Sectoral Incidence and Efficiency of Climate Policy

A Quantitative Economic Analysis of Alternative Policy Designs

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To my father

Kurzzusammenfassung

Eine gesellschaftlich akzeptable Klimapolitik darf aus der Sicht der Entscheidungsträger in der EU die Wettbewerbsfähigkeit europäischer energieintensiver Industrien nicht gefährden. Die vorliegende Dissertation bewertet intersektorale Verteilungswirkungen der europäischen Klimapolitik und analysiert verschiedene Politikmaßnahmen zur Vorbeugung potentiell nachteiliger Auswirkungen dieser Politik auf die Wettbewerbsfähigkeit von heimischen energieintensiven Industrien.

Im Rahmen einer ökonometrischen Analyse zeigt die Arbeit im ersten Teil auf, dass das Risiko für europäische Unternehmen, durch die Einführung des EU-Emissionshandelssystems (EU-EHS) an internationaler Wettbewerbsfähigkeit zu verlieren und Produktionsanlagen ins Ausland verlegen zu müssen, seitens der Politik und Industrie tendenziell überschätzt wird. So impliziert zwar die unvollständige Kostenüberwälzung in einigen energieintensiven Sektoren, dass zusätzliche Kosten, die durch die Einführung des EU-EHS den Unternehmen entstehen, nicht in vollem Umfang an die Kunden weitergegeben werden können und daher die Profitmargen reduzieren. Dennoch besteht eine signifikante Gefährdung nur für eine begrenzte Anzahl von Industrien. In der ersten Handelsperiode des EU-EHS profitierten sogar einige Sektoren (z.B. Mineralölindustrie) von der kostenfreien Zuteilung von Emissionszertifikaten, da deren Opportunitätskosten eingepreist und an die Konsumenten weitergegeben werden konnten.

Basierend auf einer numerischen Analyse bewertet die Dissertation im zweiten Teil verschiedene Instrumente zur Vorbeugung potentieller Wettbewerbsnachteile und schlussfolgert, dass diese sich in ihren gesamtwirtschaftlichen Auswirkungen beträchtlich unterscheiden können. Zwar sind die unilateralen klimapolitischen Instrumente – wie etwa intersektorale CO_2-Preisdifferenzierungsstrategien oder verschiedene Formen von Umweltzöllen – in der Lage, die Verluste an Wettbewerbsfähigkeit in energieintensiven Sektoren zu mindern bzw. zu kompensieren. Allerdings können derartige Politikmaßnahmen ökonomische Ineffizienzen verursachen. Eine graduelle Bewegung in Richtung eines globalen CO_2-Handelssystems – etwa durch eine Verknüpfung von Emissionssystemen unter den Industrienationen sowie durch den Zugang zu Vermeidungsoptionen in Entwicklungsländern – stützt im Gegensatz dazu die Wettbewerbsfähigkeit heimischer energieintensiver Industrien, ohne dem Ziel einer kosteneffizienten und global effektiven Klimapolitik zuwiderzulaufen.

Abstract

The EU advocates minimising potentially significant competitiveness losses in energy-intensive industries as a politically feasible approach to climate policy. This thesis analyses industry-distributional effects of European climate policy and evaluates different policy designs tailored to neutralise adverse impacts of ambitious climate actions on competitiveness in domestic energy intensive sectors.

Based on an econometric analysis, the first part of this thesis shows that policy makers and industrial associations tend to significantly overestimate the adverse impacts of the EU Emissions Trading Scheme (EU ETS) on international competitiveness of European energy intensive sectors and the risk of competitiveness-driven carbon leakage. Though the less-than-complete pass-through potential in some sectors implies that additional costs induced by the EU ETS are likely to be partly absorbed through a reduction of profit margins, the severe risk of competitiveness-driven carbon leakage working through this channel exists in few sectors only. During the first trading period of the EU ETS, some sectors (e.g. oil refining industries) were even benefiting from the emissions trading by passing-through opportunity costs of freely allocated allowances to consumers.

The second part of this study evaluates different policies seeking to abate negative effects on competitiveness of domestic energy intensive sectors triggered by the European climate policy. Based on a numerical analysis, it is shown that policy options under investigation may considerably differ in terms of macroeconomic implications. Unilateral policy designs – such as various inter-sectoral CO_2 price differentiation strategies and alternative forms of border adjustments – have the potential to neutralise the adverse implications on competitiveness of energy-intensive industries in Europe. These policy measures can, however, induce economic inefficiencies. The gradual movement towards a global CO_2-regime – through linking emissions trading schemes among the industrialised countries or via an access to abatement options in the developing countries – represents thereby a superior alternative. This option allows realising a cost-efficient and globally effective climate policy while simultaneously minimising the adverse impacts on competitiveness of domestic energy intensive industries.

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1 Introduction

Recent studies on climate change have contributed to a growing awareness of the long-term consequences and have stressed the need for decisive actions to mitigate global warming (IPCC, 2007; Stern, 2007). In responding to this action alert, a new field of research in the environmental and resource economics – the economics of climate change – has focused on economic impacts of climate change, a complex and uncertain externality, and guided policy recommendations on whether and how to tackle the problem by means of positive and normative economic analysis (e.g. Nordhaus, 2007; Weitzman, 2007).

The Kyoto Protocol as the first step towards a global architecture on climate change assigned legally binding greenhouse gas emissions (GHG) limits to industrialised countries during the initial commitment period 2008–2012. It also offered flexibility to trade emissions allowances between developed and developing countries (UNFCCC, 1997). The Protocol has been criticised on several grounds, including its symbolic nature by codifying Business-as-Usual (BaU) emissions in developed countries (Böhringer and Vogt, 2004) and the absence of mandatory emissions limits on (the economically more advanced) developing countries (Goulder and Pizer, 2006). In order to achieve adopted emissions reduction targets under the Kyoto Protocol, the EU and its member states have employed various instruments, with the EU Emissions Trading Scheme (ETS) as a central pillar to the European climate policy. This regulatory framework in the EU is complemented and partly overlapped (Böhringer et al., 2008) by national environmental taxes on energy and emissions (OECD, 2010) and other instruments (rules, standards, etc.).

In standard economic theory of environmental policy, introduction of market-based instruments such as uniform emissions taxes or auctioned tradable permits allows reducing emissions in a cost-efficient manner (e.g. Goulder and Nadreau, 2002). That is by equalising marginal abatement costs across heterogeneous polluters. The reality of environmental policy in the EU is somewhat different: Deviations from the textbook first-base solution such as segmentation of the emissions market, introduction of a trading system with freely and generously allocated allowances and environmental levies that are differentiated between polluters are costly solutions to the climate change problem (e.g. Böhringer et al., 2005; Böhringer and Lange 2005a,b; Böhringer and Rutherford, 1997). Seeking for the rationale behind, Bovenberg and Goulder (2001) and others revealed a potential trade-off between efficiency and political feasibility of climate policy.

Political feasibility in any climate change activities depends crucially on distributional – most notably on *industry-distributional* – impacts (Bovenberg et al., 2008), while interactions between policy makers and organised industrial associations might well shape environmental policy (Anger et al., 2006). This type of distributional considerations is more frequently labelled in both academic and political debate with the term “competitiveness”. In the world with uneven carbon constraints, a widespread concern is as to what extent nations with stringent climate policies will put domestic energy-intensive industries at a disadvantage relative to competitors in countries with a lower level of ambitions in climate actions (EU, 2008). One strand of economic analysis has therefore centred on assessing environment-competitiveness linkages of stringent environmental policies (few examples in this controversial debate: Porter and van der Linde, 1995; Xu, 2000).

A related but distinct concern that bears upon the issues of political feasibility is the risk of carbon leakage which generally refers to the change of emissions in non-abating regions as a reaction to the reduction of emissions in abating regions (e.g. Hoel, 1991; Felder and Rutherford, 1993; more recently: van Asselt and Brewer, 2010; Kuik and Hofkes, 2010). Since several channels of carbon leakage exist (Burniaux and Martins 2000; Paltsev, 2001), the discussion on the political feasibility of climate change policy is occasionally limited to the issue of the competitiveness-driven carbon leakage (Reinaud, 2008). But whether the latter indeed constitutes the most important channel is a controversial issue: While the European Commission stands on this point (EU, 2010a), academic contributions suggest that carbon leakage is rather caused by the so-called energy channel, i.e. lower prices for primary fuels due to the adverse impact on energy demand by unilateral actions, than by competitiveness effects (e.g. Fischer and Fox, forthcoming).

The failure of the negotiations on the post-Kyoto architecture beyond 2012 in Copenhagen last year has amplified the tension in the European climate policy between promoting efficiency, on the one hand, and avoiding severe adverse distributional impacts on key industries (“competitiveness concerns”) and jeopardising environmental effectiveness (“carbon leakage”), on the other hand. The Copenhagen and Cancún Accords made it very likely that the EU leadership in the GHG emissions reduction will prevail not only by 2020, but possibly even beyond this time horizon. As emissions reduction targets in the EU become more stringent – 8 percent less emissions between 2008-2012 under the Kyoto Protocol vs. 20 percent less emissions in 2020, both against the 1990 levels –, the virtue of an efficient implementation of climate policy becomes more apparent. The EU has thereupon undertaken an attempt to reduce excess costs associated with the hybrid EU regulation[1] in the third trading period from 2013 onwards, an endeavour which is fundamentally flawed (Böhringer et al., 2009a). Furthermore, there is a clear political will now to minimise the undesirable distributional impacts resulting from handing out free permits as basic allocation principle under the EU ETS between 2005 and 2012 (EU, 2009a). But if uneven carbon constraints turn out to be protracted, this may cause domestic firms to lose a competitive edge and to relocate the production plants. In the wake of these developments, there has been a prompt resurgence of the debate on the potentially adverse distributional implications across industries and the environmental integrity.

The final compromise between policy makers and organised industrial associations on this item revealed two large uncertainties under which the European Commission has been operating: What sectors will be mostly affected by the revised emissions trading scheme and what type of policy instrument can aptly address industry-distributional concerns? The missing clue has compelled the EU to accept the claim of roughly two third of sectors subjecting to the EU ETS to be vulnerable (EU, 2009b). Furthermore, the stakeholders in Brussels have acknowledged that a wide range of policy measures can be applied to address competitiveness and carbon leakage risks (EU, 2010a): The first set of options encompasses measures that level down carbon costs for the EU producers. According to the EU, the most obvious way is to maintain the free allocation of allowances for vulnerable sectors. The second set of measures aims at levying carbon taxes on non-carbon constrained EU competitors and lowering down the costs of domestic exporters at the border. This rather controversial policy option encompasses the introduction of border taxes or the inclusion of imports into the EU ETS. In order to minimise adverse impacts on competitiveness of European enterprises and to reduce carbon leakage, policy makers consider finally adopting a set of options which allows a greater sectoral and regional flexibility of the EU ETS. In this regard, the European Council has already proposed to link the EU ETS to compatible

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[1] The hybrid EU regulation – as pursued by the EU Climate Action and Renewable Energy Package – distinguishes between emissions from energy-intensive industries (subject to the EU ETS) and the remaining sectors outside the trading system (subject to complementary measures at the member state level).

mandatory schemes in third countries to reduce the compliance costs for the EU producers (EU, 2007a).

1.1 Research topic and conceptual framing

The overall objective of the thesis is to reduce uncertainties persisting over the industry-distributional impacts of climate change policy in the EU and the choice of offsetting measures to address both competitiveness and carbon leakage concerns. In dealing with this subject, the thesis builds upon the fundamentals of public finance, international trade, industrial organisation and environmental economics. It combines two major components of economic analysis (positive and normative) and uses both partial and general equilibrium perspective.

Throughout the text body, this thesis uses the term “competitiveness”. Despite some critical voices (Krugman, 1994), the prevailing agreement in the academic literature is that competitiveness concerns – even if possibly labelled with inapt terminology – deserve a serious investigation (Alesina and Perotti, 1997; van Soest et al., 2006). But beyond a policy context, competitiveness is not a subject category per se, neither in economic theory in general, nor in normative economics in particular. This explains why a plethora of alternative notions and measurement concepts exists (see for an overview: Jenkins, 1998; Reichel, 2002). To tackle this problem in a pragmatic and efficient way, this thesis employs a competitiveness notion which it interprets as a *consensus* in academic literature, instead of further underscoring the insurmountable differences between alternative definitions. Sectoral competitiveness as an *outcome-based* concept is therefore rigorously defined as the ability of an industry to be profitable (e.g. Demailly and Quirion, 2006; Smale et al., 2006) and to compete in international markets (among others: Jaffe et al., 1995; Peterson, 2006a).

One way of answering the question on how energy-intensive sectors are affected in their ability to be profitable and to compete on international markets is offered by the public finance literature dealing with economic costs’ distribution of policy interventions. In the basic concept of sectoral incidence analysis which is built upon a partial equilibrium perspective (Fullerton and Metcalf, 2002), the degree to which climate policy imposes burdens on given industries is related to the following question: Whether and to what extent the burden of CO_2 costs may be partly or fully shifted (passed) by industrial producers to another type of economic agents. That is to consumers (pass-through) as higher consumer prices or to workers and firm's owners (pass-backward) in form of lower wages and decreasing capital returns.

The extent to which environmental levies, in particular emissions allowances, affect the output prices is of major concern to policy makers (e.g. Demailly and Quirion, 2008a; Dröge and Cooper, 2010). The low degree of the pass-through lets trade flows remain insensitive to environmental levies and will keep market shares of domestic producers unchanged, at least in the short run. However, if European producers are capable to pass-through carbon costs to consumers, they will possibly lose some markets shares vis-à-vis direct competitors on both domestic and foreign market. If profit margin or market shares begin to dwindle, European manufacturers might consider relocating business abroad which drives carbon leakage. The knowledge of the degree and timing of the pass-through provides thereby valuable insights into the potential exposure of energy-intensive sectors to the risk of competitiveness-driven carbon leakage. It allows identifying the channel through which the competitiveness-driven carbon leakage works (decreasing market shares or reduced profit margins) and differentiating offsetting measures accordingly (Hepburn et al., 2006).

For the reasons given above, a limited empirical evidence on the cost pass-through relationships in the context of the EU ETS weights heavily. One branch of literature focuses on the determinants of the cost pass-through such as demand, trade and substitution elasticities (e.g. on the Armington elasticities see: Welsch, 2008). Another research strand estimates the magnitude of the cost pass-through rates: Analysis is thereby either related to a very narrowly selected range of industries at a highly disaggregated level such as power sector (Sijm, 2005, 2006a, 2006b; Zachmann and Hirschhausen, 2008) and cement sector (Walker, 2006) or it covers a wide range of industries at a very lower level of sectoral and regional disaggregation (Fitzgerald et al., 2009). Against this background, this thesis aims at complementing the literature body by providing empirical evidence on how emissions trading in general and free allocation of allowances in particular affects a wide range of energy-intensive sectors covered by the EU ETS. By estimating the pass-through potential across industries, this thesis contributes to a better understanding of implications for the profit margins at the sectoral level.

Beyond the climate policy context, the interest in the pass-through entity has spawned numerous studies through the last decades. A theoretical basis for many of these studies is provided by industrial organisation and international trade models which largely explain the extent of the pass-through in terms of market concentration, the substitutability of imported and domestic products and import penetration (McCarthy, 2006). There is a significant amount of evidence to support the view that energy-intensive commodities are sold in imperfectly competitive markets (see for an overview of empirical evidence: Menon, 1995). Utilising these principles for the assessment of the pass-through potential in this thesis is promising, as empirical literature on the pass-through of CO_2 costs typically studies price transmission mechanisms induced by the EU ETS under the assumption of perfect competition (e.g. Fitzgerald et al., 2009).

Further exploring the competitiveness implications, the emphasis of this thesis is also placed on how carbon costs differentials affect the market shares of European energy-intensive industries on international markets. This analysis constitutes a second important dimension of competitiveness impacts' evaluation (cf.: Demailly and Quirion, 2006, 2008a; Peterson, 2006a). A related question answered by this thesis is what strategies are available to European policy makers to countervail potentially adverse effects on competitiveness and how these strategies affect other sectors and change the aggregate costs of CO_2 abatement policies. As to the introduction of offsetting measures, it analyses three broad categories of policy options which are currently available to the policy makers and seeking (i) to level down carbon costs for the EU producers (preferential treatment in favour of energy-intensive industries), (ii) to levy carbon taxes on non-carbon constrained EU competitors (border measures) and (iii) to increase regional scope of the emissions trading scheme (linking-up emissions trading schemes globally).

Several recent studies have analysed the effects of various offsetting policy measures on energy-intensive industries. Convery and Redmond (2007) pointed out that in the pilot phase the emission reduction requirements for energy-intensive industries subjecting to the EU ETS have been chosen relatively lax compared to the reduction targets for non-ETS segments of the EU economy which effectively boils down to preferential emission pricing of the former. More recently, Böhringer et al. (2009a) demonstrated that lowering carbon costs for energy-intensive industries beyond 2012 works still heavily through the continuation of the inefficiently designed hybrid EU regulation and results in significant excess costs. Few papers focused on the introduction of border measures into the EU ETS: Ismer and Neuhoff (2007) demonstrated that BTA can effectively prevent European climate policy from negatively affecting competitiveness of energy-intensive industry in Europe. One main caveat in their formal set-up is that the energy efficiency decision of firms is not modelled explicitly. Studies by, among others, Demailly and Quirion (2008b) and Monjon and Quirion (2010) are in line with these findings. Peterson and Schleich (2007) emphasised in general equilibrium set-up the importance of alternative benchmarks for the level of border adjustments and corresponding economic implications. Alexeeva-Talebi et al. (2010a) showed that even restricted access to the Clean Development Mechanism (CDM) may damp adverse impacts on energy-intensive sectors in the same vein as the most ambitious BTA regime. Finally, a number of research contributions demonstrated economic effects which an increased flexibility of the emissions trading scheme might entail (in the context of linking the EU ETS see: Anger, 2008; Lokhov and Welsch, forthcoming).

This strand of literature – deeply rooted in both international trade and environmental economics – is dominated by numerical studies and skewed towards a partial equilibrium perspective that ignores behavioural responses from the rest of the economy. Much of previous research obviates therefore significant elements from the analysis of envisaged policy options in terms of their advantages and drawbacks (Parry and Oates, 2000). The sector-specific partial equilibrium framework does neither allow for a comparison of competitiveness implications across different industries nor a simultaneous assessment of economy-wide performance in terms of an overarching welfare metric. Against this background, the thesis illustrates potential pitfalls of alternative climate policy designs that narrowly focus on competitiveness concerns from a general equilibrium perspective. It complements the literature body by exploring the trade-offs at the sectoral, regional and global level for a wide range of policy options to address competitiveness and carbon leakage concerns. Given current uncertainties over the post-Kyoto climate architecture, the range of scenarios analysed in this thesis spans from unilateral climate actions of the EU to some forms of plurilateral agreements.

1.2 Methodological approach

This thesis is based on the application of both advanced econometric and numerical techniques that are employed to assess the impacts of European climate change policy at the sectoral and economy-wide level. Theoretical analysis provides a useful tool in isolating individual mechanism at work; it lays foundation for empirical estimation procedure and sets stage for the interpretation of results from numerical simulations.

