following, alternative scenario combinations of the regional and institutional climate policy dimension are implemented in the carbon-market model. For example, scenario combination *CDM [EU^+]* represents linked emissions trading schemes and government emissions trading among EU^+ regions including CDM access for all sectors of the participating economies, while all other regions fulfil their emissions reduction targets by cost-efficient domestic action only.

7.3 Simulation results

In this section we simulate the impacts of reducing deforestation and trading emissions on the post-Kyoto carbon-market in 2020 using the numerical model of the global carbon market (as presented in Section 7.1.2) that incorporates carbon abatement cost data from the numerical forestry model (as presented in Section 7.1.1). We start the discussion of results with the economic impacts for Annex B regions, before turning to the implications for CDM host countries and tropical rainforest regions. Finally, we address the implications of reduced deforestation for the case of more ambitious carbon constraints. All tables presenting the numerical simulation results are compiled in Appendix 7.5.3.

[88] An alternative approach to account for barriers to CDM project development is presented in Kallbekken et al. (2006), who introduce a “participation rate” reflecting that only some share of the potentially profitable CDM projects will be implemented.

7.3.1 Impacts on the international permit price

Emissions trading among Annex B regions

Focusing first on the emissions market equilibrium in 2020 in the absence of developing countries, Table 50 in the Appendix shows that for Annex B carbon trading (institutional scenario *Emissions Trading*) the permit price crucially depends on the regional scenario and differs between energy-intensive sectors (EIS) and non-energy-intensive sectors (NEIS). The table shows that for emissions trading among EU Member States only (regional scenario *EU)* the carbon price amounts to roughly 55 € per ton of CO_2 in EIS covered by the EU ETS, whereas it results in 248 € on the parallel carbon market for EU governments that represent their NEIS. Generally, the sectoral permit price is determined both by the stringency of emissions reduction requirements and marginal abatement costs in the respective industries. Since in our case the EU carbon constraints on energy-intensive sectors (as imposed by the allocation factors within the EU ETS) and non-energy-intensive industries (as imposed by the effective national reduction requirement) are comparable, it is the more costly abatement options in European NEIS that lead to a much higher carbon price than in EIS.[89]

By including Canada, Japan and the Former Soviet Union on the carbon market (yielding regional scenario EU^{+}), the international permit price substantially decreases to 28 € and 89 € per ton of CO_2 in the two sectors. In this setting, the three non-EU regions can trade carbon permits with European economies both within linked emissions trading schemes (among EIS) and on the post-Kyoto government carbon market (among NEIS). The lower carbon price originates from two sources. First, despite of the relatively costly emissions abatement options in Japan and Canada, their comparably low national reduction targets and loose allowance allocation to energy-intensive industries results in relatively low *levels* of marginal abatement costs in EIS and NEIS.[90] This limits the permit demand of these two regions on the carbon market. Second, as a region in economic transition the Former Soviet Union features relatively low-cost abatement options as compared to the EU, Japan and Canada. It thus represents a major supplier of carbon permits on the linked emissions market by reducing emissions below BAU levels. Note that we abstract from the allocation of potential excess permits to the covered ETS companies in the Former Soviet Union, so that the lower permit price in scenario EU^{+} only originates from low-cost abatement options in this region.

[89] For regional allocation factors and effective national reduction requirements see again Table 48 and Table 49.
[90] An assessment of marginal abatement costs across OECD countries is presented in Criqui et al. (1999).

Figure 5 illustrates that establishing the most integrated emissions trading system including Australia and the United States (regional scenario EU^{++}) causes the carbon price to decrease further in 2020, resulting in 19 € and 78 € per ton of CO_2. These efficiency gains on the enlarged carbon market originate from an increased supply of emissions permit by Australia and the United States, who impose the lowest national reduction targets and highest relative allowance allocation to their energy-intensive industries. Furthermore the United States feature relatively low-cost abatement options. Consequently, the two regions exhibit marginal abatement cost levels that are lower than the permit price on the original emissions market (regional scenario EU^{+}) and thus join the Former Soviet Union as carbon permit exporters – both within linked emissions trading schemes and on the post-Kyoto government carbon market. However, in all regional settings of institutional scenario *Emissions Trading* the parallel carbon markets of EIS and NEIS are still separated (and sectoral permit prices different), as international trading is feasible only between the same sectors of the participating economies.

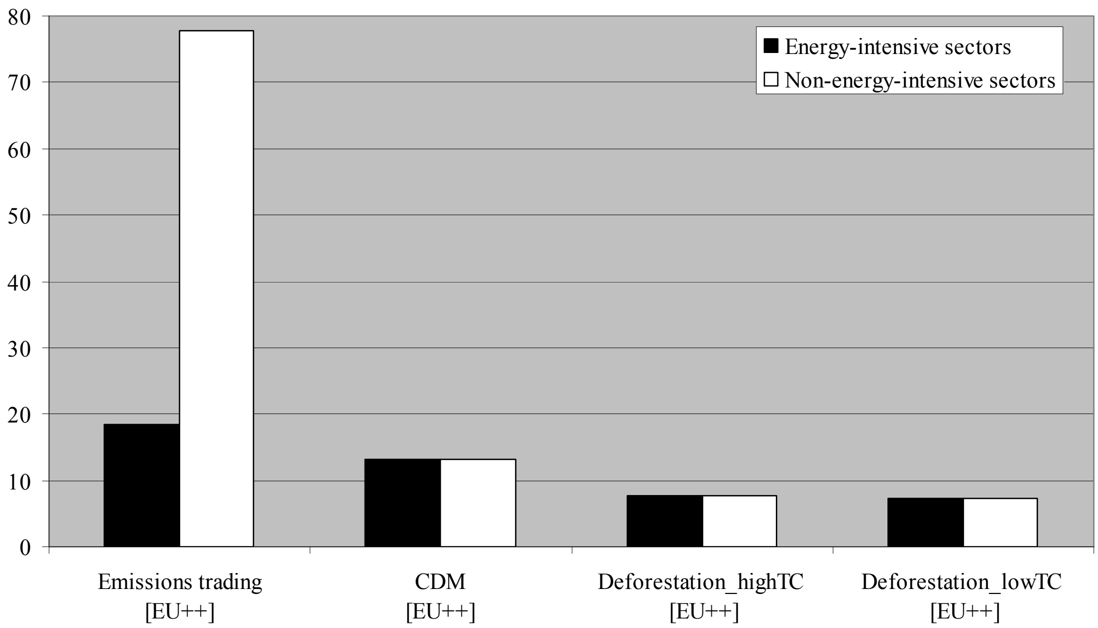

Figure 11: International carbon permit price for regional scenario EU^{++} by sector and institutional scenario (€2005 per ton CO_2)

Crediting carbon abatement via the CDM

Generating emissions reduction credits in developing countries via CDM projects may serve as a substitute for emissions permits traded between industrial countries. Figure 5 presents an interesting pattern of permit prices arising from CDM access for Annex B countries (see institutional scenario *CDM*). First it shows that the access to low-cost abatement in developing countries drastically decreases the permit price in the most integrated emissions market to roughly 13 € per ton of CO_2. As the resulting permit price is lower than both sectoral carbon price levels on the original Annex B market, this yields a sectorally uniform carbon price which de facto interconnects the formerly separated carbon markets of linked emissions trading schemes (among EIS) and post-Kyoto governments (among NEIS). The CDM thus yields not only large efficiency gains by decreasing the permit price, but establishes full where-flexibility of carbon abatement between sectors and regions. Moreover, the carbon price decreases more in the high-cost NEIS by CDM, underlining the economic importance of CDM access for Annex B governments. Table 50 in the Appendix finally shows that in the case of CDM access the carbon price is the higher, the more Annex B parties are involved in international emissions trading (i.e. lowest in a purely EU trading regime). Clearly, the increased number of participants on the carbon market with higher marginal abatement costs than developing countries drive up the CDM credit demand from EIS and NEIS and thereby increase the carbon price level.

Crediting carbon abatement from reduced deforestation

When the import of low-cost carbon abatement from developing countries is not only feasible via the CDM but also by crediting carbon abatement from avoided deforestation, the international permit price further decreases. Figure 5 shows that even when accounting for high transaction costs of forestry projects, issuing tradable carbon-offset credits for avoided deforestation reduces the sectorally uniform carbon price by more than 40 percent in 2020. The resulting price level amounts to less than 8 € per ton of CO_2 on the EU^{++} carbon market (see scenario *Deforestation_highTC*). The reason is that the relatively low returns of land use and forest products in tropical regions imply a low opportunity cost of reducing deforestation, so that its marginal abatement costs are lower than the incremental costs of conventional carbon abatement options in CDM host countries. The higher level of competition on the supply side of the emissions market thus decreases the international permit price. In the following sections we will see how the possibility of exporting carbon-offset credits from reduced deforestation for tropical rainforest regions affects the competitive position of CDM host countries on the carbon market. Furthermore, Figure 5 suggests that the carbon price differences between the cases of high and low transaction costs amount to roughly 5 percent (carbon prices of 7.6 and 7.2 € per ton of CO_2, respectively). Regarding the permit price impacts in alternative regional trading constellations, Table 50 in the Appendix shows that – as in the case of CDM access for Annex B countries – the carbon price will be the higher, the more Annex B parties are involved in international emissions trading (ranging from 5 to 8 € per ton of CO_2 across regional scenarios).

7.3.2 Emissions reductions and permit trade flows

In the following we assess the regional emissions reductions and permit flows on the global carbon market for our alternative climate policy scenarios. Table 52 in the Appendix presents the associated numerical simulation results. It shows that domestic reductions of Annex B carbon emissions generally decrease for regionally enlarged international emissions trading and are substantially diminished when industrialized countries are granted access to carbon-offset credits via the CDM. Clearly these effects correspond to the decreasing permit price across scenarios, diminishing the incentives for domestic carbon abatement. We find that integrating reduced deforestation further cuts Annex B emissions reductions and induces large abatement efforts in tropical rainforest regions. On the most integrated carbon market (regional scenario EU^{++}) Africa reduces almost two thirds of its carbon emissions from deforestation – even when accounting for high transaction costs – followed by Central and South America (16 and 15 percent reduction) and South-East Asia (8 percent).[91]

These regional emissions abatement patterns translate into international permit flows on the post-Kyoto carbon market. For transparency abstracting from emissions trading among Annex B regions only, Figure 12 illustrates imports and exports of carbon-offset credits on the most integrated emissions market (regional scenario EU^{++}). It shows that the aggregate Annex B region imports more than one gigaton of CO_2 from low-cost abatement options in CDM host countries. Moreover, Annex B imports of CDM credits are much higher in non-energy-intensive sectors that feature more costly abatement options (see Table 52 for trade flows at the sectoral level). We find that industrialized regions increase their imports of carbon-offset credits by more than 40 percent when, additional to the CDM, reduced deforestation is included into international emissions trading. The volume of offset-credit imports is even higher when transaction costs of forestry projects are low.

[91] Note than in the table, emissions reductions of the four tropical rainforest regions only refer to reduced deforestation.

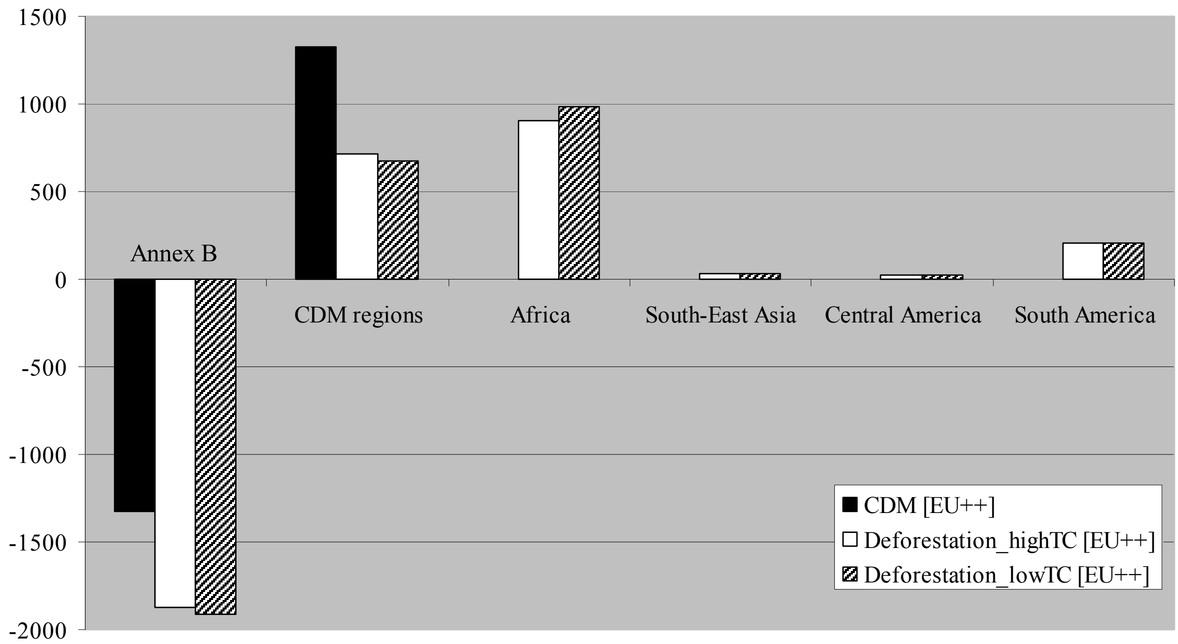

Figure 12: Offset credit exports (positive) and imports (negative) by region and scenario (Mt CO_2)

Figure 12 further illustrates that crediting carbon abatement from reduced deforestation is disadvantageous for traditional CDM host countries that feature only conventional abatement options. When tropical rainforest regions increase the supply of low-cost carbon abatement on the emissions market, aggregate permit exports of CDM regions decrease by roughly 50 percent. In this case, Africa represents the dominant supplier on the carbon market, featuring a larger export volume than all CDM regions together (amounting to almost one gigaton of CO_2). Among the regions reducing deforestation, Africa is followed by South America and South-East Asia in terms of credit-export volume. Finally, Figure 12 suggests that the export activity of tropical regions is more pronounced in the case of low forestry transaction costs: for Africa, offset-credit exports are almost ten percent higher.

7.3.3 Compliance costs and benefits from carbon trading

Economic impacts for industrialized regions

In the following we assess the overall compliance costs of carbon regulation and the potential benefits from reducing deforestation and trading emissions in 2020. Focusing first on industrialized countries, Figure 3 shows the resulting compliance costs for regional constellation EU^{++} associated with fulfilling the national Annex B emissions reduction targets across institutional scenarios (all numerical results are compiled in Table 53 of the Appendix).

Reflecting the sectorally heterogeneous marginal abatement cost levels and permit prices under pure Annex B emissions trading, we find that economic adjustment costs of NEIS amount to more than three times the compliance costs of EIS.

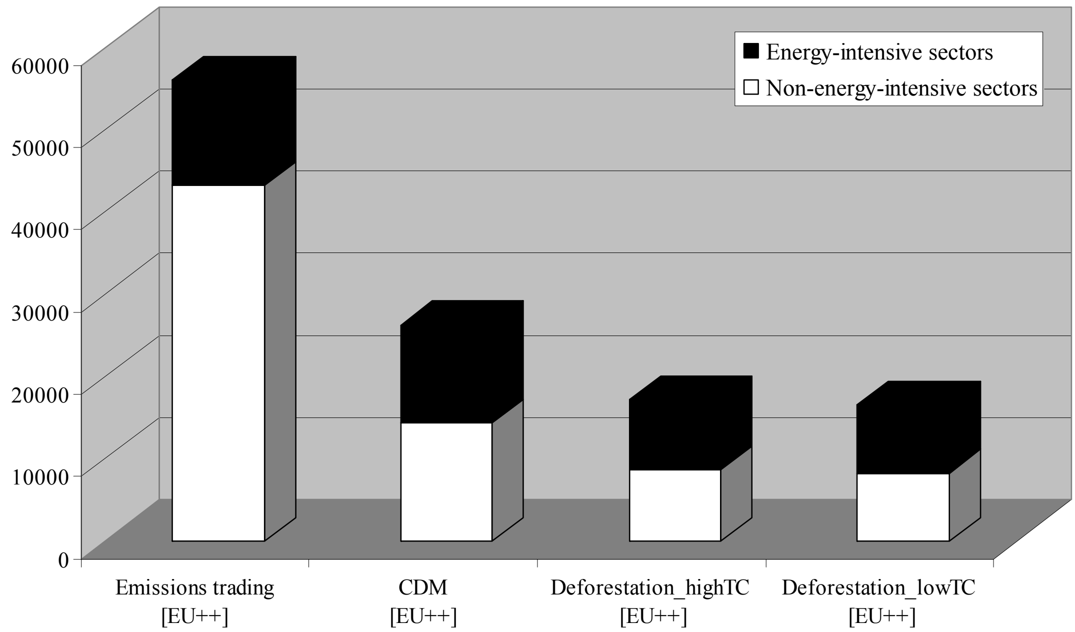

Figure 13: Annex B compliance costs by sector and scenario (million €2005)