Econometric techniques allow tracking price transmission process which is induced by the emissions trading in general and by free allocation of allowances in particular. In the ex-post analysis of the relationships between input and output prices at the sectoral level, a multi-equation estimation technique based on the (restricted) vector autoregression (VAR) models is employed. In comparison to a single-equation-based approach (e.g. autoregressive distributed lag models – ARDL), this model class treats all variables as endogenous – no restrictions on certain variables as exogenous are *a priori* imposed. If a linear combination of non-stationary price and costs time series (Dickey and Fuller, 1979; Phillips and Perron, 1988; Kwiatkowski et al., 1992) converges to a stationary process, the latter is referred to as a cointegration relationship and interpreted as a long-run equilibrium relationship (Engle and Granger, 1987). Since the omission of a cointegration component entails a misspecification error, it should be incorporated into the estimation procedure. Once a cointegration relationship is detected (Johansen, 1995), a vector error correction model (VECM) is estimated to restrict the long-run movement of endogenous variables to converge to their long-run equilibrium (steady-state), while also capturing the short-run dynamics. In comparison to the stationary VAR models, this framework allows using information “hidden” in the levels and enables to deal with non-stationarity of the data in a proper vein.

A complementing approach in thesis is to employ a class of simulation models tailored to quantify impacts of climate change policies at sectoral, regional and global level. Among applied models, computable general equilibrium (CGE) framework represents a standard tool for a comprehensive ex-ante analysis of adjustments induced by policy interference in the field of fiscal, trade and environmental policy (for an overview see e.g.: Shoven and Whalley 1984, 1992; Conrad 1999, 2001). While incorporating real world complexities – such as detailed information on production, consumption and trade patterns – CGE models portray complex price-dependent market interactions between energy, environment and the economy in a micro-consistent way. Hence, in contrast to a partial equilibrium perspective, this tool allows capturing important feedback effects of climate policy on non-carbon markets via individual price adjustments at both firms’ and consumers’ level. Focusing on the international trade dimension of competitiveness notion, a multi-region CGE model’s virtue is to trace trade pattern adjustments arising from carbon costs differentials across sectors and regions. Since the theoretical underpinning of a CGE model is rooted in traditional microeconomic theory, appraisal of available policy options relies upon a numerical welfare measure which reveals the problems to be faced when competitiveness is prioritised by policy makers.

1.3 Structure of the dissertation

This thesis comprises a selection of essays which investigates the vulnerability of energy-intensive industries and assesses a number of policy measures to counter the potential loss of competitiveness and the risk of carbon leakage in a world with different levels of ambitions in climate actions. Each individual chapter, conceptualised throughout as a stand-alone analysis, includes a precise definition of research question, methodological framework and contribution to the existing literature. Two essays are single-authored contributions; the remaining three essays have been written in collaboration with co-authors.

The dissertation has been structured along two thematic parts. Part I comprises two essays which empirically assess the pass-through relationships between (carbon) costs and prices in sectors participating in the EU ETS. Part II presents an economic impact assessment of climate policy and consists of three chapters – each chapter deals with one category of instruments to address the adverse competitiveness and carbon leakage implications: Carbon price differentiation in favour of domestic energy-intensive industries, border adjustments and the linking up of emissions trading schemes.

Employing a stylised model of industrial organisation with elements from international trade theory in spirit of Dixit and Stiglitz (1977) and Dornbusch (1987), chapter 2 analyses the extent and evaluates the differences of cost pass-through potenital across German energy-intensive sectors as the result of optimal pricing strategies on the part of large imperfectly competitive firms. This framework is appropriate for the envisaged analysis as all sectors in the sample, except for one, disclose market concentration which lies above the median value in Germany (Monopolkommission, 2008). For this analysis, monthly data of the period from January 1995 to December 2008 are used. Since the EU ETS is still in an early stage and price data for sectors of interest are typically available on a monthly basis, the carbon costs are proxied by labour, material and energy as the second-best option. The key feature of the applied model is that each domestic firm's price depends on its labour, material and energy costs and its flexible mark-up which is in turn determined by industry characteristics and the price charged by foreign competitors. The analysis makes use of a set of industry import and domestic price series at the NACE 3- and 4- digit level. It therefore overcomes the problem of high order aggregation which traditionally plaques empirical cost pass-through literature. The selection of German energy-intensive sectors participating in the EU ETS is based on Graichen et al. (2008). After testing for the non-stationary of the data and the presence of cointegration relationships among the respective variables, a sequence of vector error correction models has been estimated. This procedure allows assessing the pass-through potential of energy-intensive industries in the long-run equilibrium and inspecting the claims that future environmental policy will wipe out profit margins, as frequently argued by the industrial associations.

In a system with freely allocated allowances, profit-maximising firms retain extra-profits associated with the passing-through of opportunity costs to consumers. Initial empirical evidence on significant wind-fall profits in the power sector (Zachmann and Hirschhausen, 2008, and others) has speeded up the movement to large-scale auctioning beyond 2012. The corresponding evidence on the refining sector is still fragmentary (Oberndorfer et al., 2010, for the UK and de Bruyn et al., 2010, for Germany). Against this background, chapter 3 examines whether EU refining sectors have passed-through opportunity costs of freely allocated emissions certificates during the first phase of the EU ETS (2005–2007). The ex-post analysis makes use of weekly data (running from September 16, 2005, to March 22, 2007) at the country level for both new and old EU member states from different data bases, including the Community Independent Transaction Log (CITL) data base. The availability of weekly price data on petroleum products is of crucial importance as it allows assessing the pass-through of carbon costs directly, i.e. making need to proxy these costs as the second-best option dispensable. The analysis is as comprehensive as the weekly data permits; the time horizon is determined by the availability of spot prices for EUAs (European Union Allowances) which are not time-invariant at an extremely low level (cf. Alberola and Chevallier, forthcoming; Oberndorfer et al., 2010). In contrast to previous studies, the applied data and modelling techniques in this chapter allows accounting for the long-run equilibrium relationships and disclosing potential heterogeneity in terms of the pass-through across the EU member states. For each of the EU member states – for which a full set of data is available and the conducted tests suggest the non-stationary of the data as well as the existence of the cointegration relationships (14 EU member states in total) – two alternative specifications of vector error correction models were considered. In the basic model specification, net-of-taxes nominal retail prices for Euro-95 unleaded petrol at the EU country level, spot prices of EUAs, prices of crude oil and exchange rates between local country's currency and US$ are endogenous variables. To test the robustness of the result, the alternative model specification involves a different treatment of the exchange rate variable since the employed unit root tests (Dickey and Fuller, 1979; Phillips and Perron, 1988) and stationarity tests (Kwiatkowski et al. 1992) provide some conflicting results on the order of integration of the exchange rates time series (zero or one). The sensitivity analysis which treats the exchange rates as an exogenous variable reaffirms our conclusions on the proper specification of the basic model at the country level.

Complementary to the analysis in chapters 2 and 3, the subsequent chapters 4 to 6 focus on the question how the international trade flows respond to alternative climate change polices and evaluate a number of proposals to mitigate both competitiveness and carbon leakage risks. Chapter 4 first discusses alternative measurement concepts that can be used to quantify specific aspects of competitiveness at the level of sectors and countries. While the bulk of "competitiveness research" in the context of the EU ETS is skewed towards a partial equilibrium perspective focusing on energy-intensive industries, this chapter subsequently elaborates on a computable general equilibrium model complemented with selected competitiveness indicators to facilitate the comprehensive impact assessment of unilateral climate policies. A wide range of unilateral carbon pricing policies which include elements of tax differentiation in favour of energy-intensive industries is considered. In contrast to Böhringer et al. (2009a), the major focus of the assessment is to detail the pending trade-offs at the sectoral, regional and global level for *alternative* degrees of price differentiation in favour of energy-intensive industries. Following Böhringer and Rutherford (2002b), the total welfare effect of unilateral abatement is thereby broken down into the so-called domestic market effect (i.e. the domestic adjustment holding international prices constant) and the international spillover effect (i.e. the residual effect accounting for changes in the terms of trade). Applying this technique allows better understanding the implications of changing competitiveness at the economy-wide level (measured by the terms of trade) for adjustment costs of unilateral policies.

Levelling carbon costs at the border is one of the most controversial proposals to tackle carbon leakage problem of unilateral climate actions (e.g. Manders and Veenendaal, 2008; Fischer and Fox, forthcoming). Chapter 5 focuses on two alternative policies in contemporary EU ETS context: Border tax adjustments (BTA) and integrated emission trading (IET). The former regime levies a quantity-based, the latter an emission-based duty on imports from non-abating countries and compensates domestic exporters accordingly. The formal setup of this chapter – the stylised two-country model – advances the approach of Ismer and Neuhoff (2007), as to it explicitly models the energy efficiency decision of firms covered by countervailing border measures. This model extension enables to reveal an inherent trade-off faced by policy makers, when preferring one option over another, in terms of diminishing competitiveness losses of domestic energy-intensive industries against the opportunity to incentify foreign competitors to more vigorously reduce emissions abroad. By introducing real-world complexities, numerical analysis of both regimes investigates the associated impacts on carbon market, sectoral and economy-wide output and emissions level. This analysis detects non-negligible spillover effects to sectors not covered by border measures, in this vein revising the insights from partial equilibrium approach as in Monjon and Quirion (2010).

Dröge and Cooper (2010) rank the option to link sectoral and regional trading systems among measures potentially commensurable to address competitiveness concerns in the EU arising from different carbon price levels. Potentially favourable impacts of linking the emissions schemes on the international trade dimension of competitiveness of European producers are likely to occur (Edenhofer et al., 2007) but they have not yet been quantified. Chapter 6 delves into economic aspects of levelling carbon costs across countries through the integration of regional emissions trading programs to the EU ETS. Theoretical background in this chapter derives the efficiency aspects of integrating emissions trading schemes from a partial market perspective. Numerical analysis focuses on the interplay between carbon and merchandise markets and fills the gap in the literature by analysing how gradual linking the EU ETS to emerging schemes around the world will affect social welfare and the export performance of the targeted sectors in and beyond Europe. The chapter evaluates to what extent the attractiveness of developing supra-European ETS can represent a matter of priority for efficiency or improving a trade-based dimension of international competitiveness.

Chapter 7 summarises main findings and provides policy recommendations based on the results of this thesis.

1.4 Summarising main findings and conclusions

To preview the findings of this thesis, stringent environmental policy in the European Union in the post-Kyoto era, in particular if implemented as unilateral abatement actions, tends to have detrimental effects on both dimensions of competitiveness: profit margins and market shares of domestic energy-intensive industries. The less-than-complete pass-through implies that additional costs induced by the EU ETS in the third trading period are likely to be partly absorbed through a reduction of profit margins, but the severe risk of carbon leakage working through this channel exists in few sectors only. The numerical analysis demonstrates that impacts on trade-based competitiveness in energy-intensive industries are rather moderate, even if relatively stringent emissions reduction targets are assumed.

Furthermore, the thesis illustrates that offsetting policy measures such as the various CO_2 price differentiation strategies, alternative forms of border adjustments and increased regional flexibility of the EU ETS have the potential to neutralise the adverse implications on competitiveness of energy-intensive industries in Europe. But the sector-specific gains of preferential treatment in favour of these branches by means of non-uniform CO_2 pricing strategies or border adjustments must be traded off against the additional burden imposed on other industries and economy-wide excess costs to meet the unilateral emission reduction target. From the perspective of *global* cost-effectiveness, however, preferential emission pricing for domestic energy-intensive and trade-exposed sectors can reduce leakage and thereby lower overall cost of cutting global emissions as compared to uniform emission pricing. While border adjustments offer some prospects for improving global environmental effectiveness too, they are less suitable as a second-best strategy due to possible retaliatory measures by trading partners resulting in the welfare-decreasing trade wars. The gradual movement towards a global CO_2 market through linking emissions trading schemes is found to be superior to both emission price differentiation and border adjustments: This option allows realising a cost-efficient and globally effective climate policy while simultaneously minimising the adverse impacts on competitiveness of domestic energy-intensive industries.

Part I

Industrial Organisation and the Cost Pass-Through

2 Cost Pass-Through in Strategic Oligopoly: Empirical Evidence for German ETS Sectors[2]

Climate policy in Europe has been increasingly designed to encourage energy-intensive companies to pursue low-carbon strategies. The revised Emissions Trading Scheme (ETS) in the EU foresees tightening emissions cap and introducing auctions as the basic principle for allocation of carbon allowances beyond 2012, with an auction rate of up to 100 percent in the power sector (EU, 2009a).

In the world with uneven carbon constraints, commitments to ambitious emissions targets give rise to multiple concerns, including the potentially adverse impacts on competitiveness of European enterprises and the global environmental effectiveness. In the run-up to final consultations at the highest level in Brussels, heavy industry – in particular, cement, steel, aluminium and chemical sectors – argued that the revised scheme would force them to move factories and jobs out of the EU's borders, leading to a 'leakage' of carbon emissions. Such concerns have been particularly extensive in Germany, the biggest player in the EU ETS (EurActiv, 2009).

Successful lobbying for preferential treatment of sectors potentially exposed to a significant risk of carbon leakage established the final compromise: EU leaders agreed that eligible sectors will be granted 100 percent of benchmarked emissions allowances free of charge after 2012. In following up this decision, the European Commission (EC) defined a rather simplified catalogue of exposure criteria and ascertained that 146 out of 258 sectors at the NACE 4-digit level have been meeting these criteria (EU, 2009b). The results in this paper cast some doubt on the usefulness of such a generous provision of benchmarked emissions allowances free of charge to energy-intensive sectors.

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[2] This chapter is based on the paper: Alexeeva-Talebi, V. (2010a), Cost Pass-Through in Strategic Oligopoly: Sectoral Evidence for the EU ETS, *ZEW Discussion Paper* 10-056, ZEW, Mannheim. The manuscript has been submitted to *Environmental and Resource Economics*.

Given the importance of carbon leakage issues in current EU climate change policy, comprehensive research work has emerged over recent years. Assumptions on cost pass-through relationships determine the impact of asymmetric climate change policy on two channels of competitiveness-driven carbon leakage: (decreasing) market shares and profit margins. Numerical studies within a general equilibrium framework have focused on assessing carbon leakage and competitiveness effects associated with the implementation of the EU ETS (Böhringer and Lange, 2005a; Peterson, 2006a; Alexeeva-Talebi and Anger, 2007). Assuming that an increase in marginal carbon costs is fully borne by the demand side and, consequently, profit margins of producers remain unchanged, these studies quantify how domestic suppliers adjust market shares in both domestic and foreign markets. Cost increases are, however, not necessarily fully passed on to consumers of energy-intensive goods through price increase but can be absorbed by the industry through a reduction of profit margins. In an extreme case, this might imply constant prices and sustaining output level but decreasing profit margins (Hourcade et al., 2007). Between both extremes, asymmetric climate change policy creates incentives to relocate business abroad by affecting both market shares and profit margins. Assuming a range of cost pass-through rates, i.e. shares of an increase in marginal costs that are passed on to output prices, global sectoral models quantify the impact of stringent environmental policies on both market shares and profit margins (Demailly and Quirion, 2006, 2008a; Smale et al., 2006). As a prominent example, Demailly and Quirion (2008a) conduct a simulation analysis for the iron and steel sector. The authors conclude that pass-through rates are of major importance: Results related to competitiveness and carbon leakage crucially depend on the ability of the sector to pass-through additional costs to the demand side. More recently, Lise et al. (2010) draw similar conclusions on the role of the pass-through in the power sector.

Empirical evidence on cost pass-through relationships in sectors that are of special interest within the current EU climate change policy is rather scarce. Few studies analyse the scope and speed of output price adjustments in the event of input price shocks: Sijm (2005, 2006a, 2006b) and Zachmann and Hirschhausen (2008) estimate the potential to pass-through additional carbon costs in the power generation sector. Walker (2006) conducts a comparable study for the European cement sector. Controlling for labour costs, Fitzgerald et al. (2009) estimate cost pass-through rates for European energy-intensive sectors at the relatively low level of sectoral disaggregation. The existing evidence is thereby either related to a very narrowly selected range of industries at a highly disaggregated level such as power sector and cement sector or it covers a wide range of industries at a very lower level of sectoral and regional disaggregation (Fitzgerald et al., 2009). One exception is study by Oberndorfer et al. (2010) who analyse cost pass-through relationships in selected energy-intensive sectors in the UK. The other branch of literature focuses on determinants of the cost pass-through such as demand, trade and substitution elasticities. Welsch (2008) provides evidence for low substitution elasticities among imports and competing domestic goods (Armington elasticities) for few energy-intensive sectors in four European countries. Finally, some empirical evidence can be found in studies focusing on the ability of the EU exporters to pass-through exchange rate shocks into the foreign consumer prices (for German exporters: Knetter, 1993; Clostermann, 1996; Goldberg and Knetter, 1997; Stahn, 2006, and Gaulier et al., 2008). However, the results from these studies cannot be generalised to the case of carbon pricing.

Against this background, this chapter evaluates the exposure of a wide range of highly disaggregated German energy-intensive sectors to the risk of competitiveness-driven carbon leakage by estimating the long-run pass-through potential. Our analysis of the extent and the differences of the cost pass-through potential across industries covered by the EU ETS is as comprehensive as the data permits and covers sub-sectors in industrial branches paper and pulp, chemicals, rubber and plastic and non-metallic minerals. Using data at the high level of sectoral disaggregation (3- and 4-digit-level) for a broad sectoral coverage, the analysis overcomes the problem of high order aggregation which traditionally plagues empirical cost pass-through literature.

There is a significant amount of evidence to support the view that energy-intensive commodities are sold in imperfectly competitive markets (see for an overview of empirical evidence Menon, 1995). The empirical section employs therefore a simple mark-up model of imperfect international competition (Dixit and Stiglitz, 1977; Dornbusch, 1987) which is broadly used to study the exchange rate pass-through but have not yet been applied in the context of climate change policy. The key feature of the estimated model in this paper is that each domestic firm’s price depends on its domestic costs (i.e. labour, material and energy costs) and its *flexible* mark-up which is in turn determined by industry characteristics and the price charged by foreign competitors. Strategic interactions between domestic and foreign firms limit thereby the impact of domestic cost shocks on price competitiveness on the part of large imperfectly competitive firms. Although strategic interactions in energy-intensive sectors might be very relevant, empirical literature on the cost pass-through does not typically take them into account (Fitzgerald et al., 2009). Utilising this approach for the assessment of the pass-through potential is promising as empirical literature on the pass-through of CO_2 costs typically studies price transmission mechanisms induced by the EU ETS under the assumption of perfect competition (e.g. Oberndorfer et al., 2010).

The regional focus is motivated by the following two considerations: First, Germany represents the biggest emitter in the EU ETS and German energy-intensive sectors are expected to benefit most from preferential treatment in the third trading period beyond 2012. Hence, the characterisation of the cost pass-through and the extrapolation of the results to make claims concerning the carbon leakage potential and the preferential treatment provisions in these energy-intensive industries are highly policy-relevant. Second, applying the theoretical foundation of strategic oligopoly to German energy-intensive sectors is plausible for several reasons: Most importantly, German sectors participating in the EU ETS are typically dominated by few big companies (e.g. BASF, HeidelbergCement). According to the variant of the mark-up model applied in this paper, the existence of large companies with a significant market power is essential for strategic interactions to occur. All sectors in our sample, with only one exception, are equipped with the market power which lies above the median value in Germany. Moreover, the Dixit-Stiglitz-Dornbusch model treats domestic and foreign goods as imperfect substitutes – this assumption is widely used in numerical models which analyse climate change policies in the context of the EU ETS (the so-called Armington assumption, see further: Armington, 1969). Finally, there is sporadic evidence that German producers in energy-intensive sectors compete with foreign companies in prices and not in quantities even in relatively homogenous markets such as cement sector.

This paper contributes to the existing literature on the climate change policy twofold: First, it evaluates the risk of carbon leakage by characterising the cost pass-through in German energy-intensive sectors while using advanced time-series techniques to estimate a range of vector error correction models (VECMs). The results of the estimation procedure yield estimates of the cost pass-through potential in the long-run equilibrium varying substantially across industries. The less-than-complete pass-through implies that additional costs induced by the EU ETS are likely to be partly absorbed through a reduction of profit margins, but the severe risk of carbon leakage exists in few sectors only. It is mainly concentrated in parts of the paper and chemical industry in which producers pass-through only a small fraction of costs increases to the demand side and additional CO_2-related costs are expected to raise the total costs significantly (by up to 25 percent). Sectors with medium to high cost pass-through rates – making up the half of sectors in our sample – might still be forced to move factories out of the EU's borders through the (decreasing) market share channel, but severe implications on profit margins are rather unlikely. Second, it explains the variation in pass-through across energy-intensive sectors by industry characteristics and the price charged by foreign competitors. The analysis finds a significant role for included industrial characteristics like market power and product substitutability, but the impact on the pass-through is ultimately determined by the interplay of individual effects working in different directions. Furthermore, most of German EU ETS sectors have a *flexible* mark-up which is an outcome of strategic interactions between domestic and foreign firms. The higher the interaction with foreign producers is, the lower the pass-through potential of domestic firms. We conclude by emphasising that the strategic interactions between German and foreign firms could be a critical factor which shall be taken into consideration for the design of appropriate countermeasures to delimitate carbon leakage in the EU.

The structure of the chapter is as follows: Section 2.1 outlines the theoretical framework underpinning the model estimated in section 2.2. Section 2.3 presents and analyses the results. Section 2.4 concludes. Appendices to this chapter can be found in section 2.5.

2.1 The theory of the cost pass-through in strategic oligopoly

To analyse the potential passing-through capacity of additional costs in German energy-intensive sectors, we employ a variant of the mark-up model of price determination built upon the work of Dixit and Stiglitz (1977) and Dornbusch (1987).[3] Under the condition of imperfect competition in heterogeneous goods, this framework allows for strategic interactions between domestic and foreign firms. The key element of the model is that firms are in position to charge a *flexible* mark-up over marginal costs.

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[3] Dornbusch (1987) considers the Dixit-Stiglitz model (1977) to capture the effects of imperfect competition and product differentiation on the output price responses to exchange rate changes. Thereafter, we do not take exchange rate changes into consideration.

Assume that representative consumer maximises the following sub-utility function of the CES (constant elasticity of substitution) type:

$$U = \left(a \cdot X_d^{-\rho} + (1-a) \cdot X_f^{-\rho} \right)^{-\frac{1}{\rho}} \tag{1}$$

where $X_d = \left(\sum_{i=1}^{n^D} x_{di}^s \right)^{\frac{1}{s}}$ is a bundle of different brands x_{di} of the domestically produced commodity and $X_f = \left(\sum_{j=1}^{n^F} x_{fj}^t \right)^{\frac{1}{t}}$ is an index of different varieties x_{fj} of the same commodity produced abroad. It is assumed that there are n^D domestic firms and n^F foreign firms in (our) home market supplying some variant (brand) each. Thereby, a is the share parameter ($0 \le a \le 1$), ρ is the outer substitution parameter defined by the elasticity of substitution, σ, as $\rho = \frac{\sigma - 1}{\sigma}$ with $-1 < \rho < 0$ (and hence $\sigma > 1$). To focus on the substitution between domestic and foreign bundles only, we assume $s = t = -\rho$ (see also: Strauß, 2004).

Solving the consumer's maximisation problem yields the following demand for each individual domestic and foreign variant:

$$x_{di} = a^{\sigma} X \left(\frac{p_{di}}{P} \right)^{-\sigma} \tag{2}$$

and

$$x_{fj} = (1-a)^{\sigma} X \left(\frac{p_{fj}}{P} \right)^{-\sigma} \tag{3}$$

with

$$P = \left[a^{\sigma} \sum_{i=1}^{n^D} p_{di}^{1-\sigma} + (1-a)^{\sigma} \sum_{j=1}^{n^F} p_{fj}^{1-\sigma} \right]^{1/1-\sigma} \tag{4}$$

as industry price *P*, while p_{di} and p_{fj} denote the prices of domestically produced and imported variants, respectively. Individual (domestic and foreign) firms face demand curve as in (2) and (3) where each firm's market share $\frac{x_{di}}{X}$ or $\frac{x_{fj}}{X}$ (with X as total demand) depends on its product price relative to the industry price $\frac{p_{di}}{P}$ and $\frac{p_{fj}}{P}$, respectively.

The profits of the domestic firm k which is identical to other n^D-1 domestic firms but not to n^F foreign firms is given by:[4]

$$\pi_{dk}=\left(p_{dk}-c_{dk}\right)x_{dk} \tag{5}$$

where x_{dk} is the output quantity and c_{dk} are the unit costs of the domestic firm.

Under conditions of imperfect competition, assume now that individual firms are large enough to affect the industry price P, while strategic interactions between firms are introduced by means of conjectural variation ω $(0<\omega<1)$. The latter parameter indicates that firms respond to a one-percentage-point rise in the industry price by increasing their prices by ω percent.[5]

The first-order condition of profit maximisation for the individual domestic producer k becomes:

$$x_{dk}+\left[p_{dk}-c_{dk}\right]\left[\left(\partial x_{dk}/\partial p_{dk}\right)\right]+\left[\left(\partial x_{dk}/\partial P\right)\left(\partial P/\partial p_{dk}\right)\right]=0. \tag{6}$$

Thus, a single firm's production volume is affected directly via change in its individual price $\left[\partial x_{dk}/\partial p_{dk}\right]$ and indirectly via changes in the industry price index resulting from his own decision $\left[\left(\partial x_{dk}/\partial P\right)\left(\partial P/\partial p_{dk}\right)\right]$.

Let ε denote the elasticity of the aggregate price level with respect to the single supplier's own price:

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[4] Assume further that there is an effective separation between home and foreign markets. In doing so, it is possible to discuss the pricing behaviour of foreign producers in our market separately.

[5] In the Cournot model of imperfect competition in homogenous goods (perfect substitutability between domestic and imported goods), a firm's mark-up depends on its market share. Firms with a high market share are considered to be able to charge higher prices (see for further details: Menon, 1995). But in reality, this might be difficult if competitors are not expected to follow a firm's price increase. Hence, firm's optimal pricing strategy will not only depend on its market share but be conditioned by the anticipation of competitors' reaction to this strategy. This interrelation is expressed as the conjectural variation.

$$\varepsilon \equiv \left(dP/P\right)/\left(dp_{dk}/p_{dk}\right). \tag{7}$$

Since individual firm has to take into consideration the extent to which its action affects the industry price index P, this term captures the strategic interaction between firms as perceived from the domestic firm k. Using the above definition for ε ($0<\varepsilon<1$), the first-order condition can be simplified to:

$$1+(p_{dk}-c_{dk})\cdot(\sigma)\cdot(\varepsilon-1)/p_{dk}=0 \tag{8}$$

and solved for the optimal price under strategic interaction:

$$p_{dk}=\left[1-\frac{1}{\sigma\cdot(1-\varepsilon)}\right]^{-1}\cdot c_{dk}=\mu_{dk}\cdot c_{dk} \tag{9}$$

where μ_{dk} represents a mark-up over margin costs.

Assuming that conjectural variation for all firms i and j is given by:

$$\omega\equiv\left(dp_{di,fj}/p_{di,fj}\right)/\left(dP/P\right) \text{ with } 0<\omega<1 \tag{10}$$

one gets the following expression for the elasticity ε[6] if totally differentiating (4):

$$\varepsilon \equiv \frac{1}{\omega+(1-\omega)\left[n^{D}+\frac{(1-a)^{\sigma}}{a^{\sigma}}n^{F}\left(\frac{p_{di}}{p_{fj}}\right)^{1-\sigma}\right]}. \tag{11}$$

This elasticity depends thereby on relative prices, tconjectural variation, the elasticity of substitution among variants and the number of domestic and foreign firms. The mark-up pricing equation (9) and equation (11) highlights the fact that firm's optimal price policy is no longer to charge a constant but rather a flexible mark-up μ_{dk} over margin costs (depending on the relative prices).

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[6] In the Dixit-Stiglitz model this elasticity is zero.

From equation (9) and (11), it is obvious that domestic firm's reaction function is given by $p_{dk} = f(p_{fj}/p_{di}, \sigma, \omega, n^D, n^F) \cdot c_{dk}$. By following similar steps one gets the following reaction function for the foreign firm: $p_{fj} = f^*(p_{di}/p_{fj}, \sigma, \omega, n^d, n^f) \cdot c_{fj}$.

The main theoretical implication of the model developed in this section for the subsequent empirical investigation is that strategic interactions between domestic and foreign producers under the condition of imperfect competition will limit the ability of domestic producers to pass-through cost shocks. This can be seen from the elasticity of domestic prices calculated with respect to domestic costs and industry price[7] from equation (9):

$$\psi_1 = \frac{dp_{dk}}{dc_{dk}} \cdot \frac{c_{dk}}{p_{dk}} = 1 - \frac{\varepsilon}{(1-\varepsilon)[1-\sigma(1-\varepsilon)]} \tag{12}$$

and

$$\psi_2 = \frac{dp_{dk}}{dP} \cdot \frac{p_{dk}}{P} = \frac{\varepsilon}{(1-\varepsilon)[1-\sigma(1-\varepsilon)]}. \tag{13}$$

This yields empirical coefficients ψ_1 and ψ_2 which are estimated in the subsequent section. Thereby, equations (12) and (13) introduce the following adding-up restrictions on coefficients for domestic firm's price equation (in logarithms):

$$p_{dk} = (1-\psi_1)c_{dk} + \psi_1 p_{fj}, \quad 0 \le \psi_1 \le 1. \tag{14}$$

Equation (14) illustrates that the cost pass-through in strategic oligopoly is smaller than in the standard Dixit-Stiglitz framework where it is equal to 1. Thereby, ψ_1 captures the intensity of competitive pressure in the respective sector k. If ψ_1 is zero, domestic prices are set exclusively with respect to the domestic producer's cost situation. This reflects constant mark-up over marginal domestic costs and complete cost pass-through rates for domestic producers. If ψ_1 is one, domestic prices are set exclusively with respect to the foreign producer's prices. In this case, increasing costs are fully absorbed by the profit margin of the domestic producer. If ψ_1 varies between zero and one, domestic prices react to both domestic

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[7] Given the fact that domestic firms are identical this basically implies that domestic firm has to take foreign prices into consideration.

unit costs and foreign competitors' prices. The higher substitutability between domestic and foreign goods, the higher number of competing enterprises in the sector and the higher conjectural variation, the lower is the cost pass-through potential of the domestic firm.

In the context of the unilateral EU climate change policy, this simple framework allows illustrating important insights. The main options to address competitiveness-driven carbon leakage includes free allocation of allowances to existing and new facilities, financial compensation, border tax adjustments (BTAs) or the inclusion of importers into the EU ETS and global sectoral agreements, i.e. instruments encouraging sector-based activities in developing countries. Figure 1 and Figure 2 demonstrate price adjustments for two different policy options which play a prominent role in the current EU debate on climate policy: the inclusion of importers into the emissions trading scheme and the provision of benchmarked emissions allowances free of charge.

The curves AA and A*A* are the price reaction functions of domestic and foreign firms, respectively. Assume without a loss of generality, that B is the initial equilibrium with carbon costs being already reflected in prices of domestic firms. Now consider the case (Figure 1) in which home country imposes an import tariff on foreign products in the domestic market or includes importers into the domestic emissions trading scheme (see for further details: Alexeeva-Talebi et al., 2008). This policy will shift the foreign reaction function up and to the right due to the increased costs while leaving the domestic reaction function unchanged (A*'A*'). The new equilibrium B' is characterised through higher domestic prices too.

Alternatively, the government of the home country subsidises a fraction of the carbon costs which are reflected in the lower domestic costs (Figure 2) as it is intended by the free allocation provision. This policy will shift the domestic reaction function down and right (A'A') while leaving the foreign country's price reaction function in place. The new equilibrium is therefore at B'' with lower foreign prices. From equations (2) and (3) is clear that consumers will react to changing prices and adjust their consumption quantities accordingly.[8]

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[8] It lies outside the scope of this paper to analyse the implications of given policy measures for production quantities and emissions level. At the single firm level, both policy measures are expected to have different impacts on both profit margins and market shares.

Figure 1: Increasing prices if border adjustments apply to imports

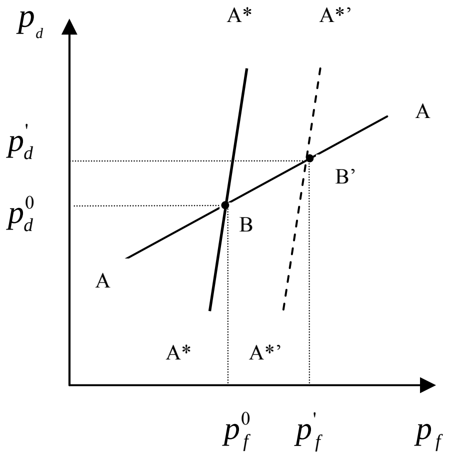
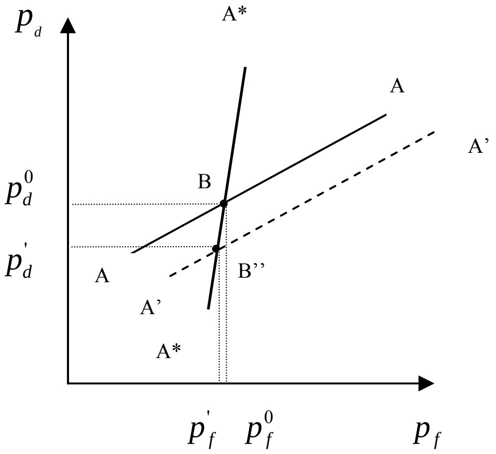


Figure 2: Decreasing prices if a subsidy applies to domestic goods



2.2 Estimating Germany’s long-run cost pass-through relationships

The empirical section investigates to what extent German energy-intensive sectors covered by the EU ETS have a flexible mark-up over marginal costs, i.e. they set prices strategically when facing domestic cost shocks.[9] This focus allows estimating cost pass-through relationships for various energy-intensive sectors while explicitly taking foreign competitors’ prices into consideration.

2.2.1 Vector error correction models (VECMs) as a suitable empirical model type

In this section, we estimate a range of models that capture *long-run equilibrium* relationships between domestic producer prices, foreign producer prices and domestic costs in German energy-intensive sectors. To analyse the relationships between input and output prices at the sectoral level, we employ a multi-equation estimation technique based on the (restricted) vector autoregression (VAR) models. In comparison to a single-equation-based approach (e.g. autoregressive distributed lag models – ARDL), this model class treats all variables as endogenous – no restrictions on certain variables as exogenous are *a priori* imposed. In comparison to the stationary VAR models, this framework allows using information “hidden” in the levels and enables to deal with non-stationarity of the data in a proper vein. The suggested method allows, finally, considering the short-run dynamics through the past changes in the respective variables.

More specifically, we broaden theoretical approach in previous section by assuming different types of input factors such as labour p_t^{lab}, material p_t^{mat} and electricity p_t^{ele} (see below). The inclusion of these variables, particularly, the input factor material is important to avoid an omission of variable problems which leads to estimating biased pass-through coefficients (Gross and Schmitt, 2000).

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[9] This is equivalent to empirically finding that $\psi_1 \neq 0$.

A linear combination of sectoral non-stationary variables (p_{it}^{dom} , p_{it}^{for} , p_{it}^{lab} , p_{it}^{mat} and p_{it}^{ele}) may thereby converge to a stationary process. The latter is referred to as a cointegration relationship and interpreted as a long-run equilibrium relationship between individual time series (Engle and Granger, 1987). Letting x_{it} represent a vector of non-stationary endogenous variables in the sector *i* $x_{it} = (p_{it}^{dom}, p_{it}^{for}, p_{it}^{lab}, p_{it}^{mat}, p_{it}^{ele})$, we assume that it follows a vector autoregressive (VAR) process of order *p*:

$$\mathrm{x}_{\mathrm{it}} = \mathrm{A}_{\mathrm{i1}}\mathrm{x}_{\mathrm{it-1}} + ... + \mathrm{A}_{\mathrm{ip}}\mathrm{x}_{\mathrm{it-p}} + \mathrm{B}\mathrm{y}_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \tag{15}$$

where y_{it} is a vector of exogenous variables (seasonal dummy variables), $\mathrm{A}_1, ..., \mathrm{A}_\mathrm{p}$ are matrices of coefficients to be estimated and $\varepsilon_{\mathrm{it}}$ is a vector of innovations. This VAR model may be rewritten as a vector error correction model (VECM) for each energy-intensive sector as:

$$\Delta \mathrm{x}_{\mathrm{it}} = \Pi_{\mathrm{i}}\mathrm{x}_{\mathrm{it-1}} + \sum_{\mathrm{k=1}}^{\mathrm{p-1}} \Gamma_{\mathrm{ik}} \Delta \mathrm{x}_{\mathrm{it-p}} + \mathrm{B}_{\mathrm{i}}\mathrm{y}_{\mathrm{it}} + \varepsilon_{\mathrm{it}} \tag{16}$$

where Δ represents the first-difference operator and Π_{i} contains information about the long-run relationships among endogenous variables.

$\mathrm{Rank}(\Pi_{\mathrm{i}}) = 1$ suggests the existence of a unique cointegration relationship among respective variables. The identification of cointegration rank(s) for each sectoral model depends on the form of the hypothesised cointegration equation. Johansen (1995) considers five deterministic trend cases. We always prefer the specification with a time trend in the cointegration equation over a specification with only an intercept in the cointegration equation if the time trend is significant:

$$\Pi_{\mathrm{i}}\mathrm{x}_{\mathrm{it-1}} + \mathrm{B}_{\mathrm{i}}\mathrm{y}_{\mathrm{it}} = \partial_{\mathrm{i}}(\beta_{\mathrm{i}}{}'\mathrm{x}_{\mathrm{it-1}} + \rho_{\mathrm{i0}} + \rho_{\mathrm{i}}\mathrm{t}_{\mathrm{i}}) + \alpha_{\mathrm{i}}\gamma_{\mathrm{i0}} \tag{17}$$

where ρ_{i0} is an intercept in the sectoral cointegration equation, t_{i} is a time trend in the cointegration equation and γ_{i0} is a deterministic term outside the cointegrating equation.

In the cointegration system, the sectoral error correction term ∂_{i} reflects the speed of an adjustment towards the long-run equilibrium.

We test the following two hypothesises:

- Hypothesis 1: Cost pass-through rates in German energy-intensive sectors are incomplete in the long-run equilibrium, albeit every sector is capable to pass-through at least one type of cost shocks.
- Hypothesis 2: Energy-intensive sectors in Germany have a flexible mark-up over domestic costs, i.e. they take foreign competitors' prices explicitly into consideration. The incentives to act strategically by taking foreign prices into consideration are higher in relatively homogenous product markets with high market concentration.

2.2.2 Data sources and variables

We start our analysis with data covering fifteen industries at the 4-digit and one sector at the 3-digit level based on the German commodity classification of production statistics (Version 2009, GP 2009). The selection of German energy-intensive sectors participating in the EU ETS is based on Graichen et al. (2008).[10] The analysis is as comprehensive as the data permits and covers sub-sectors in industrial branches including paper and pulp, chemicals, rubber and plastic and non-metallic minerals production. For our analysis, we use monthly data of the period from January 1995 to December 2008.

Both time series for domestic (P_i^{dom}) and foreign competitors' prices (P_i^{for}) are available in the required sectoral breakdown for the envisaged estimation period from the German Federal Statistical Office (Statistisches Bundesamt, 2010a). The former is a domestic output price index for each product category which can be purchased in Germany; the latter measures the price development in the same product category imported to Germany from abroad.[11] Both time series refer to producer prices.

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[10] Graichen et al. (2008) list German energy-intensive sectors which participate in the EU ETS in accordance with the German classification of economic activities (WZ). With very few exceptions, time series of sectoral indices down to the 4-digit level of the WZ 2008 are identical to GP 2009 and NACE Rev. 2.