The figure shows that the access to low-cost emissions abatement in CDM host countries decreases overall Annex B compliance costs by more than 50 percent. As the high-cost NEIS benefit more from project-based emissions crediting in developing countries through their national governments, the CDM diminishes the previous difference in sectoral economic burdens under pure emissions trading. Most importantly, we find that integrating avoided deforestation into international emissions trading induces a further substantial decrease in the costs of post-Kyoto climate policy. Total Annex B compliance costs fall by more than one third if also tropical rainforest regions may export carbon-offset credits to the industrialized world. As in the case of the CDM, it shows that NEIS of Annex B regions are benefiting to a larger extent from the access to credits from reducing deforestation than EIS, largely aligning the economic compliance burden of the two sectors in industrialized countries.

Figure 3 further suggests that consistent with the permit price impact of transaction costs related to forestry projects, their effect on overall costs is considerable: total compliance costs are resulting almost five percent higher in the case of high transaction costs as compared to low transaction costs. Finally, the numerical results in Table 53 imply that both the beneficial impact of crediting reduced deforestation and the cost-increasing impact of transaction costs are attenuated in the case of less integrated emissions trading systems (i.e. in regional scenarios *EU* and *EU*$^{+}$), as the demand for carbon-offset credits is lower in these regional constellations.

Economic impacts for developing regions

We now turn to the overall carbon-market impacts of climate policy in 2020 for developing countries. For transparency focusing on institutional scenarios involving the CDM and reduced deforestation with high transaction costs, Figure 14 shows negative compliance costs (i.e. net revenues) for regions which are exporters of permits on the international carbon market: the five CDM host countries, the four tropical rainforest regions and, for the sake of illustration, also the Former Soviet Union.[92]

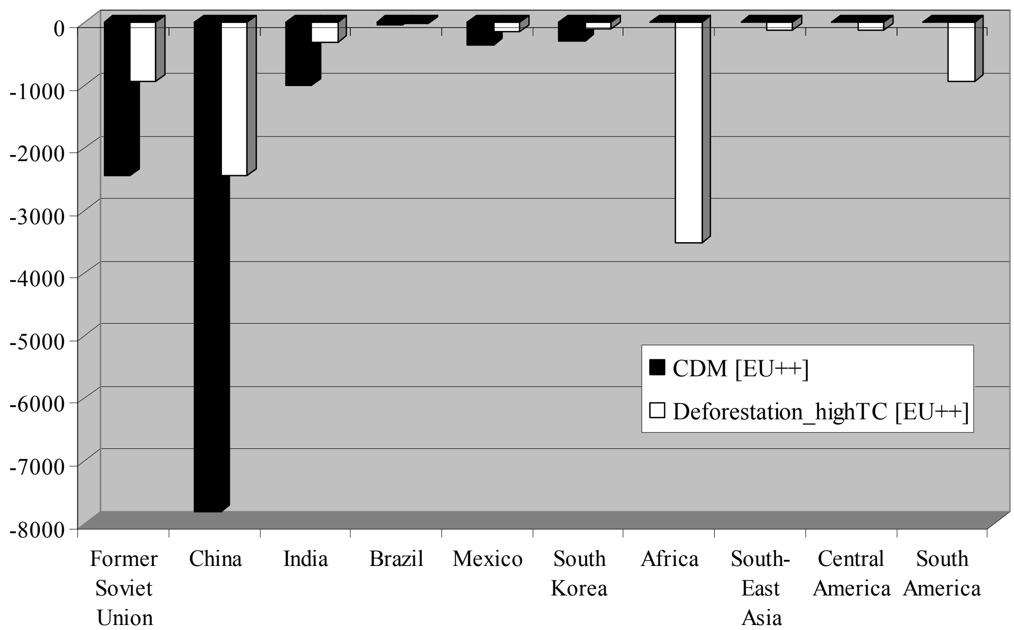

Figure 14: Compliance costs for developing regions by region and scenario (million €2005)

For the most integrated emissions trading system (regional scenario *EU*$^{++}$) the figure suggests that – consistent with the impacts on regional permit flows – including avoided deforestation in international emissions trading results in disadvantageous carbon-market impacts on the original carbon permit exporters. As soon as tropical rainforest regions may export carbon-offset credits to the industrialized world, the Former Soviet Union and all five CDM host countries face substantially decreased revenues on the carbon market. While net benefits of the Former Soviet Union decrease by more than half, China, India and Brazil even face revenue losses of more than two thirds, even when accounting for high transaction costs of forestry projects. The increased competition on the emissions market decreases both the permit price and net revenues for the original permit exporters. Instead, tropical rainforest regions receive large net benefits from reducing deforestation, as their revenues from exporting the associated carbon-offset credits exceed their abatement costs in terms of foregone revenues from land use and forest product sales. Figure 14 indicates that the impact of avoided deforestation on the carbon market is large enough for Africa to replace China as the most benefiting permit supplier.

7.3.4 The role of the deforestation baseline

The economic implications of crediting forest conservation may be substantially influenced by the baseline against which the reductions in deforestation are measured. Obviously, higher deforestation baselines *ceteris paribus* imply higher levels of credited carbon abatement and vice versa. In this section we investigate this issue by simulating net carbon stock changes for alternative deforestation baselines with the numerical model of the forestry sector described in Section 7.1.1. For the sake of illustration we focus on alternative baselines for one exemplary tropical rainforest region, South America, assume CDM access for Annex B regions and median transaction cost values of forestry projects. From the results of Monte-Carlo simulations we choose the 5th and 95th percentile values (implying low and high deforestation baselines) of carbon stock changes for a sequence of carbon prices in 2020 and estimate the alternative marginal abatement cost coefficients for South America by the procedure described in Section 7.1.2. The resulting cost coefficients are presented in Table 47 of the Appendix.

Table 51 in the Appendix presents the resulting carbon-market implications in terms of the carbon price emerging from low and high deforestation baselines (scenarios *Deforestation_lowBase and Deforestation_highBase*). The simulation results show that a high baseline of South America results in an international permit price that is more than five percent lower than for a low baseline of deforestation. Clearly, the higher volume of generated carbon-offset credits supplied to the carbon market for a high deforestation baseline

[92] Note that in the figure, the net revenues for the regions Brazil and Mexico only originate from CDM projects, while the numbers for Central and South America only include net revenues from reduced deforestation. For these regions, the carbon-market implications of the two scenarios would counteract on an aggregate level.

leads to a decrease in the permit price. Figure 15 illustrates how these carbon price impacts translate into changes in trade flows of emissions permits for the most integrated emissions trading system.

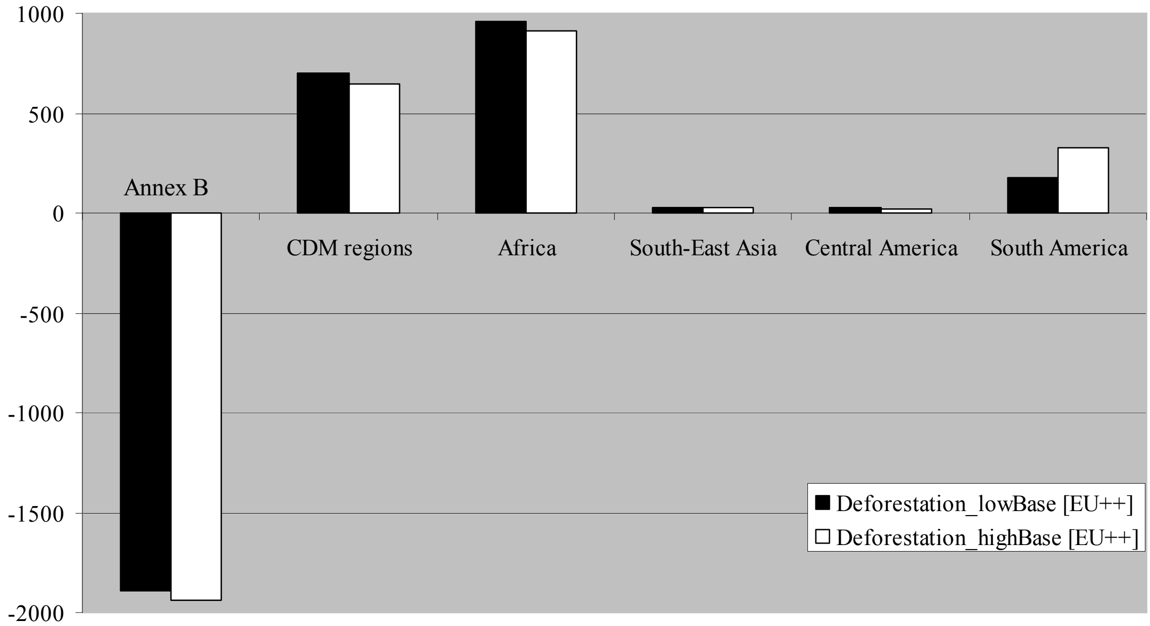

Figure 15: Offset credit exports (positive) and imports (negative) by region and scenario (Mt CO_2)

While industrialized countries import slightly more carbon-offset credits from the developing world in the case of a high deforestation baseline, traditional CDM host countries face lower permit exports due to the larger supply of low-cost carbon credits on the emissions market. Most importantly, South America's exports of carbon-offset credits to Annex B countries are more than 80 percent higher for a high deforestation baseline, causing the permit exports of the competing tropical rainforest regions Africa, South-East Asia and Central America to drop by five to eight percent. These results are underlined by the emissions reductions in

Table ***54*** of the Appendix, implying that South America almost features double the amount of abatement from reduced deforestation for a high baseline.

Table ***54*** further shows that South America receives more than 50 percent higher net revenues from avoiding deforestation and exporting the associated offset credits in the case of a high baseline, while the three remaining tropical rainforest regions face lower benefits on the carbon market. Moreover, the simulations results across regional scenarios imply that the economic differences between high and low deforestation baselines become more pronounced in more integrated regional emissions trading constellations, as then both the international permit demand and the carbon price are higher. We conclude that uncertainties in deforestation baselines play an important role for the carbon market, even when concerning a single region only. However, our results suggest that while alternative baseline levels of one region do affect the economic impacts for the remaining rainforest regions via the carbon market, they are most substantial for the respective region itself.

7.3.5 Tightening Annex B carbon constraints

The previous sections showed that crediting carbon abatement from reduced deforestation represents an important mechanism for cost-efficient climate policy. However, the low-cost carbon abatement option of reduced deforestation may not only improve economic efficiency for the achievement of given global carbon constraints. It may also increase environmental effectiveness by enabling industrialized countries to tighten their carbon regulation at a given level of mitigation costs. In the following, we analyze this role of tropical forest conservation in greater detail.

We start with a more ambitious climate policy setting by suggesting more stringent carbon constraints of Annex B regions in 2020: as compared to the national emissions reduction targets presented in Appendix 7.5.2, industrialized countries are assumed to decrease their national emissions budgets granted by a post-Kyoto agreement by five percent. Consistently, we also tighten regional allocation factors within domestic emissions trading schemes by five percent. In the following, we compare two policy cases: (i) the original carbon constraints as presented in Appendix 7.5.2 including only CDM access for Annex B countries and (ii) five percent tighter carbon constraints including additional Annex B access to carbon-offset credits from reduced deforestation. Table 55 in the Appendix presents the resulting compliance costs by region and scenario. We find that for the most integrated emissions trading system (regional scenario EU^{++}) total compliance costs of the aggregate Annex B region result in comparable levels for case (i) and case (ii), amounting to 26.3 and 25.9 billion € respectively, even when accounting for high transaction costs of forestry projects. The access to carbon-offset credits from reduced deforestation enables the industrialized world to tighten its carbon constraints substantially at similar levels of mitigation costs.

However, Table 55 implies that these comparable effects on the aggregate Annex B level originate from heterogeneous cost effects across regions. While permit importers benefit from the access to low-cost abatement options from reducing deforestation despite of the stricter emissions reduction targets, those Annex B regions exporting permits to others (such as

Eastern European economies or the Former Soviet Union) face higher compliance costs in case (ii). For these countries, the combination of lower revenues from permit sales (due to the higher aggregate permit supply) and stricter reduction targets results in economic losses. Moreover, we find divergent impacts of tightening Annex B carbon constraints at the sectoral level: while for energy-intensive industries the cost-increasing tightening of allowance allocation within linked ETS cannot be compensated by the access to offset credits from reducing deforestation, non-energy-intensive sectors experience a beneficial effect in regional scenario EU^{++}.

In less integrated emissions trading systems (regional scenarios *EU* and EU^{+}) total compliance costs are substantially even *lower* for the respective participants in the case of stricter climate policy and the access to carbon abatement from reduced deforestation. In these regional constellations the global demand for carbon-offset credits is lower, so that the cost-decreasing impact of reduced deforestation is stronger. This effect is underlined by Table 56 in the Appendix, which shows lower carbon prices for less integrated trading scenarios. An international climate regime with less Annex B participants could thus tighten regional carbon constraints by an even greater extent than five percent at constant mitigation costs, when the access to carbon abatement from reduced deforestation is facilitated.

7.4 Conclusions

Among future strategies to combat global warming, the reduction of tropical deforestation and the preservation of carbon-absorbing rainforests have gained increasing attention. This paper quantitatively assessed the implications of crediting carbon abatement from reduced deforestation for the global emissions market in 2020. In the framework of a post-Kyoto climate policy agreement, tropical rainforest regions would be able to export carbon-offset credits from reduced deforestation to the industrialized world. For our quantitative assessment we linked a numerical multi-country equilibrium model of the global carbon market with a dynamic model of the forestry sector by explicitly incorporating marginal cost functions of carbon abatement from reduced deforestation.

The simulation results show that integrating avoided deforestation into international emissions trading substantially decreases the costs of post-Kyoto climate policy. We find that the international carbon permit price is almost halved due to the low-cost credit supply from tropical rainforest regions. Consequently, total compliance costs for industrialized countries are decreased by more than one third if tropical rainforest regions may export carbon-offset credits to the industrialized world – even when accounting for conventional low-cost abatement options in developing countries via the CDM. Decomposition of these effects at the sectoral level shows that the compliance cost savings from crediting reduced deforestation are more substantial for non-energy-intensive sectors of Annex B countries, as these industries originally feature relatively high marginal abatement costs.

At the same time, tropical rainforest regions receive substantial net revenues from exporting carbon-offset credits from reducing deforestation to the industrialized world. However, as a consequence of including forestry management in the carbon market CDM host countries face decreasing revenues due to the increased competition for carbon-offset credit supply. Regarding international permit flows, we find that Africa represents the dominant supplier of carbon-offset credits from avoiding deforestation, reducing emissions from deforestation by roughly two thirds and exporting almost one gigatonne of CO_2. Africa is followed by South America, South-East Asia and Central America as secondary carbon credit exporters.

Regarding institutional barriers to reducing deforestation, we find that transaction costs of forestry projects arising from search, negotiation or insurance costs increase the international carbon price to a considerable extent. High levels of transaction costs may thus decrease the permit export activity of tropical rainforest regions, thereby increasing Annex B compliance costs by almost five percent. Furthermore, we show that the impact of forestry transaction costs generally increases with the number of Annex B countries participating in international emissions trading due to the higher global demand for carbon-offset credits.