[11] The appropriate price is the C.I.F. price (cost, insurance, freight) at the German border which is converted to Euro. The available data do not allow distinguishing between European and non-European competitors. Acknowledging the data availability constraints, we do not consider this to be a source of major concern. Indeed, we consider domestic goods to be different from imported goods, independently from where abroad they are produced (Armington, 1969).

For convenience, we use the subscript *i* to refer to sectoral affiliation in the GP 2009 classification: For example, P_{1712}^{dom} and P_{1712}^{for} are domestic and import prices in the sector manufacturing of paper and paperboard (GP09-1712), respectively.

By plotting sectoral producer prices in Figure 3[12], we observe a considerable heterogeneity in the movement of domestic and foreign price series across the sectors. The similar course of both series is observable in some sectors (e.g. manufacture of fertilisers and nitrogen compounds), while other industrial branches can be characterised through a pronounced divergence of domestic and foreign competitors' prices during the period 1995 – 2008 (e.g. manufacturing of dyes and pigments).

Since no price data on a more frequent basis than monthly is available for sectors of interest and the EU ETS is still in the early stage, the pass-through capacity of additional carbon prices cannot be directly estimated. Instead, we assess the potential pass-through capacity of *domestic* type of cost shocks into sectoral producer prices using price indices for labour, material and energy. According to the Table 1, which contains the sector-specific input shares for 1995 and 2007, expenditures on labour, material and energy costs cover more than 75 percent of the total production costs.

Sectoral labour costs are not available in the same sectoral breakdown as the domestic and foreign producer price indices, i.e. at the 3- and 4-digit level. In our analysis we therefore make use of sector-specific gross wages at the 2-digit level (P_i^{lab}) which come from Eurostat (2010) since they are not available from the German Federal Statistical Office. Four different wage time series are employed. These wages are paid in industries producing paper and paper products (GP 17), chemical products (GP 20), rubber and plastic products (GP 22) and other non-metallic mineral products (GP 23).

The proper identification of applicable material and energy cost indices is an important and challenging task, given the heterogeneity in terms of production inputs across the energy-intensive sectors. To identify the best proxy for material and energy at the sectoral level, we rely on additional data source from the German Federal Statistical Office (Statistisches Bundesamt, 2009) which provides very detailed information on input factors for German sectors at the 2-, 3- and 4-digit level of sectoral disaggregation in the WZ2003

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[12] We plot only data which will be subsequently included into our analysis.

classification.[13] Typically, the production structure includes more than a dozen material and energy input factors. To improve the analysis, we make use of the sector-specific input factor material. The best proxy for the latter at the sectoral level is identified as having the highest input share among all other material input factors in the production.[14] In total, there are six different material input factors. Domestic prices (P_i^{mat}) from the German Federal Statistical Office (Statistisches Bundesamt, 2010a) are used to proxy them.[15] Finally, electricity (P^{ele}) appears to be the most important energy-related input factor.

All data series with the 2005 monthly average as the base value are in logarithms and the seasonally unadjusted indexes except for the labour cost (Gross and Schmitt, 2000).

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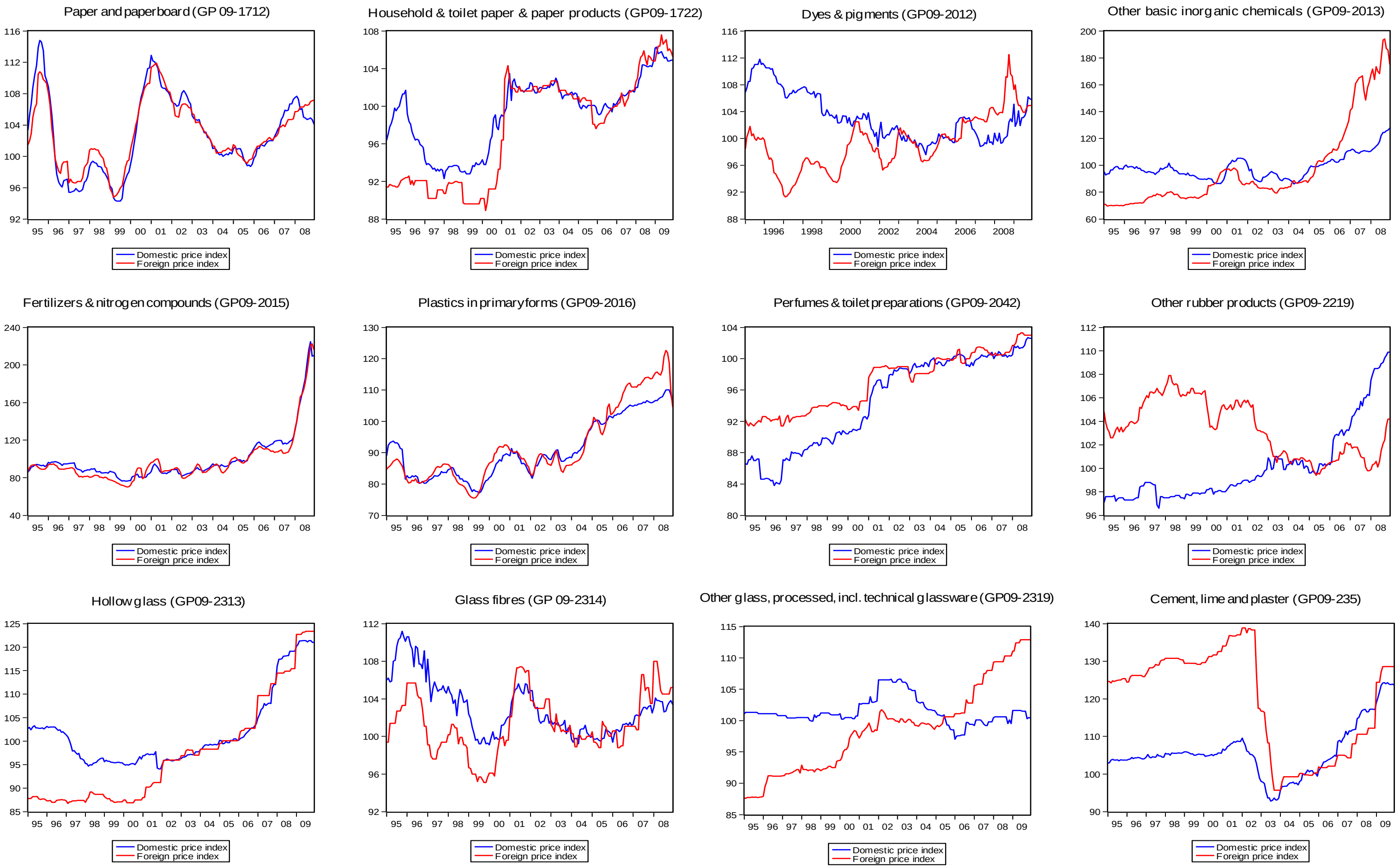
[13] We use concordance tables to assign the sectoral data in the WZ2003 to the GP2009 classification.

[14] In some sectors, material and energy shares are not shown for reasons of confidentiality. We then test alternative proxies.

[15] For example, in order to model the domestic price in the sub-sector dyes and pigments (GP09-2012) P_{2012}^{dom}, we use the (domestic) price index for ferrous metals P_{27}^{mat} to proxy material costs and electricity prices P^{ele} to proxy energy costs since the German Federal Statistical Office (Statistisches Bundesamt, 2009) identifies both input factors as the most important in this sub-category.

Figure 3: Co-movement of domestic and import prices on German markets



Paper and paperboard (GP 09-1712)

Household & toilet paper & paper products (GP09-1722)

Dyes & pigments (GP09-2012)

Other basic inorganic chemicals (GP09-2013)

Fertilizers & nitrogen compounds (GP09-2015)

Plastics in primary forms (GP09-2016)

Perfumes & toilet preparations (GP09-2042)

Other rubber products (GP09-2219)

Hollow glass (GP09-2313)

Glass fibres (GP 09-2314)

Other glass, processed, incl. technical glassware (GP09-2319)

Cement, lime and plaster (GP09-235)

Source: German Federal Statistical Office (Statistisches Bundesamt, 2010a), monthly data from January 1995 to December 2008.

Table 1: Labour, material and energy shares in German EU ETS sectors (% of the gross production value) in 1995 and 2007

Code GP 2009	**Sector**	**Labour**	**Material**	**Energy**	**Labour**	**Material**	**Energy**
		1995			***2007***		
17	*Manufacture of pulp, paper and paper products*						
1712	Manufacture of paper and paperboard				24.9	46.9	10.8
1722	Manufacture of household and toilet paper and paper products	38.8	33.5	3.6	33.1	34.5	4.6
20	*Manufacture of chemicals and chemical products*						
2012	Manufacture of dyes and pigments	30.9	52.8	4.8	30.7	40.3	6.4
2013	Manufacture of other basic inorganic chemicals	29.9	23.4	5.5	27.1	41.6	10.4
2015	Manufacture of fertilizers and nitrogen compounds	26.7	39.0	16.1	33.9	28.3	6.6
2016	Manufacture of plastics in primary forms	30.0	38.1	5.1	25.7	38.2	4.2
2042	Manufacture of perfumes and toilet preparations	53.3	26.6	0.6	41.7	36.6	0.7
22	*Manufacture of rubber and plastic products*						
2219	Manufacture of other rubber products	42.9	31.0	2.5	34.4	38.8	2.2
23	*Manufacture of non-metallic mineral products*						
2313	Manufacture of hollow glass	42.2	24.0	8.8	39.1	20.5	12.0
2314	Manufacture of glass fibres	37.0	24.9	6.5	36.3	26.9	8.1
2319	Manufacture of other glass, processed, incl. technical glassware	52.4	21.7	5.8	50.7	23.6	7.6
235	Manufacture of cement, lime and plaster	33.4	17.7	15.9	37.0	17.7	18.5

Source: German Federal Statistical Office (Statistisches Bundesamt, 2010b)

Note: German Federal Statistical Office (Statistisches Bundesamt, 2010b) provides data for labour, material and energy shares (% of the gross production value) for 1995 and 2007, respectively. Labour costs encompass wages for both permanently and temporally employed workers and social contributions. However, data is available at sectoral level in the WZ2003 classification only. Concordance tables have therefore been used to assign the sectoral data in the WZ2003 to the GP2009 classification which is subsequently used to estimate the cost pass-through rates. In 11 out of 16 sectors, the concordance is unique. For the remaining sectors in the GP2009 classificatoin the following assignments have been done:

GP2009 **2013** -> WZ2003 **24.13** [Manufacture of other basic inorganic chemicals]; GP2009 **2014** -> WZ2003 **24.14** [Manufacture of other basic organic chemical];
GP2009 **2042** -> WZ2003 **24.52** [Manufacture of perfumes and toilet preparations]; GP2009 **2219**-> WZ2003 **25.13** [Manufacture of other rubber products];
GP2009 **2229** -> WZ2003 **25.24** [Manufacture of other plastic products].

2.2.3 Estimation procedure

The first step of the econometric procedure is to test whether all price series are non-stationary: Unit root tests are performed following Dickey and Fuller (1979) and Phillips and Perron (1988). Table 5a.-c. (Appendix) display the results of two alternative versions of the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests with and without a trend for all domestic and foreign producer price series in (logs of) levels and first differences over the sample period from January 1995 to December 2008. It also includes *sector-specific* material and labour costs (Table 6 in Appendix). There are 43 time series in total. If a unit root does not exists, the time series are said to be stationary or integrated of order zero (I(0)). The time series are considered to be integrated of order one (I(1)) if there is a unit root but differencing one time makes them stationary.

In 41 out of 43 cases, ADF and PP tests provide consistent results regarding the integration of order one I(1): The null hypothesis of a unit root in the (logs of) level data cannot be rejected in both models with and without trend at the 99 percent confidence level, while the null hypothesis of non-stationarity is rejected for each of these series after the first differencing at the 99 percent level. The variable P_{2229}^{dom} appears to be integrated of order zero I(0) according to both ADF and PP tests – it will be excluded from the cointegration analysis. Since the results for the remaining variable P_{20}^{lab} are less consistent, we additionally apply the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992). These results confirm that P_{20}^{lab} is non-stationary in levels but stationary in first differences at the reasonable confidence level.

We proceed now to the second step of the econometric analysis by testing whether the linear combination of the respective variables is stationary. In our case there are five I(1) variables in each sectoral model. If so, this finding implies that there is a long-run relationship between the variables. Following Johansen (1988) and Johansen and Juselius (1990), we apply trace and maximum eigenvalue tests to identify the number of cointegration relationships *r* among the respective variables. First, the selection of the deterministic components in the Johansen's cointegration analysis is important as the cointegration rank may depend on the form of the hypothesised cointegration equation. We therefore follow Johansen and Juselius (1992) by testing the joint hypothesis of both rank order and deterministic components and report the results for all deterministic trend cases (Table 7a.-d. in Appendix). Second, Stock and Watson (1993) show that Johansen's analysis is sensitive to the lag lengths used in the VAR models.

The optimal lag length obtained with the Akaike information criterion (AIC) becomes, however, questionable if residuals remain autocorrelated, heteroscedastic or “deviate too much from Gaussian white noise” (Johansen, 1995).[16] As a remedy, one may add one or more lags for each variable. Alternatively or additionally, economically meaningful dummy variables (Table 8 in Appendix) may be needed (see further: Strauß, 2004; Farzanegan and Markwardt, 2009). To minimise the effect of seasonal fluctuations, we make use of centred (orthogonalised) seasonal dummy variables which are factored in (Johansen, 1995).

There is strong evidence – relying on a more powerful maximum eigenvalue tests (Johansen and Juselius, 1990) – that in 12 out of 15 sectors, domestic output prices, foreign output prices, wages, material and energy input costs cointegrate with at least one cointegrating vector. The null hypothesis that the system’s rank is zero $(r = 0)$ cannot be rejected at the 5 percent significance level for the following three sectors: manufacture of abrasive products, manufacture of other basic organic chemicals and manufacture of basic pharmaceutical products – these sectors will be excluded from the further analysis. In all sectors with the system’s rank of one, the more encompassing model with statistically significant time trend in the cointegration equation was selected (Table 7a.-d. in Appendix, column five) except for producers of paper and paperboard, manufacturers of other basic inorganic chemicals and processed, including technical glassware. In the latter case, the model with only an intercept in the cointegration equation was preferred due to an insignificant time trend.

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[16] These assumptions were clearly violated in our basis models (i.e. lag length obtained through the minimisation of the Akaike information criterion (AIC) and no (impulse) dummy variable).

2.3 Estimation results

2.3.1 Discussing the cost pass-through relationships

Table 2a.-b. provide estimation results on long-run cost pass-through elasticities for labour, material and energy costs in energy-intensive sectors in Germany. For example, a 1 percent increase in wages lets the domestic producer price in the sector producing dyes and pigments (GP09-2012) rise by 0.27 percent. In our sample, 71 percent of all coefficients in the cointegration equations are significant and have the expected sign (the share of coefficients with an expected positive sign is even higher if we restrict to significant coefficients only: 75 percent). Coefficients with a negative sign mainly relate to the material input factors – one potential underlying reason could be some measurement problems in the respective time series. The magnitude of the estimated coefficients – with only one exception – is plausible when shares of individual input factors from Table 1 are taken into consideration.

We use "the rule of thumb" to group all sectors into the categories with low (*l*), medium (*m*) and high (*h*) pass-through potential (Table 3). This grouping depends on how many types of cost shocks can be passed on to consumers and on the size of pass-through elasticities.[17] Table 3 shows that the pass-through potential varies significantly across the industries. Thereby, producers of cement, lime and plaster and other rubber products are found to be capable to pass-through all three types of cost shocks (labour, material and energy) which represent roughly 75 percent of the total costs. Four industrial branches – household and toilet paper; dyes and pigments; plastics in primary forms and hollow glass –are capable to pass-through cost shocks of two input factors representing roughly 40 percent of total production costs. The remaining industries pass-through only a small fraction of domestic cost shocks, if any at all. Additional costs induced by the EU ETS are therefore likely to be absorbed through a reduction of profit margins in most energy-intensive sectors, creating, however, rather strong incentives to relocate business abroad in sectors with low pass-through potential only.

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[17] One reason why we decided to use "the rule of thumb" is because testing the coefficients against the input's share of total cost in a single year is not informative. Table 1 suggests that expenditure shares between 1995 and 2007 have been changed, possibly due to the input substitution effect.

Table 2a.: Cost pass-through and strategic pricing coefficients in the long-run equilibrium

Manufacture of paper and paperboard (GP09-1712)				
P_{1712}^{dom}	P_{1712}^{for}	P_{222}^{mat}	P_{17}^{lab}	P^{ele}
-1.00	1.12*** (0.09)	-0.10 (0.27)	0.06 (0.20)	0.01 (0.03)
Manufacture of household and toilet paper and paper products (GP09-1722)				
P_{1722}^{dom}	P_{1722}^{for}	P_{222}^{mat}	P_{17}^{lab}	P^{ele}
-1.00	0.21*** (0.09)	-0.46*** (0.19)	2.03*** (0.21)[18]	0.25*** (0.03)
Manufacture of dyes and pigments(GP09-2012)				
P_{2012}^{dom}	P_{2012}^{for}	P_{27}^{mat}	P_{20}^{lab}	P^{ele}
-1.00	-0.10 (0.09)	-0.06 (0.04)	0.27*** (0.15)	0.09*** (0.02)
Manufacture of other basic inorganic chemicals (GP09-2013)				
P_{2013}^{dom}	P_{2013}^{for}	P_{27}^{mat}	P_{20}^{lab}	P^{ele}
-1.00	0.33*** (0.07)	-0.31*** (0.13)	0.08 (0.39)	0.24*** (0.08)
Manufacture of fertilisers and nitrogen compounds (GP09-2015)				
P_{2015}^{dom}	P_{2015}^{for}	P_{192}^{mat}	P_{20}^{lab}	P^{ele}
-1.00	1.13*** (0.10)	-0.23*** (0.08)	-0.56 (0.52)	0.28*** (0.06)
Manufacture of plastics in primary forms (GP09-2016)				
P_{2016}^{dom}	P_{2016}^{for}	P_{192}^{mat}	P_{20}^{lab}	P^{ele}
-1.00	0.22* (0.14)	0.15* (0.10)	-0.10 (0.29)	0.10** (0.05)
Manufacture of perfumes and toilet preparations (GP09-2042)				
P_{2042}^{dom}	P_{2042}^{for}	P_{222}^{mat}	P_{20}^{lab}	P^{ele}
-1.00	0.64*** (0.22)	-0.35** (0.23)	0.06 (0.16)	-0.10 *** (0.02)
Manufacture of other rubber products (GP09-2219)				
P_{2219}^{dom}	P_{2219}^{for}	P_{2017}^{mat}	P_{22}^{lab}	P^{ele}
-1.00	0.47* (0.29)	0.29*** (0.08)	0.66*** (0.27)	0.06* (0.04)
Manufacture of hollow glass (GP09-2313)				
P_{2313}^{dom}	P_{2313}^{for}	P_{201}^{mat}	P_{23}^{lab}	P^{ele}
-1.00	0.73*** (0.12)	0.48*** (0.06)	0.37*** (0.10)	0.02 (0.03)

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[18] The pass-through ability of labour costs in the sector manufacturing of household and toilet paper and paper products (GP09-1722) is with 2.03% disproportionally high. This is somewhat surprising but such a high elasticity of input factors with respect to the output prices is occasionally found in the empirical literature.

Table 2b.: Cost pass-through and strategic pricing coefficients in the long-run equilibrium

Manufacture of glass fibres (GP09-2314)				
P_{2314}^{dom}	P_{2314}^{for}	P_{201}^{mat}	P_{23}^{lab}	P^{ele}
-1.00	0.51*** (0.07)	0.25*** (0.04)	-0.01 (0.04)	-0.00 (0.01)
Manufacture of other glass, processed, incl. technical glassware (GP09-2319)				
P_{2319}^{dom}	P_{2319}^{for}	P_{201}^{mat}	P_{23}^{lab}	P^{ele}
-1.00	-0.09 (0.20)	0.43*** (0.12)	0.05 (0.13)	-0.14*** (0.05)
Manufacture of cement, lime and plaster (GP09-235)				
P_{235}^{dom}	P_{235}^{for}	P_{20}^{mat}	P_{23}^{lab}	P^{ele}
-1.00	0.37*** (0.03)	0.11** (0.07)	0.39*** (0.08)	0.18*** (0.02)

Note: Numbers in parenthesis are standard errors of estimated parameters. *** (** and *) denotes significance at the 1 percent (5 percent and 10 percent) level.

Table 3: Passing-through domestic costs in the long-run equilibrium

Code GP 2009	**Sectors**	**Labor CPT**	**Material CPT**	**Energy CPT**	**Total CPT**
1712	Manufacture of paper and paperboard	(□)		(□)	*l*
2013	Manufacture of other basic inorganic chemicals		(□)	□	*l*
2015	Manufacture of fertilizers and nitrogen compounds			□	*l*
2042	Manufacture of perfumes and toilet preparations		(□)		*l*
2314	Manufacture of glass fibres		□		*l*
2319	Manufacture of other glass, processed, incl.	(□)	□		*l*
1722	Manufacture of household and toilet paper	□		□	*m*
2012	Manufacture of dyes and pigments	□		□	*m*
2016	Manufacture of plastics in primary forms		□	□	*m*
2313	Manufacture of hollow glass	□	□	(□)	*m*
2219	Manufacture of other rubber products	□	□	□	*h*
235	Manufacture of cement, lime and plaster	□	□	□	*h*

Note: Acronyms of the variables are ***l*** (low pass-through potential), ***m*** (medium pass-through potential) and ***h*** (medium pass-through potential). Only coefficients with an expected (positive) sign are considered; significant coefficients are marked with “v”, not-significant coefficients are marked with ”(v)”.

Turning now to the strategic component in our estimations, empirical evidence illustrates that all German EU ETS sectors, except for producers of dyes and pigments and other glassware, take prices of foreign competitors into consideration and have therefore a *flexible* mark-up over marginal costs. For example, following a 1 percent competitors' price increase, manufacturers of cement, lime and plaster increase domestic prices by 0.37 percent. Hence, firms "capitalise" on the opportunity to increase their own prices if foreign competitors start charging higher prices. Alternatively, one might interpret these elasticities as "willingness" to alter mark-up if facing domestic price shocks (Clostermann, 1996).

In section 2.1 we argued that strategic interactions between domestic and foreign producers under conditions of imperfect competition will limit the ability of producers to pass-through domestic cost shocks. Contrary to expectations from equations (12) and (13), the adding-up restrictions on estimated elasticities are not always fulfilled in practice. This might occur due to the index aggregation problem which plagues both domestic and foreign price series. Notwithstanding that the evidence is somewhat inconclusive, the following interrelationship holds for most sectors: the higher the impact of foreign prices, the lower the ability to pass-through the domestic cost shocks, and vice versa. For example, domestic prices are set (almost) exclusively with respect to foreign producers' prices in sectors producing paper and paperboard and fertilisers and nitrogen compounds. In these industries, we observe that the potential to pass-through domestic costs is rather limited.

Now, we are interested in explaining the differences across sectors in terms of the cost pass-through and strategic interactions with foreign competitors. Theoretical framework in section 2.1 suggests that cost pass-through rate in strategic oligopoly depends on the following four factors: the substitutability between domestic and foreign varieties, market shares of domestic and foreign firms, relative prices of domestic and foreign firms and the conjectural variation.

Data on industrial characteristics as reported in Table 4 are used to explain the variation in the pass-through across sectors. First, the substitutability between domestic and foreign varieties is difficult to proxy. We therefore make use of a more general approach measuring the level of product homogeneity in each sector. To account for the degree of product homogeneity across the sectors, we report the number of subsectors at the NACE 9-digit level for each sector in our sample. We assume that the higher the number of sub-sectors, the more heterogeneous (at the lower level of sectoral disaggregation) the product markets are. Second, to measure how the German market is split between domestic and foreign producers we calculate the quotient of import values in each sector over the revenues of domestic firms gained in German market in the same sector. Third, the conjectural variation is hard to measure too. We therefore rely only on the data from the Monopolies Commission (Monopolkommission, 2008) on the concentration degree in German energy-intensive sectors. According to Table 9 (Appendix) which describes the distribution of the Herfindahl-Hirschman index in German sectors at the NACE 4-digit level, each of sectors in our sample possesses a significant degree of market concentration: The sectoral Herfindahl-Hirschman indices in our sample are well above the median value (495.21) in all sectors except for producers of paper and paperboard. Fourth, relative prices of domestic and foreign prices are not explicitly reported in Table 4 but the corresponding plots can be found in Figure 3.

Table 4 suggests that the impact on the pass-through is ultimately determined by the interplay of individual effects working in different directions. We find that in more homogenous product markets – dyes and pigments; fertilisers and nitrogen compounds; other rubber products; hollow glass, glass fibres, other glass, processed, incl. technical glassware; cement, lime and plaster – the higher the market power, the lower in general the cost pass-through and the more pronounced the adjustment towards the foreign producers. Among these industries, producers of fertilisers and nitrogen compounds, glass fibres and other glass (incl. technical) glassware have the highest market power (Herfindahl-Hirschman index values varying between 1625 and 4013) and the lowest pass-through potential. It is worth stressing that all remaining sectors (cement, lime and plaster; other rubber products and hollow glass) have lower market power and higher cost pass-through rates. The graphical inspection of plots in Figure 3 depicts that in two sectors (cement, lime and plaster and other rubber products) the prices of foreign competitors were above the domestic prices over a long period of time – this might have significantly facilitating the pass-through of domestic costs to consumers in the past as indicated by high cost pass-through rates. Given the fact that foreign producers serve a relatively small fraction of German market in the cement, lime and plaster sector and despite the fact that the price gap has recently disappeared, the significant potential to pass-through domestic costs might still persist in the future. In contrast, the domestic producers of other rubber products might be exposed to a significant competitive pressure from foreign producers limiting the potential to pass-through domestic costs.

In more heterogeneous product markets – paper and paperboard; household and toilet paper; plastics in primary forms and perfumes and toilet preparations – the higher market concentration of domestic firms is, the higher the cost pass-through rate and the less pronounced the orientation towards the foreign producers' prices. Consider manufacturers of plastics in primary forms and perfumes and toilet preparations which are exposed to a high penetration rate of foreign producers (0.83 and 0.92, respectively). The former industry is the second most concentrated sector in our sample (10 percent of most concentrated sectors in Germany). It is capable to pass-through a significant fraction of the domestic costs to consumers in the long-run with a moderate orientation towards the price development of foreign producers. The latter sector is much less concentrated – this results in much higher orientation towards the competitors' prices and the disability to pass-through costs in the long-run. The observation that market concentration in heterogeneous markets leads to higher cost pass-through rates is confirmed also for the manufacturers of paper and paperboard and household and toilet paper and paper products. The relatively low cost pass-through rate by producers of other basic inorganic chemicals (GP 2013) seems to be driven rather by the extreme high penetration of the market by the foreign producers (import/domestic revenue ratio: 2.03) than by the level of product homogeneity and the market power.

Table 4: Market shares of domestic and foreign producers, the level of product homogeneity and market concentration in energy-intensive sectors

Code GP 2009	**Sector**	**Import value relative to the revenues of German producers in domestic market**[19]	**Number of sub-sectors at the NACE 9-digit level**	**Herfindahl-Hirschman index**[20]
17	*Manufacture of pulp, paper and paper products*			
1712	Manufacture of paper and paperboard	0.38	11.00	344.86
1722	Manufacture of household & toilet paper and paper products	0.36	11.00	849.53
20	*Manufacture of chemicals and chemical products*			
2012	Manufacture of dyes and pigments	1.18	4.00	903.03
2013	Manufacture of other basic inorganic chemicals	2.03	14.00	549.10
2015	Manufacture of fertilizers and nitrogen compounds	0.92	5.00	4013.88
2016	Manufacture of plastics in primary forms	0.83	14.00	2606.04
2042	Manufacture of perfumes and toilet preparations	0.94	12.00	861.38
22	*Manufacture of rubber and plastic products*			
2219	Manufacture of other rubber products	0.78	7.00	533.14
23	*Manufacture of non-metallic mineral products*			
2313	Manufacture of hollow glass	0.44	4.00	701.75
2314	Manufacture of glass fibres	1.55	3.00	1902.67
2319	Manufacture of other glass, processed, incl. technical glassware	0.72	4.00	1625.59
235	Manufacture of cement, lime and plaster	0.08	3.00	898.49

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[19] The data for this level of sectoral disaggregation are available for the year 2008 only.

[20] Concentration degree as measured by the Herfindahl-Hirschman index (in absolute values multiplied by 10.000). The reference year is 2005.

Source: Own calculations based on data from the Monopolies Commission (Monopolkommission, 2008) and the German Federal Statistical Office (Statistisches Bundesamt 2010c, d).

To sum up, our results provide evidence for a significant role of included industrial characteristics in explaining the extent of the cost pass-through. In most theoretical and empirical papers, market concentration reduces the pass-through potential. This result holds in our sample for more homogenous product markets. High market power of domestic firms on relatively homogenous product markets leads to lower cost pass-through rates and to the more pronounced orientation towards the foreign producers' prices. Drawing on the specific example from manufacturing of fertilisers and nitrogen compounds, a sector with the highest degree of concentration in our sample and among the most concentrated industrial sectors in Germany, domestic prices can even be set almost exclusively with respect to foreign producers' prices. The higher the market concentration of domestic firms in more heterogeneous product markets, the higher the cost pass-through potential and the less pronounced the adjustment towards the foreign producers' prices.

Finally, we observe a considerable heterogeneity with respect to the magnitude and the speed of the short-run pass-through potential across sectors.[21] Even in industries with the high pass-through, the short-run cost pass-through potential varies substantially: While producers of cement, lime and plaster and other rubber products appear to bear a very significant fraction of cost increases over a long-time horizon, German manufacturers of hollow glass are found to rapidly pass-through costs to consumers. Moreover, there is a difference between the short-run and the long-run degree of the pass-through: Sectors which are not able to pass-through costs in the long-run appear to be capable to pass-through at least a fraction of cost increases in the short run (e.g. manufacturers of paper and paperboard).

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[21] The estimations of the short-run cost pass-through coefficients are available upon request.

2.3.2 Discussing tests for Granger causality and misspecification

The existence of one cointegrating vector suggests that there must be Granger causality in at least one direction in each sectoral VEC model. While the direction of causation is not evident, we tested it by reviewing the significance of the error-correction terms (long-run causality) and by observing the significance of the lagged differences of the respective variables (short-run causality). The following patterns emerge: All estimated error correction terms which are reported in the ECM for domestic prices (Table 10a.-b. in Appendix, second column) have the correct sign and are statistically significant. Hence, we observe the long-run causality running from input factor prices and foreign output prices to domestic prices. Obviously, domestic prices in these sectors are Granger-caused in the long-run by competitors' prices (and input factor prices). In some sectors, there is also the long-run causality running to foreign prices and/or input factors.

Diagnostic statistics suggest that sectoral VEC models are reasonably specified (Table 11 in Appendix): All specifications pass the autocorrelation and heteroscedasticity tests except for manufacturing of paper and paperboard. However, the Jarque-Bera (JB) test rejects the null hypothesis of normality of the residuals in most cases: The decomposition of the JB statistic into tests using separate measures of skewness and kurtosis demonstrate that the deviation from normality is due to excess kurtosis. In the applied work, VEC residuals are apparently found to be non-normally distributed (Johansen and Juselius, 1990; Juselius and MacDonald, 2000; Bjørnland and Hungnes, 2002). Since the properties of the VEC models are not very sensitive to deviations from the normality due to excess kurtosis, we consider our results to be still valid (see further: Gonzalo, 1994).

2.4 Conclusions and suggestions for further research

For the EU policy makers, the risk of sector-specific carbon leakage is at the centre of discussions on how to design climate policy under globally asymmetric carbon constraints. To assess the exposure of energy-intensive sectors, the potential for carbon leakage under the EU ETS is linked in this chapter to the sectoral ability to transmit some of the costs on to consumers.

For our analysis, we have combined time series of domestic costs and producers' prices with data on import prices to estimate the pass-through potential in 12 German energy-intensive industries. The estimated cost pass-through relationships differ from the traditional approach in the empirical research: The inclusion of the foreign competitors' prices as the dependent variable in the respective pass-through equation zoom in the analysis on the pass-through as an outcome of interactions between domestic and foreign firms in a particular industrial and market environment. The relatively low long-run cost pass-through rates in our sample – in comparison to studies which do not consider strategic interactions – are consistent with both predictions from the theoretical model and earlier findings of Gross and Schmitt (2000). We found that high market power of domestic firms on more homogenous product markets leads to lower cost pass-through rates and to the more pronounced orientation towards the foreign producers' prices. The higher the market concentration of domestic firms in more heterogeneous product markets, the higher the cost pass-through potential and the less pronounced the adjustment towards the foreign producers' prices.

In the long-run equilibrium, most German energy-intensive sectors in our sample raise prices less than proportionally when facing domestic cost shocks. Contrary to the study by Fitzgerald et al. (2009), the extent of cost pass-through significantly varies not only across energy-intensive sectors, but also within the respective industry at the sub-sectors level. Producers in 6 out of 12 industries – paper and paperboard, basic inorganic chemicals, fertilisers and nitrogen compounds, perfumes and toilet preparations, glass fibres and other glassware – are found to pass on only a small fraction of domestic cost shocks to consumers (if any at all!). Additional costs induced by the EU ETS are therefore likely to be absorbed through a reduction of profit margin, rather than through decreasing market shares. For the remaining industries, empirical results give support for medium to high pass-through elasticities, with cement and rubber manufacturing ranging among the sectors with the highest pass-through potential (rouhgly 75 percent of total costs).

The results in this paper cast doubt on the usefulness of too generous provision of preferential treatment to German energy-intensive sectors which makes climate policy more costly. Using our findings as a criterion to assess the vulnerability, we conclude that few sectors only shall be shortlisted to receive preferential treatment in the third phase of the EU ETS from 2013 on. Severe risk of carbon leakage is concentrated in Germany in industries producing paper and paperboard, basic inorganic chemicals as well as fertilisers and nitrogen compounds. Those sectors are found to pass-through insignificant fraction of total costs in the long-run equilibrium. At the same time, the additional (ETS-related) costs in these industries are expected to raise the total costs by roughly 10 to 25 percent (cf. Graichen et al., 2008). Severe implications on profit margins in sectors with medium to high cost pass-through rates are rather unlikely, though they still might be forced to move factories out of the EU's borders due to an adverse impact on market shares.

Besides the issues of the vulnerability, our findings are directly related to the recent discussion on appropriate countermeasures to delimitate carbon leakage in the energy-intensive sectors in the EU. In particular, the current proposal of the European Commission to possibly introduce “additional and alternative means” to address the risk of carbon leakage, most notably through the inclusion of imports into the EU ETS, needs to be put into perspective (EU, 2010a). Perhaps the most interesting result in this paper is that most of the German EU ETS sectors have a *flexible* mark-up over marginal costs. In the oligopolistic framework with strategic interactions firms’ decisions on how to adjust market shares *and* profit margins are endogenous to a particular shock. The main insight from the empirical part is that the hypothesis of strategic interactions with foreign competitors holds for the most of the EU ETS sectors in Germany. Introducing additional offsetting instruments – e.g. the inclusion of importers into the EU ETS – is likely to produce an opportunity for domestic firms to “capitalise” on increasing prices of foreign competitors.

We close with limitations of our study and suggestions on future work. First, a shortcoming of the used data set refers to the small number of energy-intensive sectors with a sufficient time horizon for which domestic producer prices and matching foreign price series exist. The limited industry sample does not allow regressing estimates of pass-through elasticities on a number of industry characteristics to receive robust empirical results. Second, since no price data on a more frequent basis than monthly is available for sectors of interest and the EU ETS is still in an early stage, the pass-through capacity of additional carbon prices cannot be directly estimated. Using labour, material and electricity costs as proxy for carbon costs has practical advantage of estimating long-run cost pass-through relationships for few energy-intensive sectors. In doing so, we consider our results to be generalisable to the carbon pricing given that economic burden in considered sectors will mostly depend on indirect CO_2 costs (i.e. the increase of electricity prices) (cf. Graichen et al., 2008). We will, however, leave the design of optimal offsetting instruments to reduce carbon leakage in strategic oligopolies to future research.

In contrast to this chapter, the availability of weakly data at the country level allows directly exploring the ability of European refineries to pass-through costs associated with the introduction of the EU ETS. The next chapter 3 will therefore analyse whether refineries in old and new EU member states were capable to pass-through opportunity costs to consumers in the early phase of the EU ETS in a manner it was observable in the power sector.