The economic implications of crediting carbon abatement from avoided deforestation may be substantially influenced by the baseline against which the reductions in deforestation are measured. Simulating the economic implications for the case of South America, we find that deforestation baselines play an important role for the carbon market – even when concerning only a single region. South America almost doubles its exports of carbon-offset credits and receives more than 50 percent higher net revenues on the carbon market in the case of a high deforestation baseline. A higher baseline of one region also affects the economic impacts for others via the carbon market: both the remaining tropical rainforest regions and traditional CDM host countries exhibit lower permit exports.

Finally, the low-cost carbon abatement option of reduced deforestation may not only improve economic efficiency for the achievement of given global carbon constraints: it may also increase environmental effectiveness by enabling Annex B countries to strengthen their carbon regulation. Our simulation results show that crediting carbon abatement from reduced deforestation enables the industrialized world to tighten its carbon constraints by at least five percent – at constant levels of mitigation costs for post-Kyoto climate policy.

7.5 Appendix

7.5.1 Marginal abatement cost coefficients

Table 45: Conventional abatement options: Marginal abatement cost coefficients in 2020 (€2005)

Regions	Energy-intensive sectors (EIS)			Non-energy-intensive sectors (NEIS)		
	$\beta_{1,EIS,r}$	$\beta_{2,EIS,r}$	$\beta_{3,EIS,r}$	$\beta_{1,NEIS,r}$	$\beta_{2,NEIS,r}$	$\beta_{3,NEIS,r}$
Austria	21.1480	-3.3392	0.8094	11.4095	2.8620	-0.1012
Belgium	2.8430	-0.0984	0.0026	5.8176	0.1881	0.0176
Denmark	11.1840	-0.5817	0.0235	59.6656	-12.7515	5.7710
Finland	3.0710	-0.0566	0.0032	75.2956	-14.0624	1.5541
France	0.9439	-0.0078	0.0002	1.5191	0.0784	-0.0007
Germany	0.3668	-0.0017	0.0000	0.9417	0.0111	0.0000
Greece	1.8843	-0.0118	0.0005	30.8964	-1.6083	0.3375
Ireland	3.0683	-0.1585	0.0110	23.4662	-0.3972	0.2788
Italy	0.9413	0.0036	0.0001	2.5992	0.1511	-0.0005
Netherlands	0.8665	0.0393	-0.0004	10.9863	-0.4063	0.1088
Portugal	11.0386	-0.5740	0.0175	56.1921	-9.2007	2.4941
Spain	0.8090	-0.0097	0.0002	10.3924	-0.4192	0.0137
Sweden	7.7433	-0.2814	0.0102	12.5684	1.7070	0.3807
United Kingdom	0.4066	-0.0022	0.0000	1.4731	0.0244	-0.0001
Central Europe	0.1466	0.0001	0.0000	0.7554	0.0008	0.0000
Canada	0.2766	0.0007	0.0000	0.8316	0.0044	0.0001
Japan	0.2666	0.0023	0.0000	1.3130	0.0313	-0.0001
Former Soviet Union	0.0218	0.0002	0.0000	0.1075	0.0004	0.0000
Pacifc OECD	0.7244	-0.0094	0.0001	1.8636	-0.0315	0.0005
United States	0.0245	0.0000	0.0000	0.1453	0.0000	0.0000
Brazil	11.5525	-0.0631	0.0001	4.1163	0.0006	0.0004
China	0.0129	0.0000	0.0000	0.3052	-0.0004	0.0000
India	0.0960	-0.0001	0.0000	2.2685	-0.0346	0.0008
Mexico	0.0116	0.0191	-0.0001	0.3852	0.0204	-0.0001
South Korea	0.3405	-0.0011	0.0000	4.1598	-0.0027	0.0010

Table 46: Avoided deforestation: Marginal abatement cost coefficients in 2020 (€2005)

Regions	High transaction costs			Low transaction costs		
	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$
Africa	0.0175	-0.0001	0.0000	0.0191	-0.0001	0.0000
South-East Asia	0.2234	-0.0018	0.0000	0.1993	-0.0004	0.0000
Central America	0.2467	-0.0021	0.0000	0.2197	-0.0004	0.0000
South America	0.0303	0.0000	0.0000	0.0270	0.0000	0.0000

Table 47: Avoided deforestation – alternative baseline for South America: Marginal abatement cost coefficients in 2020 (€2005)

Regions	Low baseline			High baseline		
	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$	$\beta_{1,r}$	$\beta_{2,r}$	$\beta_{3,r}$
Africa	0.0175	-0.0001	0.0000	0.0191	-0.0001	0.0000
South-East Asia	0.2234	-0.0018	0.0000	0.1993	-0.0004	0.0000
Central America	0.2467	-0.0021	0.0000	0.2197	-0.0004	0.0000
South America	0.0158	0.0005	0.0000	0.0166	0.0000	0.0000

7.5.2 Incorporation of carbon market data

Three central inputs are incorporated into the carbon market model: baseline emissions, emissions reduction commitments and allowance allocation associated with a potential post-Kyoto climate policy regime. Baseline, or business-as-usual (BAU), carbon dioxide emissions trajectories are based on van Vuuren et al. (2006) who provide a nationally downscaled dataset from the implementation of the global IPCC-SRES scenario B2 (IPCC, 2000) into the environmental assessment model IMAGE 2.2.

Emissions reduction targets

In order to analyze future climate policy scenarios we first have to assume regional emissions reduction commitments for the year 2020. Under the Kyoto Protocol, industrialized countries (listed in Annex B of the agreement) committed to cut their greenhouse gas emissions by 5.2 percent on average during 2008-2012 as compared to 1990 levels (UNFCCC, 1997). The EU Kyoto target of eight percent was then redistributed by an internal Burden Sharing Agreement among EU Member States (EU, 1999). Motivated by its ambitious current climate policy goals the EU is assumed to commit to a 20 percent emissions reduction versus 1990 levels in 2020 (EU, 2007a). We adopt the burden-sharing approach also for this ambitious future EU target, so that the aggregate EU commitment of effectively 27.2 percent versus business-as-usual emissions levels in 2020 implies very heterogeneous effective reduction targets across EU Member States. Given the leadership role of current European climate policy, non-EU regions are assumed to commit to less stringent emissions targets. Canada and Japan, who have ratified the Kyoto Protocol early, both assume a 20 percent effective reduction target versus business-as-usual emissions levels in 2020. The recent Kyoto-ratifier Australia and the non-ratifier United States commit to an effective reduction target of 15 percent versus BAU. Having received excess emissions permits under the Kyoto Protocol, the Former Soviet Union is assumed to hold its emissions constant in 2020, so that the phenomenon of “Hot Air” is not existent.[93]

For non-Annex B regions no emissions reduction commitments are assumed, as developing countries have so far refrained from assuming any quantified targets under the Kyoto Protocol. As the inclusion of these countries under the CDM or a regime crediting reduced deforestation requires a baseline, all developing regions are assigned their BAU emissions.

[93] Our assumption of an existing binding international agreement in 2020 building on the Kyoto Protocol abstracts from long-term stability aspects of such agreements. For a comprehensive introduction into related game-theoretic approaches to international environmental agreements see Finus (2001).

Table 48 lists regional carbon dioxide emissions from energy and industry for 1990 (the reference year of the Kyoto commitments), as well as projected emissions for 2010 (the central year of the first Kyoto compliance period) and 2020. The table further shows the resulting emissions reduction requirements in 2010 and 2020 versus 1990 emissions levels, as well as the effective reduction requirements in 2020 versus BAU emissions levels in 2020.[94]