2.5 Appendices to chapter 2

2.5.1 Mathematical appendix

Equation (2) and (3)

In order to derive the demand functions (2) for each variant of the composite good x_i, $i = 1,...,n^D$, we solve the dual problem: the expenditure minimization problem, subject to a given level of utility :

$$\max_{x_{di},x_{fj},\lambda} \; L = \sum_{i=1}^{n^D} p_{di}x_{di} + \sum_{j=1}^{n^F} p_{fj}x_{fj} - \lambda[\overline{U}^{-\rho} - a\sum_{i=1}^{n^D} x_{di}^{-\rho} - (1-a)\sum_{j=1}^{n^F} x_{fj}^{-\rho}]\,. \tag{1A}$$

The first order condition (FOC) for the variant x_{di} is given as:

$$\frac{\partial L}{\partial x_{di}} = p_{di} - \lambda\rho a x_{di}^{-\rho-1} \overset{!}{=} 0\,. \tag{2A}$$

In analogy, one receives the following FOC for the variant x_{fj}:

$$\frac{\partial L}{\partial x_{fj}} = p_{fj} - \lambda\rho(1-a)x_{fj}^{-\rho-1} \overset{!}{=} 0\,. \tag{3A}$$

Solving for λ and plugging into (2A) and (3A) yields the following demand functions:

$$x_{di} = p_{di}^{-\frac{1}{\rho+1}} a^{\frac{1}{\rho+1}} [a^{\frac{1}{\rho+1}} \sum_{i=1}^{n^D} p_{di}^{\frac{\rho}{\rho+1}} + (1-a)^{\frac{1}{\rho+1}} \sum_{j=1}^{n^F} p_{fj}^{\frac{\rho}{\rho+1}}]^{\frac{1}{\rho}} \cdot \overline{U} \tag{4A}$$

and

$$x_{fj} = p_{fj}^{-\frac{1}{\rho+1}} (1-a)^{\frac{1}{\rho+1}} [a^{\frac{1}{\rho+1}} \sum_{i=1}^{n^D} p_{di}^{\frac{\rho}{\rho+1}} + (1-a)^{\frac{1}{\rho+1}} \sum_{j=1}^{n^F} p_{fj}^{\frac{\rho}{\rho+1}}]^{\frac{1}{\rho}} \cdot \overline{U}\,. \tag{5A}$$

The expenditure function is given by:

$$E=\sum_{i=1}^{n^D} p_{di}x_{di}+\sum_{j=1}^{n^F} p_{fj}x_{fj}=\sum_{i=1}^{n^D} p_{di}^{\frac{\rho}{\rho+1}}a^{\frac{1}{\rho+1}}[a^{\frac{1}{\rho+1}}\sum_{i=1}^{n^D} p_{di}^{\frac{\rho}{\rho+1}}+(1-a)^{\frac{1}{\rho+1}}\sum_{j=1}^{n^F} p_{fj}^{\frac{\rho}{\rho+1}}]^{\frac{1}{\rho}}\cdot\bar{U}+ \tag{6A}$$
$$\sum_{j=1}^{n^F} p_{fj}^{\frac{\rho}{\rho+1}}(1-a)^{\frac{1}{\rho+1}}[a^{\frac{1}{\rho+1}}\sum_{i=1}^{n^D} p_{di}^{\frac{\rho}{\rho+1}}+(1-a)^{\frac{1}{\rho+1}}\sum_{j=1}^{n^F} p_{fj}^{\frac{\rho}{\rho+1}}]^{\frac{1}{\rho}}\cdot\bar{U}$$

or

$$E=PX=\underbrace{\left[a^{\sigma}\sum_{i=1}^{n^D} p_{di}^{1-\sigma}+(1-a)^{1-\sigma}\sum_{j=1}^{n^F} p_{fj}^{1-\sigma}]^{\frac{1}{1-\sigma}}\right]}_{P}\cdot\underbrace{\left[a\sum_{i=1}^{n^D} x_{di}^{\frac{\sigma-1}{\sigma}}+(1-a)\sum_{j=1}^{n^F} x_{fj}^{\frac{\sigma-1}{\sigma}}]^{\frac{\sigma}{\sigma-1}}\right]}_{X}. \tag{7A}$$

Plugging P and X from (7A) in (4A) and (5A) yields the demand function for domestic and foreign varieties:

$$x_{di}=a^{\sigma}X\left[\frac{p_{di}}{P}\right]^{-\sigma} \tag{2}$$

and

$$x_{fj}=(1-a)^{\sigma}X\left[\frac{p_{fj}}{P}\right]^{-\sigma}. \tag{3}$$

Equation 9

The profits of the domestic firm k which is identical to other $n^D - 1$ domestic firms but not to n^F foreign firms is given by:

$$\max_{p_{dk}} \pi_{dk} = \left(p_{dk} - c_{dk} \right) x_{dk} . \tag{5}$$

The FOC is defined by:

$$\frac{\partial \pi_{dk}}{\partial p_{dk}} = x_{dk} + (p_{dk} - c_{dk}) \left[-\sigma a^{\sigma} p_{dk}^{-\sigma-1} X P^{\sigma} + \sigma a^{\sigma} X p_{dk}^{-\sigma} P^{\sigma-1} \frac{\partial P}{\partial p_{dk}} \right] \overset{!}{=} 0 . \tag{8A}$$

Using (7), the equation (8A) can be restated as:

$$1 + (p_{dk} - c_{dk}) \cdot (\sigma) \cdot (\varepsilon - 1) / p_{dk} \overset{!}{=} 0 . \tag{8}$$

Solving (8) for p_{dk} we obtain the first order condition:

$$p_{dk} = \left[1 - \frac{1}{\sigma \cdot (1 - \varepsilon)} \right]^{-1} \cdot c_{dk} = \mu_{dk} \cdot c_{dk} . \tag{9}$$

Equation (11)

Totally differentiating (4), we obtain:

$$dP = \frac{\partial P}{\partial p_{dk}} dp_{dk} + \sum_{i}^{n^D - 1} \frac{\partial P}{\partial p_{di \neq k}} dp_{di \neq k} + \sum_{j}^{n^F} \frac{\partial P}{\partial p_{df}} dp_{df} , \tag{9A}$$

and hence:

$$\varepsilon = \frac{dP}{P} \cdot \frac{p_{dk}}{dp_{dk}} = \frac{1}{1 + (n^d - 1)[1 - \omega] + \frac{(1-a)^{\sigma}}{a^{\sigma}} n^F [1 - \omega] \left(\frac{p_{fj}}{p_{di}} \right)^{1-\sigma}} \tag{10A}$$

Using that $p_{dk} = p_{di \neq k}$ one obtains the equation (11):

$$\varepsilon \equiv \frac{1}{\omega + (1-\omega)\left[n^D + \frac{(1-a)^\sigma}{a^\sigma} n^F \left(\frac{p_{fj}}{p_{di}} \right)^{1-\sigma} \right]}. \qquad (11)$$

2.5.2 List of tables and dummy variables

Table 5a: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root test on domestic output prices

Variables	**ADF**				**PP**			
	Level		**First-diff.**		**Level**		**First-diff.**	
	Model				***Model***			
	Constant	**Constant & trend**	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**	**Constant**	**Constant & Trend**
P_{1712}^{dom}	-3.40^{**}	-3.52^{**}	-4.17^{***}	-4.19^{***}	-2.22	-2.26	-5.77^{***}	-5.76^{***}
P_{1722}^{dom}	-0.54	-1.39	-11.94^{***}	-11.96^{***}	-0.82	-1.65	-12.04^{***}	-12.04^{***}
P_{2012}^{dom}	-1.53	-1.97	-14.57^{***}	-14.57^{***}	-1.44	-1.91	-14.59^{***}	-14.60^{***}
P_{2013}^{dom}	-0.88	-1.64	-5.62^{***}	-5.73^{***}	-0.30	-1.16	-9.97^{***}	-10.03^{***}
P_{2014}^{dom}	-1.87	-3.75^{**}	-3.96^{***}	-3.90^{**}	-1.04	-2.83	-9.03^{***}	-8.95^{***}
P_{2015}^{dom}	1.84	0.44	-5.32^{***}	-8.27^{***}	2.58	1.03	-7.87^{***}	-8.27^{***}
P_{2016}^{dom}	-0.64	-3.27^{*}	-8.94^{***}	-9.08^{***}	-0.52	-2.41	-8.92^{***}	-9.07^{***}
P_{2042}^{dom}	-0.64	-1.72	-12.50^{***}	-12.46^{***}	-0.65	-1.80	-12.50^{***}	-12.46^{***}
P_{2110}^{dom}	-0.97	-2.21	-14.26^{***}	-14.22^{***}	-0.90	-2.21	-14.53^{***}	-14.50^{***}
P_{2219}^{dom}	2.11	0.04	-12.39^{***}	-10.85^{***}	2.13	0.04	-12.38^{***}	-12.88^{***}
P_{2229}^{dom}	-3.7^{***}	-3.52^{**}	-13.35^{***}	-13.39^{***}	-3.72^{***}	-3.55^{**}	-13.38^{***}	-13.42^{***}
P_{2313}^{dom}	2.72	0.61	-4.90^{***}	-12.29^{***}	1.84	0.47	-11.62^{***}	-12.34^{***}
P_{2314}^{dom}	-1.59	-1.41	-15.73^{***}	-15.72^{***}	-1.76	-1.80	-15.54^{***}	-15.56^{***}
P_{2319}^{dom}	-1.28	-1.34	-13.35^{***}	-13.34^{***}	-1.28	-1.34	-13.35^{***}	-13.34^{***}
P_{2391}^{dom}	-1.65	-1.63	-12.85^{***}	-12.83^{***}	-1.67	-1.65	-12.85^{***}	-12.83^{***}
P_{235}^{dom}	-0.42	-0.56	-6.52^{***}	-6.69^{***}	-0.44	-0.56	-10.86^{***}	-10.97^{***}

Table 5b.: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root test on foreign output prices

Variables	ADF				PP			
	Level		First-diff.		Level		First-diff.	
	Model				*Model*			
	Constant	Constant & Trend	Constant	Constant & trend	Constant	Constant & trend	Constant	Constant & trend
P_{1712}^{for}	-2.70*	-2.80	-4.82***	-4.83***	-2.14	-2.20	-7.95***	-7.92***
P_{1722}^{for}	-1.11	-2.30	-6.55***	-6.54***	-0.89	-1.97	-12.22***	-12.19***
P_{2012}^{for}	-1.68	-3.48**	-6.11***	-6.27***	-0.85	-2.11	-11.03***	-11.11***
P_{2013}^{for}	0.75	-1.05	-9.46***	-9.61***	1.13	-0.85	-9.44***	-9.60***
P_{2014}^{for}	-1.38	-3.21*	-7.19***	-7.19***	-1.06	-2.85	-7.14***	-7.15***
P_{2015}^{for}	0.36	-1.08	-6.90***	-7.23***	3.38	1.54	-6.62***	-6.72***
P_{2016}^{for}	-1.21	-3.16*	-6.12***	-6.08***	-0.89	-2.21	-4.60***	-4.56***
P_{2042}^{for}	-0.47	-2.84	-12.16***	-12.13***	-0.48	-2.96	-12.15***	-12.11***
P_{2110}^{for}	-1.75	-1.97	-10.53***	-10.52***	-1.81	-1.91	-10.54***	-10.53***
P_{2219}^{for}	-1.40	-1.75	-9.27***	-9.25***	-1.48	-1.52	-9.34***	-9.32***
P_{2229}^{for}	-2.44	-2.43	-9.85***	-9.82***	-2.35	-2.35	-9.85***	-9.82***
P_{2313}^{for}	1.67	-1.49	-10.94***	-11.24***	1.57	-1.53	-10.92***	-11.13***
P_{2314}^{for}	-1.86	-1.98	-11.41***	-11.38***	-2.11	-2.22	-11.41***	-11.38***
P_{2319}^{for}	0.03	-1.63	-11.70***	-11.67***	-0.05	-1.80	-11.65***	-11.63***
P_{2391}^{for}	-1.62	-1.65	-11.47***	-11.44***	-1.80	-1.83	-11.47***	-11.44***
P_{235}^{for}	-1.10	-1.72	-7.83***	-7.80***	-1.09	-1.51	-7.76***	-7.74***

Table 5c.: Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root test on input prices

Variables	**ADF**				**PP**			
	Level		**First-diff.**		**Level**		**First-diff.**	
	Model				***Model***			
	Constant	**Constant & trend**	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
P_{17}^{lab}	-0.79	-1.99	-11.34***	-11.30***	-1.57	-3.51**	-26.98***	-27.62***
P_{20}^{lab}	-1.48	-1.16	-11.59***	-11.71***	-4.29***	-4.27***	-27.59***	-31.11***
P_{22}^{lab}	-0.51	-2.48	-6.62***	-6.58***	-0.86	-2.70	-17.60***	-17.52***
P_{23}^{lab}	-1.84	-0.87	-13.00***	-13.17***	-1.53	-1.97	-19.15***	-19.24***
P^{ele}	0.01	-0.84	-9.61***	-10.21***	-0.10	-0.76	-9.75***	-10.21***
P_{222}^{mat}	-0.56	-2.13	-7.12***	-7.08***	0.18	-1.58	-7.03***	-6.82***
P_{27}^{mat}	-0.91	-2.68	-4.18***	-9.74***	0.06	-1.99	-10.11***	-10.15***
P_{2017}^{mat}	0.72	-0.84	-10.55***	-10.78***	0.32	-1.45	-11.18***	-11.24***
P_{192}^{mat}	-1.40	-2.82	-9.21***	-9.20***	-1.26	-2.53	-9.23***	-9.20***
P_{201}^{mat}	-0.35	-2.91	-7.20***	-7.44***	-0.07	-2.13	-7.29***	-7.38***
P_{20}^{mat}	0.02	-2.74	-7.26***	-7.58***	0.40	-1.92	-7.45***	-7.68***

Notes: The sample period is from January 1995 to December 2008. The MacKinnon critical values across the sample are -3.47*** / -2.88**/ -2.58* for the model with a constant and -4.01*** / -3.44** / -3.14* for a model with a constant and a trend at the 1 percent / 5 percent / 10 percent levels of significance. The optimum lag lengths are AIC-based. Test critical values for the PP test are -3.47***/-2.88**/-2.58* for a model with a constant and -4.01***/-3.44**/-3.14* for a model with a constant and a trend at the 1 percent/ 5 percent / 10 percent levels of significance. The notation * (**, ***) means the rejection of the hypothesis at the 10 percent (5 percent or 1 percent) significance level, respectively.

Acronyms of the variables: The superscripts *dom* and *for* indicate domestic and foreign output prices, respectively. For labour, electricity and material we use the superscripts *lab*, *ele* and *mat*. The subscripts represent the number of a sector in the GP 2009 classification at the 2-, 3- and 4-digit level. The corresponding sectors are enumerated in Table 1.

Table 6: Sectoral assignment for input factors material and labour

Price index for input factor material	**Wages**
P_{222}^{mat} Manufacture of plastics products (GP 222) P_{27}^{mat} Manufacture of basic metals (GP 27) P_{2017}^{mat} Manufacture of synthetic rubber in primary forms (GP 2017) P_{192}^{mat} Manufacture of refined petroleum products (GP 192) P_{201}^{mat} Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms (GP 201) P_{20}^{mat} Manufacture of chemicals (GP20)	P_{17}^{lab} Manufacture of paper and paper products (GP 17) P_{20}^{lab} Manufacture of chemical products (GP 20) P_{22}^{lab} Manufacture of rubber and plastic products (GP 22) P_{23}^{lab} Manufacture of other non-metallic mineral products (GP 23)

Table 7a.: Number of cointegrating relations at the 0.05 level (GP09 1712 – 2013)

Manufacture of paper and paperboard (GP09-1712)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	2	2	2	2	2
Max-Eig	2	2	1	2	1

Endogenous variables: P_{1712}^{dom}, P_{1712}^{for}, P_{17}^{lab}, P_{222}^{mat} and P^{ele}; number of selected lags: 5 (AIC: 3); exogenous variables: centred seasonal dummies, d96_01

Manufacture of household and toilet paper and paper products (GP09-1722)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	2	2	2	2	2
Max-Eig	1	1	1	1	1

Endogenous variables: P_{1722}^{dom}, P_{1722}^{for}, P_{17}^{lab}, P_{222}^{mat} and P^{ele}; number of selected lags: 7 (AIC: 4); exogenous variables: centred seasonal dummies, d96_01

Manufacture of dyes and pigments (GP09-2012)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	0	1	1	1	2
Max-Eig	1	1	1	1	2

Endogenous variables: P_{2012}^{dom}, P_{2012}^{for}, P_{20}^{lab}, P_{27}^{mat} and P^{ele}; number of selected lags: 3 (AIC: 3); exogenous variables: centred seasonal dummies, d96_01, d_97_01

Manufacture of other basic inorganic chemicals (GP09-2013)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	1	0	1
Max-Eig	1	1	1	1	1

Endogenous variables: P_{2013}^{dom}, P_{2013}^{for}, P_{20}^{lab}, P_{27}^{mat} and P^{ele}; number of selected lags: 4 (AIC: 2); exogenous variables: centred seasonal dummies, d96_01, d97_01

Table 7b.: Number of cointegrating relations at the 0.05 level (GP09 2014 – 2042)

<table>
<tr><td colspan="6"><i>Manufacture of other basic organic chemicals (GP09-2014)</i></td></tr>
<tr><td>Data Trend:</td><td>None</td><td>None</td><td>Linear</td><td>Linear</td><td>Quadratic</td></tr>
<tr><td>Test Type</td><td>No Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept Trend</td><td>Intercept Trend</td></tr>
<tr><td>Trace</td><td>0</td><td>0</td><td>1</td><td>2</td><td>2</td></tr>
<tr><td>Max-Eig</td><td>0</td><td>0</td><td>0</td><td>0</td><td>0</td></tr>
<tr><td colspan="6">Endogenous variables: P_{2014}^{dom}, P_{2014}^{for}, P_{20}^{lab}, P_{2013}^{mat} and P^{ele}; number of lags: 5 (AIC:2); exogenous variables: centred seasonal dummies, d96_01</td></tr>
</table>

<table>
<tr><td colspan="6"><i>Manufacture of fertilizers and nitrogen compounds (GP09-2015)</i></td></tr>
<tr><td>Data Trend:</td><td>None</td><td>None</td><td>Linear</td><td>Linear</td><td>Quadratic</td></tr>
<tr><td>Test Type</td><td>No Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept Trend</td><td>Intercept Trend</td></tr>
<tr><td>Trace</td><td>1</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Max-Eig</td><td>1</td><td>1</td><td>1</td><td>0[22]</td><td>1</td></tr>
<tr><td colspan="6">Endogenous variables: P_{2015}^{dom}, P_{2015}^{for}, P_{20}^{lab}, P_{192}^{mat} and P^{ele}; number of selected lags: 6 (AIC: 2); exogenous variables: centred seasonal dummies, d96_01</td></tr>
</table>

<table>
<tr><td colspan="6"><i>Manufacture of plastics in primary forms (GP09-2016)</i></td></tr>
<tr><td>Data Trend:</td><td>None</td><td>None</td><td>Linear</td><td>Linear</td><td>Quadratic</td></tr>
<tr><td>Test Type</td><td>No Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept Trend</td><td>Intercept Trend</td></tr>
<tr><td>Trace</td><td>1</td><td>2</td><td>2</td><td>2</td><td>1</td></tr>
<tr><td>Max-Eig</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td colspan="6">Endogenous variables: P_{2016}^{dom}, P_{2016}^{for}, P_{20}^{lab}, P_{2014}^{mat} and P^{ele}; number of lags: 5 (AIC:2); exogenous variables: centred seasonal dummies, d96_01</td></tr>
</table>

<table>
<tr><td colspan="6"><i>Manufacture of perfumes and toilet preparations (GP09-2042)</i></td></tr>
<tr><td>Data Trend:</td><td>None</td><td>None</td><td>Linear</td><td>Linear</td><td>Quadratic</td></tr>
<tr><td>Test Type</td><td>No Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept No Trend</td><td>Intercept Trend</td><td>Intercept Trend</td></tr>
<tr><td>Trace</td><td>2</td><td>2</td><td>2</td><td>1</td><td>1</td></tr>
<tr><td>Max-Eig</td><td>0</td><td>0</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td colspan="6">Endogenous variables: P_{2042}^{dom}, P_{2042}^{for}, P_{20}^{lab}, P_{222}^{mat} and P^{ele}; number of lags: 6 (AIC:2); exogenous variables: centred seasonal dummies, d96_01, d01_01</td></tr>
</table>

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[22] The hypothesis that there is at least one cointegration relationship cannot be rejected at the 0.1 level.

Table 7c.: Number of cointegrating relations at the 0.05 level (GP09 2110 – 2314)

Manufacture of basic pharmaceutical products (GP09-2110)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	0	0	0
Max-Eig	0	0	0	0	0

Endogenous variables: P^{dom}_{2110}, P^{for}_{2110}, P^{lab}_{20}, P^{mat}_{2014} and P^{ele}; number of lags: 4 (AIC:4); exogenous variables: centred seasonal dummies, d96_01

Manufacture of other rubber products (GP09-2219)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	1	1	1
Max-Eig	1	1	1	1	1

Endogenous variables: P^{dom}_{2219}, P^{for}_{2219}, P^{lab}_{22}, P^{mat}_{2017} and P^{ele}; number of lags: 10 (AIC:2); exogenous variables: centred seasonal dummies, d96_01

Manufacture of hollow glass (GP09-2313)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	3	3	3	4	1
Max-Eig	3	2	1	1	1

Endogenous variables: P^{dom}_{2313}, P^{for}_{2313}, P^{lab}_{23}, P^{mat}_{201} and P^{ele}; number of lags: 8 (AIC:4); exogenous variables: centred seasonal dummies, d96_01, d07_01

Manufacture of glass fibres (GP09-2314)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	1	1	1	2	2
Max-Eig	1	1	1	2[23]	2

Endogenous variables: P^{dom}_{2314}, P^{for}_{2314}, P^{lab}_{23}, P^{mat}_{201} and P^{ele}; number of lags: 6 (AIC:2); exogenous variables: centred seasonal dummies, d96_01, d06_08

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[23] Max eigenvalue statistic which fails to reject the hypothesis of 2 cointegrating equations (in favour of 1 cointegration equitation) is very close to the critical value of 0.05.