Table 48: CO_2 benchmark emissions and reduction requirements by region and year

Regions	CO_2 emissions in 1990 (Mt CO_2)	CO_2 emissions in 2010 (Mt CO_2)	CO_2 emissions in 2020 (Mt CO_2)	Reduction requirements in 2010 (% vs. 1990)	Reduction requirements in 2020 (% vs. 1990)	Reduction requirements in 2020 (% vs. 2020)
Austria	59.6	73.4	74.1	13.0	24.3	39.1
Belgium	110.1	142.7	143.9	7.5	19.6	38.5
Denmark	50.4	58.6	59.1	21.0	31.3	41.4
Finland	54.2	64.7	65.2	0.0	13.0	27.7
France	377.3	418.0	421.0	0.0	13.0	22.1
Germany	988.3	954.6	963.0	21.0	31.3	29.5
Greece	75.8	105.5	106.1	-25.0	-8.7	22.3
Ireland	33.0	49.5	49.8	-13.0	1.7	34.9
Italy	417.5	508.4	511.7	6.5	18.7	33.7
Netherlands	158.5	200.3	201.8	6.0	18.3	35.8
Portugal	43.6	74.3	74.7	-27.0	-10.4	35.6
Spain	225.8	349.0	351.1	-15.0	0.0	35.7
Sweden	49.8	49.8	49.8	-4.0	9.6	9.6
United Kingdom	577.4	640.0	646.5	12.5	23.9	32.0
Central Europe	1042.1	893.2	1110.4	-4.8	8.8	14.4
Canada	427.5	597.9	602.3	6.0	-12.7	20.0
Japan	1091.4	1264.8	1168.3	6.0	14.4	20.0
Former Soviet Union	3605.4	2489.4	2764.3	0.0	23.3	0.0
Pacific OECD	292.0	449.7	446.1	(-8.0)	-29.9	15.0
United States	4890.8	6410.1	6500.0	(7.0)	-13.0	15.0
Brazil	214.0	567.4	838.2	-	-	-
China	2495.7	5038.3	6491.2	-	-	-
India	616.1	1764.9	2934.5	-	-	-
Mexico	309.0	572.4	733.7	-	-	-
South Korea	253.7	658.7	853.0	-	-	-

Sources: Netherlands Environment Assessment Agency (Van Vuuren et al., 2006), UNFCCC (1997), EU (2007a); own calculations

Emissions trading schemes and the allocation of allowances

As the most prominent instrument of current European climate policy, the EU Emissions Trading Scheme (ETS) is operating at the installation level in a "warm-up" phase since 2005 (EU, 2003). An important characteristic of the scheme is the exclusive coverage of energy-intensive companies. More recently, the EU has proposed to strengthen the European ETS by linking the scheme to emerging trading systems beyond Europe in order to achieve its climate policy objectives more cost-efficiently (EU, 2007c). At the same time, several non-EU

[94] Note that in our analysis Australia is approximated by the model region Pacific OECD.

countries such as Canada, Japan, Australia and the United States are contemplating the set up of domestic ETS with the intention of linking up to the EU ETS (see CEPA Environmental Registry, 2005; Japanese Ministry of the Environment, 2004; Point Carbon, 2006; RGGI, 2007). As these schemes are also expected to cover mainly energy-intensive companies, the EU ETS may form the nucleus for a gradually expanding global emissions trading system for energy-intensive industries.

A central input for our policy assessment is the allocation of emissions allowances for EU Member States and linking candidates, which specifies an overall cap on emissions for those installations covered by the respective trading schemes. Here, we assume that the EU continues its predominant grandfathering method (i.e. the free allocation of allowances) to the covered installations in 2020. Numerically, emissions allocation can be described by so-called allocation factors, i.e. the fraction of baseline emissions that are freely allocated as allowances. In order to derive allocation factors for EU Member States in 2020 we build on empirical allocation data for the second trading period of the EU ETS (2008 to 2012) as published in the National Allocation Plan of each Member State and on recent emissions projections for 2010 (EU, 2007b). For the future trading period in 2020, we assume that the relative allowance allocation is decreased by 20 percent as compared to the second trading period.[95] This yields regional EU allocation factors ranging between 0.55 (Spain) and 0.85 (Sweden), implying emissions reduction requirements for the covered sectors between 45 and 15 percent versus BAU emissions, respectively.

In consistence with our national climate policy targets in 2020, non-EU regions also exhibit a less stringent allowance allocation than the EU for sectors covered by their emissions trading schemes: the early Kyoto-ratifiers Japan and Canada implement an allocation factor of 0.80, while the recent ratifier Australia and the non-ratifier United States allocate emissions allowances based on a factor of 0.85 in 2020. For the Former Soviet Union we assume an allocation factor equal to one in 2020, consistently implying no allocation of excess permits to installations covered by a domestic ETS.[96] Table 49 summarizes all resulting allocation factors for EU and non-EU regions.

[95] Two limitations apply here: Due to lacking information for Bulgaria and Romania, for these countries we start from an allocation factor equal to one in the second trading period. Moreover, allocation factors are chosen so that emissions reductions of the covered sectors do not exceed the respective national reduction requirement (this applies to the regions Greece, Sweden and Central Europe).

[96] Excess emissions permits (so-called “Hot Air”) are due to lower projected baseline emissions than the target level implied by the Former Soviet Union’s reduction commitment in 2020. We abstract from “Hot Air” here, as a grandfathered allowance allocation of “Hot Air” would imply an indirect subsidy for installations of this region

Table 49: Allocation factors by region in 2010 and 2020

Model region	Allocation factor in 2010	Allocation factor in 2020
Austria	0.813	0.650
Belgium	0.943	0.755
Germany	0.876	0.701
Denmark	0.822	0.657
Spain	0.693	0.554
France	0.907	0.726
Finland	1.000	0.800
Greece	0.865	0.692
Ireland	0.750	0.600
Italy	0.849	0.679
Netherlands	0.893	0.715
Portugal	0.839	0.671
Sweden	1.065	0.852
United Kingdom	0.900	0.720
Central Europe	0.928	0.742
Canada	-	0.800
Japan	-	0.800
Former Soviet Union	-	1.000
Pacific OECD	-	0.850
United States	-	0.850

(the allocated permits could be directly exported to other ETS regions). It is not unambiguous if such an ETS design may prevail or even be linked to an EU scheme.

7.5.3 Numerical simulation results

Table 50: Core scenarios: Carbon permit price by scenario and sector in 2020 (€2005 per tCO_2)

Scenario / Scenario	***Emissions Trading***		***CDM***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	54.9	248.2	9.2	9.2
[EU⁺]	27.6	88.7	10.8	10.8
[EU⁺⁺]	18.5	77.7	13.2	13.2
Scenario / Scenario	***Deforestation_highTC***		***Deforestation_lowTC***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	5	5	4.9	4.9
[EU⁺]	5.8	5.8	5.2	5.2
[EU⁺⁺]	7.6	7.6	7.2	7.2

Table 51: Alternative baseline for South America: Carbon permit price by scenario and sector (€2005 per tCO_2)

Scenario / Scenario	***Deforestation_lowBase***		***Deforestation_highBase***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	4.9	4.9	4.7	4.7
[EU⁺]	5.5	5.5	5.3	5.3
[EU⁺⁺]	7.5	7.5	7	7

Table 52: Core scenarios: Total emissions reductions (% of BAU) and sectoral net exports of carbon-offset credits by scenario and region in 2020 (Mt CO_2)

Scenario / Region	**Emissions Trading [EU]**			**CDM [EU]**			**Deforestation_highTC [EU]**			**Deforestation_lowTC [EU]**		
	Reduction TOTAL	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**
EU	54.1	0	0	8.2	-584.9	-522.6	4.6	-659.8	-539.8	4.4	-662.9	-540.6
EU^{+}	35.5	0	0	11.8	-584.9	-522.6	9.9	-659.8	-539.8	9.8	-662.9	-540.6
EU^{++}	33.1	0	0	19.6	-584.9	-522.6	18.5	-659.8	-539.8	18.5	-662.9	-540.6
Africa	0	0	0	0	0	0	26.9	378.6		27.9	392.5	
South-East Asia	0	0	0	0	0	0	4.5	17.3		4.8	18.1	
Central America	0	0	0	0	0	0	9.6	15.1		10.1	15.8	
South America	0	0	0	0	0	0	8.7	123		9.1	128.8	
Scenario / Region	**Emissions Trading [EU^{+}]**			**CDM [EU^{+}]**			**Deforestation_highTC [EU^{+}]**			**Deforestation_lowTC [EU^{+}]**		
	Reduction TOTAL	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**
EU	30.1	0	0	9.6	-398.4	-488.4	5.2	-537.2	-529.5	4.7	-552.6	-533.8
EU^{+}	35.5	0	0	12.3	-477.8	-592.1	7.4	-659.1	-652	6.7	-682.5	-659.4
EU^{++}	33.1	0	0	19.9	-477.8	-592.1	17	-659.1	-652	16.6	-682.5	-659.4
Africa	0	0	0	0	0	0	42.6	599.3		49.8	700.9	
South-East Asia	0	0	0	0	0	0	5.4	20.8		5.2	19.7	
Central America	0	0	0	0	0	0	11.5	18.1		11	17.3	
South America	0	0	0	0	0	0	10.4	147.4		9.9	140.5	
Scenario / Region	**Emissions Trading [EU^{++}]**			**CDM [EU^{++}]**			**Deforestation_highTC [EU^{++}]**			**Deforestation_lowTC [EU^{++}]**		
	Reduction TOTAL	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**	**Reduction TOTAL**	**Credit-Ex EIS**	**Credit-Ex NEIS**
EU	23.6	0	0	11.7	-277.9	-630.1	6.8	-573.8	-677.6	6.5	-589.9	-681.5
EU^{+}	29.2	0	0	14.5	-334.9	-742	9.2	-689.6	-815.4	8.8	-711.3	-821.6
EU^{++}	33.1	0	0	16.4	-368.9	-959.9	9.9	-808.6	-1066.6	9.4	-840.8	-1074.7
Africa	0	0	0	0	0	0	64	901		69.7	981.3	
South-East Asia	0	0	0	0	0	0	7.6	28.9		7.7	29.2	
Central America	0	0	0	0	0	0	16	25.2		16.2	25.5	
South America	0	0	0	0	0	0	14.5	205.2		14.6	207.6	