Table 7d.: Number of cointegrating relations at the 0.05 level (GP09 2319 – 2391)

Manufacture of other glass, processed, incl. (GP09-2319)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept	Intercept	Intercept	Intercept	Intercept
	No Trend	No Trend	No Trend	Trend	Trend
Trace	5	5	2	1	1
Max-Eig	1	1	1	0	0

Endogenous variables: P^{dom}_{2319}, P^{for}_{2319}, P^{lab}_{23}, P^{mat}_{201} and P^{ele}; number of lags: 6 (AIC:2); exogenous variables: centred seasonal dummies

Manufacture of cement, lime and plaster (GP09-235)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept	Intercept	Intercept	Intercept	Intercept
	No Trend	No Trend	No Trend	Trend	Trend
Trace	1	1	1	1	1
Max-Eig	1	0	0	1	1

Endogenous variables: P^{dom}_{235}, P^{for}_{235}, P^{lab}_{23}, P^{mat}_{20} and P^{ele}; number of lags: 5 (AIC: 4); exogenous variables: centred seasonal dummies, d96_01, d02_10

Manufacture of other rubber products (GP09-2391)

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept	Intercept	Intercept	Intercept	Intercept
	No Trend	No Trend	No Trend	Trend	Trend
Trace	5	4	1	0	0
Max-Eig	1	1	0	0	0

Endogenous variables: P^{dom}_{2391}, P^{for}_{2391}, P^{lab}_{23}, P^{mat}_{20} and P^{ele}; number of lags: 5 (AIC: 2); exogenous variables: centred seasonal dummies, d96_01, d00_04

Note: In parentheses we indicate the lag length suggested by the Akaike information criterion (AIC).

Table 8: List of dummy variables

d96_01: The German "Electricity Feed Law" (Stromeinspeisegesetz) which guarantees premium prices for producers of electricity from renewable resources was approved by the German Federal Constitutional Court (Bundesverfassungsgericht). The input factor electricity is used in all sectoral models to proxy the input factor energy. This seems to be the most parsimonious way to achieve the normality (skewness) of residuals in sectoral VEC models.

d97_01: Sharp increase of the steel price following an exceptionally strong growth in demand. The input factor basic metals (GP09-27) is intensively employed in the production of both dyes and pigments (GP09-2012) and other basic inorganic chemicals (GP09-2013) and used in sectoral models to proxy material input, respectively. This seems to be the most parsimonious way to avoid the residual heteroscedasticity in both sectoral VEC models.

d01_01: The dummy is needed to address a price increase of foreign producers of other basic inorganic chemicals (GP 2042) and to achieve the normality of residuals in sectoral VEC model (GP09-2042).

d07_01: Strong price increase by foreign manufacturers of hollow glass (GP09-2313). Dummy was used to achieve the normality (skewness) of residuals in sectoral VEC models.

d06_08: Strong price increase by foreign manufacturers of glass fibres (GP09-2314). Dummy was used to achieve the normality (skewness) of residuals in sectoral VEC models.

d02_10: Strong price decrease by foreign producers of cement, lime and plaster (GP09-235) after a cartel has been discovered. This seems to be the most parsimonious way to achieve the normality in the sectoral VEC model.

Table 9: Distribution of the Herfindahl-Hirschman index (HHI) in German sectors at the NACE 4-digit level

Percentiles	Values of HHI		
1%	2.33		
5%	21.68		
10%	46.27		
25%	125.86	Number of observations	333
50%	495.21	Mean	928.944
75%	1128.45	Std. Dev.	1285.953
90%	2585.00		
95%	3142.59		
99%	6133.18		

Source: Own calculations based on data from the Monopolies Commission (Monopolkommission, 2008)

Table 10a.: Loading coefficients

Manufacture of paper and paperboard (GP09-1712)

	$\Delta P^{dom}_{1712,\ t}$	$\Delta P^{for}_{1712,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{17,\ t}$	$\Delta P^{mat}_{222,\ t}$
ec_{t-1}	-0.15 (0.05)***	0.04 (0.05)	0.29 (0.12)**	-0.09 (0.10)	0.01 (0.10)

Manufacture of household and toilet paper and paper products (GP09-1722)

	$\Delta P^{dom}_{1722,\ t}$	$\Delta P^{for}_{1722,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{17,\ t}$	$\Delta P^{mat}_{222,\ t}$
ec_{t-1}	-0.16 (0.05)***	0.12 (0.06)**	0.50 (0.11)***	0.23 (0.08)***	-0.01 (0.02)

Manufacture of dyes and pigments (GP09-2012)

	$\Delta P^{dom}_{2012,\ t}$	$\Delta P^{for}_{2012,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{20,\ t}$	$\Delta P^{mat}_{27,\ t}$
ec_{t-1}	-0.16 (0.05)***	-0.03 (0.05)	0.09 (0.09)	0.23 (0.10)**	-0.23 (0.07)***

Manufacture of other basic inorganic chemicals (GP09-2013)

	$\Delta P^{dom}_{2013,\ t}$	$\Delta P^{for}_{2013,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{20,\ t}$	$\Delta P^{mat}_{27,\ t}$
ec_{t-1}	-0.10 (0.03)***	-0.01 (0.05)	0.06 (0.03)**	-0.01 (0.03)	-0.08 (0.02)***

Manufacture of fertilizers and nitrogen compounds (GP09-2015)

	$\Delta P^{dom}_{2015,\ t}$	$\Delta P^{for}_{2015,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{20,\ t}$	$\Delta P^{mat}_{192,\ t}$
ec_{t-1}	-0.12 (0.07)**	0.21 (0.07)***	-0.04 (0.05)	-0.12 (0.05)**	0.08 (0.11)

Manufacture of plastics in primary forms (GP09-2016)

	$\Delta P^{dom}_{2016,\ t}$	$\Delta P^{for}_{2016,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{20,\ t}$	$\Delta P^{mat}_{2014,\ t}$
ec_{t-1}	-0.14 (0.04)***	-0.04 (0.04)	0.14 (0.06)***	0.13 (0.06)**	-0.15 (0.06)**

Manufacture of perfumes and toilet preparations (GP09-2042)

	$\Delta P^{dom}_{2042,\ t}$	$\Delta P^{for}_{2042,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{20,\ t}$	$\Delta P^{mat}_{222,\ t}$
ec_{t-1}	-0.24 (0.05)***	0.06 (0.03)**	0.06 (0.13)	0.22 (0.15)*	-0.03 (0.02)

Manufacture of other rubber products (GP09-2219)

	$\Delta P^{dom}_{2219,\ t}$	$\Delta P^{for}_{2219,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{22,\ t}$	$\Delta P^{mat}_{2017,\ t}$
ec_{t-1}	-0.06 (0.02)***	-0.04 (0.02)**	-0.24 (0.07)***	0.15 (0.05)***	0.10 (0.09)

Table 10b: Loading coefficients

Manufacture of hollow glass (GP09-2313)					
	$\Delta P^{dom}_{2313,\ t}$	$\Delta P^{for}_{2313,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{23,\ t}$	$\Delta P^{mat}_{201,\ t}$
ec_{t-1}	-0.10 (0.03)***	-0.08 (0.03)***	-0.25 (0.09)***	0.05 (0.07)	0.20 (0.05)

Manufacture of glass fibres (GP09-2314)					
	$\Delta P^{dom}_{2314,\ t}$	$\Delta P^{for}_{2314,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{23,\ t}$	$\Delta P^{mat}_{201,\ t}$
ec_{t-1}	-0.44 (0.09)***	-0.03 (0.13)	-0.17 (0.20)	0.30 (0.17)*	0.31 (0.12)***

Manufacture of other glass, processed, incl. (GP09-2319)					
	$\Delta P^{dom}_{2319,\ t}$	$\Delta P^{for}_{2319,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{23,\ t}$	$\Delta P^{mat}_{201,\ t}$
ec_{t-1}	-0.03 (0.02)**	-0.06 (0.01)***	-0.11 (0.05)**	-0.00 (0.04)	0.05 (0.02)***

Manufacture of cement, lime and plaster (GP09-235)					
	$\Delta P^{dom}_{235,\ t}$	$\Delta P^{for}_{235,\ t}$	ΔP^{ele}_{t}	$\Delta P^{lab}_{23,\ t}$	$\Delta P^{mat}_{20,\ t}$
ec_{t-1}	-0.19 (0.05)***	0.14 (0.08)**	-0.09 (0.14)	-0.08 (0.11)	0.10 (0.05)**

Note: ec_{t-1} is an error correction term. Numbers in parenthesis are standard error of the estimated parameters. *** (**, *) denotes significance at the 1 percent (5 percent, 10 percent) level. Optimal lag length was set as indicated in Table 7a.-d., respectively.

2.5.3 Diagnostic test results

Table 11: Diagnostic tests for sectoral VEC models

Sectoral VEC model		Autocorrelation				Normality			Heteros.
		LM (3)	LM (6)	LM (9)	LM (12)	Skewness	Kurtosis	JB	WHn
1712	Manufacture of paper and paperboard	18.53 [0.82]	15.44 [0.93]	20.39 [0.72]	26.36 [0.55]	12.77 [0.03]	12.09 [0.03]	24.87 [0.01]	1096 [0.00]
1722	Manufacture of household and toilet paper	31.32 [0.17]	18.01 [0.84]	21.23 [0.68]	26.65 [0.37]	8.81 [0.12]	43.04 [0.00]	51.85 [0.00]	1327 [0.09]
2012	Manufacture of dyes and pigments	23.84 [0.53]	22.83 [0.59]	18.51 [0.82]	48.97 [0.00]	3.93 [0.56]	16.40 [0.01]	20.33 [0.03]	719 [0.12]
2013	Manufacture of other basic inorganic chemicals	35.13 [0.09]	15.84 [0.92]	35.12 [0.09]	45.16 [0.01]	2.93 [0.71]	13.42 [0.02]	16.36 [0.09]	878 [0.10]
2015	Manufacture of fertilizers and nitrogen	17.34 [0.87]	18.48 [0.82]	22.99 [0.58]	37.01 [0.06]	8.47 [0.13]	16.23 [0.01]	24.70 [0.01]	1175 [0.15]
2016	Manufacture of plastics in primary forms	14.18 [0.96]	17.95 [0.84]	13.14 [0.97]	28.33 [0.29]	10.85 [0.05]	20.06 [0.00]	30.91 [0.00]	1043 [0.03]
2042	Manufacture of perfumes and toilet	24.17 [0.51]	8.88 [0.99]	19.31 [0.78]	26.47 [0.38]	8.89 [0.11]	13.95 [0.02]	22.84 [0.01]	1156 [0.36]
2219	Manufacture of other rubber products	45.03 [0.01]	16.29 [0.91]	21.59 [0.66]	35.34 [0.08]	4.28 [0.51]	51.27 [0.00]	55.55 [0.00]	1702 [0.55]
2313	Manufacture of hollow glass	31.25 [0.18]	13.81 [0.96]	34.20 [0.10]	38.05 [0.05]	11.44 [0.04]	43.60 [0.00]	55.04 [0.00]	1389 [0.75]
2314	Manufacture of glass fibres	13.23 [0.97]	19.52 [0.77]	17.40 [0.87]	28.27 [0.30]	10.49 [0.06]	11.93 [0.04]	22.42 [0.01]	1178 [0.21]
2319	Manufacture of other glass, processed, incl.	14.64 [0.95]	19.38 [0.78]	14.84 [0.95]	26.86 [0.36]	35.37 [0.00]	172.1 [0.00]	207.5 [0.00]	1154 [0.17]
235	Manufacture of cement, lime and plaster	30.11 [0.22]	15.53 [0.93]	19.84 [0.76]	24.04 [0.52]	8.37 [0.14]	9.14 [0.10]	17.51 [0.07]	1044 [0.07]

Note: The table reports test statistics and probability values for rejecting the null hypothesis of the following tests: Lagrange Multiplier (LM) autocorrelation test up to the 3rd, 6th and 12th lag (H0: no serial correlation at lag order h); Jarque-Bera normality test (orthogonalisation: Cholesky (Lutkepohl), H0: residuals are multivariate normal); White heteroskedasticity test without cross terms (WHn) (H0: residuals are homoskedastic).

3 Cost Pass-Through of the EU Emissions Allowances: Examining Price Dynamics in European Petroleum Markets[24]

The EU Emissions Trading Scheme (ETS) as a centrepiece to the European climate change policy has been operating since January 2005 (EU, 2003a). The evolvement of the trading scheme encompasses thereby several temporal stages: the first phase of the EU ETS from 2005 until 2007, the second phase from 2008 until 2012 which coincides with the first Kyoto commitment period and the third trading phase from 2013 until 2020 which covers the potential post-Kyoto commitment period.

The trading system applies to installations from energy-intensive sectors that in its opening phase included all major CO_2 producing plants such as power generation, oil refineries, iron and steel production, some parts of mineral industries (e.g. cement) and of pulp and paper manufacturing. Based on the National Allocation Plans (NAP)[25], each member states in the EU specified an overall cap on emissions allowances for all installations included in the scheme at the country level and defined how the total amount of allowances will be distributed among individual plants. The main changes to the emissions trading scheme in the third trading period in comparison to both initial trading phases have been the extended scope – i.e. additional economic activities and further greenhouse gases – and the rule alterations with respect to the allocation mechanism based on harmonised allocation and auctioning. The former part of the rule alteration has made the heavily disputed NAPs obsolete; the latter has introduced auctions as the basic principle for allocation of carbon allowances beyond 2012, with the auction rate of up to 100 percent in the power sector.

One of the major characteristics of the EU ETS during both initial “warm-up phases” is that almost all emissions allowances were allocated free of charge to the covered installations. The impact of freely allocated allowances on product prices has become a source of controversy in both academic and policy papers. At the firm level, holding CO_2 allowances instead of trading

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[24] This chapter is based on the paper: Alexeeva-Talebi, V. (2010b), Cost Pass-Through of the EU Emissions Allowances: Examining the European Petroleum Markets, *ZEW Discussion Paper* 10-086, Mannheim. The manuscript has been submitted to *Energy Economics*.

[25] NAP I and NAP II for the first and second trading period, respectively.

them represents opportunity costs that are likely to be added to other costs and passed-through to consumers (Sijm, 2006b). The political perception of this potential is clear enough as it raises severe distributional concerns. At the EU level, the "windfall profits" that were generated by the power sector during the first trading period have formed the political will to minimise the undesirable distributional impacts resulting from handing out free permits. National authorities have, on their part, proceeded against companies that were abusing their market power by excessively passing-through CO_2 costs to consumers. Fell (2008) reports on German Federal Cartel Office (Bundeskartellamt) issuing a warning to German electricity generator RWE in 2006.

In the context of the EU ETS, empirical evidence on the ability to pass-through carbon costs in the early phases of the emissions trading is still rather scarce, with the exception of the power sector. Sijm et al. (2005, 2006a, 2006b) provided initial empirical evidence of passing-through opportunity costs of holding European Union Allowances (EUAs) to power prices for, among others, Germany, the Netherlands, France, Belgium. Zachmann and Hirschhausen (2008) substantiated the evidence using data from the European Energy Exchange in Leipzig and applying advanced econometric techniques. Walker (2006) and Ponssard and Walker (2008) analysed the impact of EU ETS on the profitability of the cement sector for some European countries and reported rather low pass-through rates. More recently, Alexeeva-Talebi (2010a) and Oberndorfer et al. (2010) analysed the cost pass-through relationships in energy-intensive sectors in Germany and in the UK, respectively. De Bruyn et al. (2010) presented some empirical evidence on energy-intensive sectors in the EU, including the refining industry. The major drawback of the latter study is that data used for the econometric analysis does not allow considering potential heterogeneity in terms of the pass-through across EU member states as it relies for the refining sector on German data only.

Another strand of the literature focuses on price transmissions in refining sectors in a broader context. Among others, Meyer and Cramon-Taubadel (2004), Geweke (2004) and more recently Frey and Manera (2007) provided a comprehensive literature review on this item. A large body of empirical literature focused on passing-through crude oil prices and exchange rates to prices of petroleum products within a multi-national framework (among many others: Reilly and Witt, 1998; Galeotti et al. 2003; Wlazlowski, 2007; Wlazlowski et al., 2009). With a strong regional focus on the US, the tax incidence literature studied finally the effects of sales taxes on gasoline prices (e.g. Doyle and Samphantharak, 2008).

Against this background, in this chapter we analyse the implications of the EU ETS for the refining sector, notably the impact of freely distributed emissions allowances on prices of unleaded petrol. Since the EU ETS is still in an early stage and price data for sectors of interest are typically available on a monthly basis, the carbon costs are often proxied by labour, material and energy as the second-best option. The availability of weekly price data on petroleum products at the country level is a distinct characteristic of refining sector which allows an envisaged analysis.

The contribution of this chapter to the pass-through literature in the context of the climate change policy is twofold: First, we provide robust empirical evidence on the interactions between prices of petroleum products and market-based mechanisms such as the EU ETS. We add to the literature body by revealing that carbon costs enter the cointegration space with petrol prices, crude oil prices and exchange rates in the trial phase of the EU ETS in European petroleum markets. Second, the applied data and modelling techniques allow disclosing potential heterogeneity in terms of pass-through across the EU member states. The estimation results based on a VECM (vector error correction model) framework detail the ability of producers to pass-through carbon costs to consumers during the trial phase from 2005 to 2007. The increase of EUA prices by 1 percent typically leads to an increase of petrol prices by 0.01-0.09 percent across Europe in the long-run. The relatively low elasticity of petrol prices with respect to the EUA prices is due to a small share of carbon costs in the total costs of petrol production. The impulse-response analysis shows that petrol prices typically reach the new long-run equilibrium at the latest 20 weeks after the one-time innovation (in carbon costs). The overall conclusion of this chapter is that European refineries have been strongly benefiting from the design of the EU ETS, i.e. free allocation of allowance in the first trading period. As to the policy implications, our analysis questions on grounds of severe adverse distributional impacts the continuation of the freely allocation of allowances to refining sector beyond 2012.

The remainder of this chapter is structured as follows: Section 3.1 describes the methodological approach and data used for the estimation. Section 3.2 presents empirical findings on the pass-through of CO_2 emissions allowances to petrol prices at the EU country level. Section 3.3 outlines major findings and policy implications. Section 3.4 contains appendices to this chapter.

3.1 Empirical Analysis

3.1.1 Methodology and modelling strategy

Empirical literature on pass-through relationships typically applies three modelling techniques: single-equation-based approach, stationary (differenced) vector autoregression (VAR) models and cointegrated VAR models (An, 2006). The latter technique parameterises short-run and long-run dynamics and is therefore used extensively in papers assessing the pass-through linkages between prices of petroleum products and crude oil: Arpa et al. (2006), Wlazlowski (2007), Wlazlowski et al. (2009) and de Bruyn et al. (2010) estimate, for example, separately VAR models for different petroleum product at the country level. The analysis in this chapter follows this strand of literature by estimating a sequence of cointegrated VAR models for the European refining sector.

The notion of cointegration has been introduced by Engle and Granger (1987). Johansen (1988) and Johansen and Juselius (1990) have developed the cointegration test procedure which specifies as a starting point the VAR of order *p* as a vector-error-correction model in its basic form:

$$\Delta x_t = \Pi \ x_{t-1} + \sum_{k=1}^{p-1} \Gamma_k \Delta x_{t-p} + B \ y_t + \varepsilon_t \tag{1}$$

where x_t represents a vector of non-stationary endogenous variables for $t = 1,...,n$:

$$x_t = (p_t^{pet}, p_t^{oil}, p_t^{car}, p_t^{ex})$$

$p_t^{pet} =$ the net-of-taxes nominal retail prices for Euro-95 unleaded petrol (in national currency);

$p_t^{oil} =$ the prices for crude oil (in US$);

$p_t^{car} =$ the prices for EUAs (in national currency);

$p_t^{ex} =$ the exchange rates between the local country's currency and US$.