Table 53: Core scenarios: Compliance costs by scenario, region and sector in 2020 (million €2005)

Region \ Scenario	***Emissions Trading [EU]***			***CDM [EU]***			***Deforestation_highTC [EU]***			***Deforestation_lowTC [EU]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	75487.6	17776.6	57711	11171.8	6166.3	5005.5	6336.1	3557.5	2778.6	6129.9	3443.9	2686
EU^{+}	100954.8	21940.8	79014	36639	10330.5	26308.5	31803.3	7721.7	24081.6	31597.1	7608.1	23989
EU^{++}	120949.2	25431.9	95517.3	56633.4	13821.6	42811.8	51797.7	11212.8	40584.9	51591.5	11099.2	40492.3
Africa	0	0	0	0	0	0	-1042.4			-990.1		
South-East Asia	0	0	0	0	0	0	-54			-55.1		
Central America	0	0	0	0	0	0	-48.2			-49.3		
South America	0	0	0	0	0	0	-391.9			-400.5		

Region \ Scenario	***Emissions Trading [EU^{+}]***			***CDM [EU^{+}]***			***Deforestation_highTC [EU^{+}]***			***Deforestation_lowTC [EU^{+}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	50496.2	14113.6	36382.6	12915.8	7079.5	5836.3	7244.6	4055.3	3189.3	6541	3670	2871
EU^{+}	38944.3	11193.3	27751	14545.6	7407.1	7138.5	8571.8	4558.4	4013.4	7787	4161.6	3625.4
EU^{++}	58938.7	14684.4	44254.3	34540	10898.2	23641.8	28566.2	8049.5	20516.7	27781.4	7652.7	20128.7
Africa	0	0	0	0	0	0	-1708.3			-1585.9		
South-East Asia	0	0	0	0	0	0	-72.9			-63.7		
Central America	0	0	0	0	0	0	-65.1			-56.9		
South America	0	0	0	0	0	0	-529.1			-462.5		

Region \ Scenario	***Emissions Trading [EU^{++}]***			***CDM [EU^{++}]***			***Deforestation_highTC [EU^{++}]***			***Deforestation_lowTC [EU^{++}]***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	43893.6	10827.1	33066.5	15429.9	8365.7	7064.2	9310.1	5174.6	4135.5	8852.7	4928.4	3924.3
EU^{+}	37514.6	10121.9	27392.7	16985.9	8458.5	8527.4	10820.4	5669.2	5151.2	10329.6	5430.2	4899.4
EU^{++}	56108.2	12835.6	43272.6	26293.2	11889.1	14404.1	17258.1	8580.8	8677.3	16503	8252.1	8250.9
Africa	0	0	0	0	0	0	-3522.7			-3705.1		
South-East Asia	0	0	0	0	0	0	-127.7			-124		
Central America	0	0	0	0	0	0	-114.2			-111.1		
South America	0	0	0	0	0	0	-928.7			-903.2		

Table 54: Alternative baseline for South America: Total emissions reductions (% of BAU), sectoral net exports of carbon-offset credits and compliance costs by scenario and region in 2020 (Mt CO_2)

Scenario / Region	***Deforestation_lowBase [EU]***			***Deforestation_highBase [EU]***			***Deforestation_lowBase [EU]***			***Deforestation_highBase [EU]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	4.5	-662	-540.4	4.3	-665.5	-541.2	6186.2	3475	2711.2	5952.4	3346.2	2606.2
EU^+	9.8	-662	-540.4	9.8	-665.5	-541.2	31653.4	7639.2	24014.2	31419.6	7510.4	23909.2
EU^{++}	18.5	-662	-540.4	18.4	-665.5	-541.2	51647.8	11130.3	40517.5	51414	11001.5	40412.5
Africa	28	394.6		24.2	340.7		-1027.8			-886.3		
South-East Asia	4.6	17.6		4.4	16.7		-54			-49.6		
Central America	9.8	15.4		9.3	14.6		-48.2			-44.3		
South America	8.6	121.9		14.2	201.4		-412.3			-610.1		

Scenario / Region	***Deforestation_lowBase [EU⁺]***			***Deforestation_highBase [EU⁺]***			***Deforestation_lowBase [EU⁺]***			***Deforestation_highBase [EU⁺]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	5	-545.6	-531.8	4.8	-551.2	-533.2	6867.9	3849.4	3018.5	6673.5	3743	2930.5
EU^+	7	-671.7	-655.8	6.8	-678.1	-658.1	8152.8	4347.3	3805.5	7935.5	4237.3	3698.2
EU^{++}	16.8	-671.7	-655.8	16.7	-678.1	-658.1	28147.2	7838.4	20308.8	27929.9	7728.4	20201.5
Africa	47.1	662.7		41.9	589.8		-1684.7			-1484.2		
South-East Asia	5.3	20.3		5.1	19.5		-68.1			-64		
Central America	11.3	17.7		10.8	17.1		-60.9			-57.1		
South America	9.5	134.7		16.5	234.5		-503.1			-786.4		

Scenario / Region	***Deforestation_lowBase [EU⁺⁺]***			***Deforestation_highBase [EU⁺⁺]***			***Deforestation_lowBase [EU⁺⁺]***			***Deforestation_highBase [EU⁺⁺]***		
	Reduction TOTAL	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Reduction TOTAL***	***Credit-Ex EIS***	***Credit-Ex NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***	***Costs TOTAL***	***Costs EIS***	***Costs NEIS***
EU	6.7	-578.1	-679	6.2	-600.8	-683.6	9162.1	5094.9	4067.2	8598.4	4791.1	3807.3
EU^+	9	-696.6	-817.5	8.6	-723.3	-824.8	10661.9	5592	5069.9	10054.9	5295.7	4759.2
EU^{++}	9.7	-818.9	-1069.3	9.1	-859	-1078.9	17014.7	8475.2	8539.5	16078.4	8064.8	8013.6
Africa	67.9	956.6		64.9	913.7		-3758.6			-3237.3		
South-East Asia	7.7	29.5		7.1	27.2		-129.1			-112.1		
Central America	16.4	25.8		15.1	23.8		-115.6			-100.3		
South America	12.4	175.4		22.9	325		-868.8			-1376.2		

Table 55: Tighter carbon constraints: Compliance costs by scenario, region and sector (million €2005)

Scenario / Region	***CDM [EU]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	11171.8	6166.3	5005.5	7784.8	4314.7	3470.1
EU$^+$	36639	10330.5	26308.5	47553.3	10874.2	36679.1
EU^{++}	56633.4	13821.6	42811.8	80931.6	16588.1	64343.5
Africa	0	0	0	-1363.4		
South-East Asia	0	0	0	-63.8		
Central America	0	0	0	-57		
South America	0	0	0	-463.1		
Scenario / Region	***CDM [EU$^+$]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU$^+$]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	12915.8	7079.5	5836.3	8752.4	4838.6	3913.8
EU$^+$	14545.6	7407.1	7138.5	11412.9	6049	5363.9
EU^{++}	34540	10898.2	23641.8	44791.2	11762.9	33028.3
Africa	0	0	0	-2075.4		
South-East Asia	0	0	0	-82.7		
Central America	0	0	0	-73.9		
South America	0	0	0	-600.9		
Scenario / Region	***CDM [EU^{++}]*** ***- Original carbon contraints -***			***Deforestation_highTC [EU^{++}]*** ***- Tighter carbon constraints -***		
	TOTAL	***EIS***	***NEIS***	***TOTAL***	***EIS***	***NEIS***
EU	15429.9	8365.7	7064.2	12489	6832.2	5656.8
EU$^+$	16985.9	8458.5	8527.4	15965	8304	7661
EU^{++}	26293.2	11889.1	14404.1	25932.9	12873.1	13059.8
Africa	0	0	0	-5056.7		
South-East Asia	0	0	0	-182.5		
Central America	0	0	0	-163.5		
South America	0	0	0	-1329.3		

Table 56: Tighter carbon constraints: Carbon permit price by scenario and sector (€2005 per tCO_2)

Scenario / Scenario	***CDM*** ***- Original carbon contraints -***		***Deforestation_highTC*** ***- Tighter carbon constraints -***	
	EIS	***NEIS***	***EIS***	***NEIS***
[EU]	9.2	9.2	5.5	5.5
[EU$^+$]	10.8	10.8	6.2	6.2
[EU^{++}]	13.2	13.2	9	9

8 General Conclusions

Global climate change has become a growing international concern. The projected consequences include rising sea levels, melting glaciers and changes in ecological systems. While strong and early action to combat global warming could yield considerable benefits in terms of prevented damages, the economic adjustment costs of climate change policy have traditionally represented a major obstacle to extensive action. As a consequence, industrialized nations have implemented market-based instruments of climate policy such as environmental taxation or tradable emissions permits in order to respond to global warming in a cost-efficient way. The objective of this thesis was to analyze both the political-economy determinants and the economic impacts of climate change policy.

Part I presented a political-economy analysis of climate policy and consisted of three chapters. Chapter 2 investigated the political-economy determinants of environmental tax differentiation across industries. Based on a common-agency model, propositions for tax differentiation within environmental tax reforms that use additional tax revenues to lower labor cost were derived. It was shown how differentiation is not only determined by the activity of lobby groups favoring reduced environmental tax rates, but also by the groups' interest in revenue rebates to labor. An empirical analysis using German data underpinned the theoretical results, explaining environmental tax differentiation by the presence of sectoral interest groups. Besides the activities of lobby groups, market concentration and international trade exposure of industries play an important role for the environmental tax design.

Chapter 3 provided a political-economy analysis of allowance allocation in the EU Emissions Trading Scheme (EU ETS). A common-agency model suggested that a political-support maximizing government allocates an inefficiently large number of permits when considering the preferences of sectoral interest groups besides public interest. As a consequence, the regulatory burden is shifted to those sectors excluded from the trading scheme. Sectoral lobbying for allowances affects the distribution of permits within the scheme, but its impact depends on the level of industrial emissions. An empirical analysis of the first trading phase of the EU ETS corroborated these predictions for a large cross-section of German firms. It was found that the distribution of EU allowances has been partly driven by lobbying activities: firms represented by powerful interest groups were allocated more generously, if simultaneously being exposed to regulation in terms of high emissions levels. However, by inducing a significant deviation of the observed permit allocation from its economically desirable level, lobbying does not only affect the distribution of allowances – it also determines the efficiency of emissions regulation.

Chapter 4 presented a meta-regression analysis of model-based simulation studies assessing the employment effects of environmental tax reforms. Besides the role of central modeling assumptions, the implications of contracting bodies on the simulation results were investigated. The analysis revealed the importance of unobservable study characteristics for the prospects of a simulated double dividend in terms of lower emissions along with higher employment levels. While at first sight specific labor market assumptions and the contracting body seem to play a role for the model outcome, these observable features are no longer decisive when unobservable study features are controlled for. In contrast, the simulated employment impacts of environmental tax reforms were found to be determined by a joint set of modeling features as well as implicit characteristics of the respective publications. Furthermore, the meta-regression suggested that employment levels are negatively affected by the stringency of environmental taxation.

Part II provided an economic impact assessment of climate change policy and consisted of three chapters. Chapter 5 assessed the economic impacts of linking the EU Emissions Trading Scheme to emerging schemes beyond Europe in the presence of a post-Kyoto agreement in 2020. Numerical simulations with a multi-country equilibrium model of the global carbon market showed that linking the European ETS induces only minor economic benefits. As trading is restricted to energy-intensive industries that are assigned high initial emissions, the major compliance burden is carried by the non-trading industries excluded from the linked ETS. In the presence of parallel government trading under a post-Kyoto Protocol, the burden of the excluded sectors can be substantially alleviated by international permit trade at the country level. From an efficiency perspective, the most desirable future climate policy regime is thus represented by a joint trading system facilitating international emissions trading between ETS companies and post-Kyoto governments. While the Clean Development Mechanism (CDM) is not able to attenuate the inefficiencies within linked ETS, in a parallel or joint trading regime the economy-wide access to project-based abatement options of developing countries induces large additional cost savings.

Chapter 6 assessed the efficiency and international trade aspects of linking the EU Emissions Trading Scheme to emerging trading schemes outside Europe. A stylized partial market analysis suggested that independently of the regional cost characteristics, the integration of emissions trading schemes yields economic efficiency gains for all participating regions. A computable general equilibrium analysis confirmed these findings at the macroeconomic level: the welfare losses from emissions regulation of both permit-importing EU Member States and permit-exporting non-EU regions are diminished by linking ETS. However, the quantitative analysis suggested opposite trade-based incentives of linking ETS: while EU Member States improve their terms of trade by integrating with emerging ETS, all non-EU linking candidates face competitiveness losses by linking up. These disadvantageous impacts may only be attenuated when the linked ETS is further extended by additional non-EU regions. Consequently, for non-EU regions the attractiveness of developing supra-European ETS is a matter of priorities for efficiency or international competitiveness.

Chapter 7 quantitatively analyzed the economic implications of crediting carbon abatement from reduced deforestation for the emissions market in 2020 by linking a numerical equilibrium model of the global carbon market with a dynamic model of the forestry sector. It showed that integrating avoided deforestation in international emissions trading considerably decreases the costs of post-Kyoto climate policy – even when accounting for conventional abatement options of developing countries under the CDM. At the same time, tropical rainforest regions receive substantial net revenues from exporting carbon-offset credits to the industrialized world. Furthermore, reduced deforestation can increase environmental effectiveness by enabling industrialized countries to tighten their carbon constraints without increasing mitigation costs. Regarding uncertainties of this future carbon abatement option, both forestry transaction costs and deforestation baselines were shown to play an important role for the post-Kyoto carbon market.

This thesis aimed to contribute to the understanding of the political-economy determinants and the economic impacts of climate change policy. It showed that the design of market-based instruments of climate policy can be explained by the behavior of environmental regulators who maximize their political support. The consideration of the preferences of sectoral interest groups in the regulatory decision can induce economic inefficiencies in terms of a sectoral differentiation of environmental taxes or a too generous allocation of tradable emissions permits to parts of the economy. In turn, the design of climate policy instruments plays a decisive role for the associated economic impacts: The thesis showed that the economic benefits of an international linkage of domestic emissions trading schemes depend on their sectoral scope and the regional stringency of allowance allocation. If designed properly, linked emissions trading systems represent a cost-efficient instrument to achieve global carbon constraints of industrialized nations and alleviate international competiveness distortions. Establishing regional flexibility of emissions abatement via the access to carbon abatement options in developing countries further improves the prospects for a cost-efficient and ambitious implementation of future commitments – and will eventually pave the way for the integration of emerging economies into a global climate policy regime.

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Ehrenwörtliche Erklärung

Hiermit erkläre ich, dass ich diese Dissertation selbständig verfasst und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle gekennzeichnet. Diese Arbeit wurde nicht schon als eine Diplom- oder ähnliche Prüfungsarbeit einer anderen Prüfungsbehörde vorgelegt.

Mannheim, 27. September 2008

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