The matrix Π contains the information about the long-run relationships among endogenous variables and can be decomposed as $\Pi = \alpha\beta'$, whereas β and α represent the cointegrating vectors and the matrix with the estimations on the speed of adjustments to equilibrium, respectively. $\mathrm{Rank}(\Pi) = 1$ suggests that there is a unique cointegration relationship among the analysed time series. Furthermore, Δ represents the first-difference operator, the matrix Γ_k includes the estimations of the short-run parameters, $\varepsilon_t \sim \mathrm{Niid}(0,\Sigma)$ is a vector of innovations, y_t is a vector of exogenous variables (e.g. seasonal dummy variables) with B containing respective estimated coefficients. Using carbon costs p_t^{car} in the cointegrated VAR system allows differentiating the analysis in this chapter from a substantial literature body on passing-through behaviour in the refining sector.

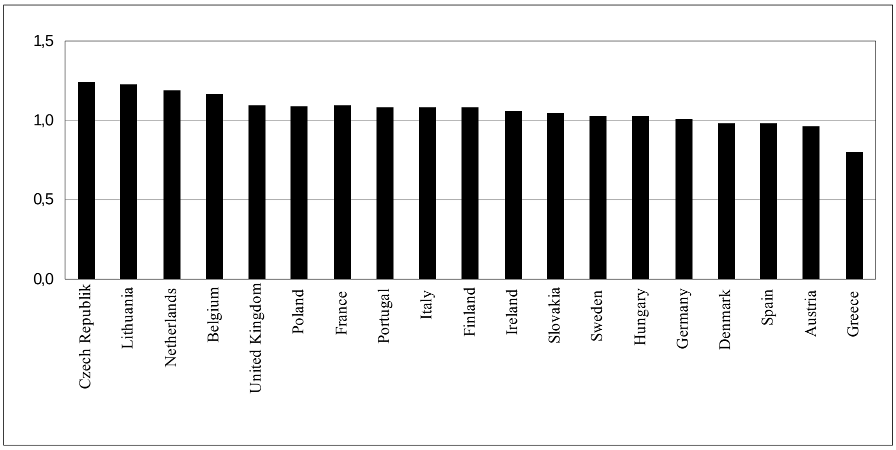
3.1.2 Relative allocation of allowances in EU refineries and main data sources

This section presents the data basis underlying the pass-through analysis in the refining sector. As a starting point, we discuss the issue of the relative allocation of emissions allowances to the refining sectors at the country level during the first trading period of the EU ETS. A detailed description of the data used for the subsequent econometric analysis of the pass-through relationships associated with the EU ETS in European petroleum markets follows these introductory remarks.

Relative allocation of allowances in the refining sector

The EU Community Independent Transaction Log (CITL) contains data for 19 member states on the verified emissions and allocated emissions allowances for the economic activities codified as “mineral oil refineries” (EU, 2010b). The 2006 data were used for the calculation of a sequence of allocation factors relating allocated allowances to the verified emissions in the refining sector. An allocation factor which exceeds the value of 1 indicates the over-allocation: an installation has received more certificates than it emitted. In contrast, a value of less than 1 suggests that installations have to undertake abatement activities or to purchase certificates in order to comply with their individual emissions cap. Whether the empirical allocation factors represent a suitable measure to trace the relative allocation is a controversial issue in the literature. While Kettner et al. (2007) support this view, Ellerman and Buchner (2008) and Di Maria et al. (2009) emphasise potential distortions of this measurement concept. Notwithstanding, the abatement in the early phases of the EU ETS appears to be rather small. We therefore consider empirical allocation factors to provide valuable insights into the relative allocation of the certificates (Anger and Oberndorfer, 2008).

Figure 4: Allocation factors in the refining sectors across the EU (2006)



Source: EU 2010b, own calculations.

Figure 4 depicts a considerable heterogeneity in terms of the relative allocation of certificates in the refining sector. It shows that refining sector in few countries – Denmark, Spain, Austria and Greece – received less allowances as verified emissions, with Greece showing an allocation factor of around 0.8. Germany represents a border line case, while all other EU member states received more allowances than their respective emissions. The Czech Republic benefited most from the allocation scheme in 2006. In comparison to Kettner et al. (2007) who used the 2005 data we observe some dynamics regarding the relative allocation of allowances. Producers appear to adjust production quantities and emissions level easily. For example, Ireland was short in 2005 but become long in 2006. Whereas Greece extended the production volume and the emissions level between 2005 and 2006 significantly, ending at a much shorter position.

Main data sources and variables

The data set used for the empirical analysis consists of four weekly time series: net-of-taxes nominal retail prices for Euro-95 unleaded petrol at the EU country level, prices of EUAs, prices of crude oil and exchange rates between a local country's currency and US$.

In order to separate the first and second trading periods, the analysis in this chapter relies on the weekly data running from September 16, 2005, to March 22, 2007.[26] We thereby focus only on those EU member states which have received emissions allowances during the first trading period according to the CITL:[27] Austria (AT), Belgium (BE), Czech Republic (CZ), Denmark (DK), Finland (FI), France (FR), Germany (DE), Greece (GR), Ireland (IE), Italy (IT), Hungary (HU), Lithuania (LT), the Netherlands (NL), Poland (PL), Portugal (PT), Sweden (SE), Slovakia (SK), Spain (ES) and United Kingdom (UK). Hence, among the EU-15 all member states are covered, except for Luxemburg; among the EU-12, only six countries are registered to host mineral oil refineries in 2006 and are therefore considered in our analysis.

Retail prices for Euro-95 unleaded petrol are obtained from the Oil Bulletin. This data source is published by the European Commission on a weekly basis (EU, 2010c). The Oil Bulletin reports both the net-of-taxes retail prices at the country level in Euro and the corresponding exchange rates. For the purpose of the investigation, all retail prices are used in national currencies. As repeatedly underlined by empirical literature, the choice of crude oil time series does matter for the estimation results. In this chapter, we rely on nominal prices for Brent crude oil as suggested by Hagstromer and Wlazlowski (2007) and Wlazlowski et al. (2009). Since these data are available in US$ only, the additional data set with exchange rates between US$ and national currencies is needed. Data on crude oil and exchange rates (between US$ and national currencies) stem from Thomson Datastream. Carbon costs of the firms are represented by the spot prices based on Point Carbon enquiry (Point Carbon Spot Index) – the latter data are available from September 2005 onwards from Datastream and converted into the national currencies (other than Euro) by means of the Oil Bulletin's

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[26] Having started with the weekly data running from September 16, 2005, to September 17, 2010, the testing results (not reported here, but available upon the request) favour the existence of a break between the first and the second trading period. The first trading period has been, however, shortened to March 22, 2007, i.e. until the period where allowance prices geared toward zero (cf. Alberola and Chevallier, forthcoming; Oberndorfer et al., 2010).

[27] In 2006.

exchange rates. The full data set is available for all countries with the exception of Slovakia. All time series are used in logarithms.

3.1.3 Estimating the multivariate system

We start our estimating procedure by testing the existence of a unit root in data and cointegration relationship(s) among the employed variables. Both sets of tests relate to the question whether the envisaged VAR models shall be estimated in levels or in first-differences. If variables are non-stationary in levels but stationary in first differences, then they are considered to be integrated of order one, i.e. I(1). Given the non-stationarity of variables and the existence of cointegration relationships, the application of a cointegrated VAR is appropriate. But if testing rejects the existence of cointegration relationships among non-stationary data, estimating VAR in first differences (stationary VAR models) shall be selected to avoid spurious regression.

Using two alternative versions of the Phillips-Perron (PP) test (Phillips and Perron, 1988) for a unit root with and without a trend, 33 out of 35 series are found to be integrated of order one (I(1)) in both model specifications. The null of a unit root in level data for these series cannot be rejected at usual significance levels but it is rejected when applied to the first differenced data (Table 14a.-c. in Appendix).[28] A common strategy is to employ additionally a stationarity test, e.g. the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test (Kwiatkowski et al., 1992). The results of the KPSS and the PP are partially in contradiction which is mainly contributed to a pervasive tendency of the former in finding the lower level of integration than a unit root test (Strauß, 2004). Notwithstanding, the KPSS test rejects the null of stationarity when applied to the data in levels in a test specification with a constant and a trend at usual significance levels in all variables with the exception of few exchange rate series, but cannot reject the null when applied to the first-differenced data in all variables.[29]

Whether all components of the vector have to be integrated of the same order is disputed in the literature: Engle and Granger (1987) and Hamilton (1994), among others, argue that all variables must be integrated of the same order. Johansen (1995) considers, for example, the

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[28] Prices for petroleum products in Poland and UK ($p_{pet,PL}$ and $p_{pet,UK}$) are found to be I(2).

[29] Since the time trend is significant in each cointegration equation, the problem of some inconsistency in results from the PP and KPSS exists in some exchange rates time series only.

possibility of cointegrating relationships between the stationary and the integrated of order one non-stationary variables. The applied work tends to include the stationary variables into the VECM framework as an endogenous variable if economically reasonable (cf. Strauß, 2004; Hüfner and Schröder, 2002). According to the PP and the KPSS tests, some exchange rate series represent a border line case between the I(0) and I(1). The augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) applied to these time series supports our findings on the I(1). We therefore pursue testing the existence of cointegration relationships under the assumption that all time series are integrated of the order one in all countries with the exception of Poland and UK.[30]

Table 15 (Appendix) details the results on the number of cointegrating vectors and the optimal VAR lag length in our sample. The maximum eigenvalue test (Johansen and Juselius, 1990) rejects the null hypothesis of no cointegrating vector $\mathrm{Rank}(\Pi_i) = 0$ against the specific alternative $\mathrm{Rank}(\Pi_i) = 1$ for all countries with the exception of Finland at the 5 percent significance level. The trace test statistics reject the hypothesis of no cointegration relationships at the 5 percent significance level in all countries with the exception of Ireland, Denmark and Sweden. Concluding on the existence of the cointegration relationships we rely on the findings from the more powerful maximum eigenvalue tests (Johansen and Juselius, 1990). The most appropriate model in all countries includes a trend and an intercept in cointegration space and permits a constant in the VAR. In the cointegration literature, it is common to consider both specifications – with and without a trend in the cointegration equation (CE) – and to select the most encompassing model with a time trend. This specification is the least restrictive as it does not impose *a priory* any arbitrary restrictions on the VECM (Kaufmann and Cleveland, 2001). It allows avoiding omitted variable bias in the estimated coefficients of the variables under investigation (Welsch, 2008).[31] Linear time trend captures the effects of further costs (e.g. labour costs) on the retail petroleum prices (Wlazlowski, 2003). Finally, the trend allows accounting for “catch-up” effects in new EU member states (Beirne and Bijsterbosch, 2009). The decision on the number of lags included in the equation is based on the Schwarz information criterion (SIC) but additional lags were added to correct for serial correlation and to achieve normality and homoscedasticity in residuals (Enders, 2004). Given the fact that the number of degrees of freedom shrinks

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[30] These results can be provided upon request.

[31] We thereby closely follow the procedure suggested by Welsch (2008).

quickly in a (cointegrated) VAR model, the strategy is to develop the most parsimonious model specification which is consistent with well-behaved errors. In most cases two lags were sufficient to receive residuals that are free of autocorrelation and heteroscedasticity and mostly following the normal distribution.[32]

We run two alternative specifications of the VECM: in our basic model specification, all variables are endogenous. The results for this model specification are reported in a detailed way. As in Arpa et al. (2006) and Wlazlowski (2007) we estimate a sequence of models for each EU member states. To test the robustness of the result, we then conduct a sensitivity analysis which involves a different treatment of the exchange rate variable. Under this alternative specification, we include the exchange rate as an exogenous variable to address the problem of possible stationarity of these time series (Clostermann and Seitz, 2002).

3.2 Empirical results

This section presents the results from our basic model specification on how strongly and rapidly the net retail prices of Euro-95 unleaded petrol across the EU member states react to changes in crude oil prices, carbon costs and exchange rates. Table 12 details the long-term elasticities of petrol prices across the EU member states in the normalised cointegrating relationships. The overall results suggest that petrol prices are elastic with respect to crude oil prices and exchange rates but inelastic with respect to the EUA prices.

We now turn to the long-run elasticities of petrol prices in response to changes in crude oil prices. A value of 1.05 implies, for example, that producers increase the price of petrol by 1.05 percent if crude oil prices rise by 1 percent. All long-term coefficients have the expected sign. The elasticities are likely to be particularly high in the new EU member states (i.e. the Czech Republic and Hungary) but producers in Sweden and Germany tend to increase the retail prices in a comparable vein. In contrast, the pass-through elasticity in Italy is relatively low, while other EU member states lie in between these extremes. Our results are partly in

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[32] These results are available upon the request. In very few models, there is a sign of non-normality due to the excess kurtosis. As shown in Gonzalo (1994), the test statistics on the cointegration relationships are robust to the non-normality, whereas it is due to the excess kurtosis. The violation of normality assumptions (related to both skewness and kurtosis) is found in Czech Republic, while the autocorrelation in the residuals in the VECM for Ireland cannot be removed even at a higher lag order. We therefore decided not to report the estimation results for the latter as the residuals do not fulfil the basic requirements for the model specification.

line with findings of Arpa et al. (2006) who reported lower pass-through rates for most countries in our sample, with the exception of Czech Republic. There are few reasons for diverging results: First, the estimations in Arpa et al. (2006) might be biased as this study does not take into consideration both exchange rates and carbon costs. Second, our sample covers a different period of time which is characterised through a significant increase in crude oil prices. The pass-through behaviour of producers over this time horizon might differ from the period with the less pronounced price increases.

Table 12: Long-run relationships between petrol prices, crude oil prices, carbon costs and exchange rates

Countries	**Variables**			
	p_t^{pet}	p_t^{oil}	p_t^{car}	p_t^{ex}
Austria	-1.00	1.27** (0.17)	0.08** (0.04)	2.45** (0.83)
Belgium	-1.00	1.38** (0.14)	0.05 (0.04)	2.69** (0.78)
Czech Republic	-1.00	1.97** (0.33)	0.07 (0.06)	0.65 (1.44)
Denmark	-1.00	1.13** (0.14)	0.01 (0.03)	2.05** (0.74)
France	-1.00	1.41** (0.12)	0.04 (0.03)	1.62** (0.65)
Germany	-1.00	1.47** (0.15)	0.05* (0.04)	2.36** (0.77)
Greece	-1.00	1.23** (0.11)	-0.02 (0.03)	0.74 (0.62)
Hungary	-1.00	1.47** (0.10)	-0.09** (0.03)	-1.01** (0.30)
Italy	-1.00	1.05** (0.15)	0.09** (0.04)	3.09** (0.76)
Lithuania,	-1.00	1.15** (0.09)	0.03 (0.02)	1.14** (0.54)
The Netherlands	-1.00	1.18** (0.10)	0.03 (0.03)	1.93** (0.61)
Portugal	-1.00	1.25** (0.19)	0.09** (0.04)	3.49** (0.95)
Spain	-1.00	1.37** (0.11)	0.02 (0.03)	1.64** (0.58)
Sweden	-1.00	1.65** (0.20)	-0.01 (0.05)	0.68 (0.90)

Note: Standard errors of the estimated parameters are indicated in parentheses; asterisks "**" denote significance at 5 percent level or better; "*" indicates significance at 10 percent level. The estimates for p_t^{car} in Belgium are close to the significance level of 10 percent.

The long-term elasticities of petrol prices with respect to the carbon costs changes vary typically between 0.01 and 0.09 percent across the EU member states. First, it stands out that all coefficients with three exceptions have an expected sign. Second, the magnitude of the estimated coefficient is rather small as carbon costs account for a tiny share in the cost structure in the refining industry: de Bruyn et al. (2010) summarise the findings in the literature on the emissions factor for the petrol production with roughly 400 grams of CO_2 per litre. Using the net-of-taxes nominal retail prices of around 550€/1000L and assuming the carbon costs of 20€/ton of CO_2[33], the share of carbon costs in total costs can be estimated at roughly 2 percent. The values of the estimated coefficients for the pass-through of the EUA prices (and their respective standard errors) are close to 0.02. Hence, the full pass-through (100 percent) is rather likely for the respective estimates.

Table 13 details the speed of the adjustments to the long-run equilibrium in the VECM at the country level. The lack of the statistical significance of the *t*-test of the loading factors indicates the presence of the long-run weak exogeneity (Masih and Masih, 1996). The adjustment coefficients are statistically significant (with few exceptions) and have the correct sign only in columns two and four, i.e. in the error correction models (ECMs) for petrol prices and carbon prices. For the former, the estimated adjustment coefficients are relatively low across the regions. For the latter, we observe some regional heterogeneity, albeit the speed of the adjustments is found to be markedly higher. Crude oil prices and exchange rates are statistically significant in most cases, but the interpretation of these results is difficult due to the wrong sign of the estimated adjustment coefficients.

The estimated short-run coefficients for crude oil prices, carbon costs and exchange rates (differenced explanatory variables) are found to be individually significant in the respective ECMs indicating the existence of the short-run causality. The highly significant short-run coefficients for passing-through crude oil prices to consumers have an expected sign in most countries in our sample (Figure 5, Appendix).[34]

In the Netherlands, Germany, France and Sweden the refining industry tends to pass on between 50 percent and 75 percent of crude oil price increases to the consumers within two weeks after a shock. Others (Austria, Belgium, Spain, Italy, Lithuania and Denmark) pass-

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[33] This price is observable for petrol in most countries in our sample on September 16, 2005.

[34] To save space we restrict the discussion of the short-term coefficients to the ECM for the petrol prices and focus only on the past changes in crude oil and EUA prices.

through roughly 50 percent of the crude oil price increases within this time horizon. In contrast, the refining industry in Portugal is likely to pass-through only around 25 percent. In the remaining sectors, price shocks are likely to be borne by producers within a time horizon of two weeks. As to the estimated impact of changes in carbon costs in the ECMs for petrol prices (Figure 6, Appendix), it stands out that all significant coefficients have a negative sign. One of the interpretations of this finding might be that in the short-run producers are likely to increase prices when facing decreasing carbon costs. This is an unexpected result but given the fact the time span in our analysis is characterised through steadily decreasing prices for the EUAs the findings are not implausible. Our results indicate that these shocks are passed-through almost immediately in most countries.

Table 13: Loading factors

Countries	**Variables**			
	p_t^{pet}	p_t^{oil}	p_t^{car}	p_t^{ex}
Austria	-0.05** (0.03)	0.21** (0.07)	-1.14** (0.22)	0.08** (0.02)
Belgium	-0.16* (0.08)	0.21** (0.07)	-1.23** (0.19)	0.05** (0.02)
Czech Republic	-0.06** (0.01)	0.10** (0.04)	-0.44** (0.13)	0.01 (0.01)
Denmark	-0.17** (0.08)	0.34** (0.08)	-1.29** (0.30)	0.06** (0.02)
France	-0.04 (0.04)	0.31** (0.09)	-1.46** (0.26)	0.09** (0.02)
Germany	-0.17** (0.06)	0.22** (0.07)	-1.07** (0.20)	0.07** (0.02)
Greece	-0.27** (0.06)	0.21** (0.10)	-0.99** (0.32)	0.05** (0.02)
Italy	-0.08** (0.04)	0.25** (0.07)	-1.19** (0.21)	0.08** (0.02)
Hungary	-0.20** (0.04)	0.19** (0.09)	-0.54** (0.31)	0.06** (0.04)
Lithuania	-0.21** (0.07)	0.49** (0.13)	-1.84** (0.43)	0.06** (0.03)
The Netherlands	-0.11* (0.07)	0.29** (0.08)	-1.47** (0.24)	0.09** (0.02)
Portugal	-0.02 (0.02)	0.19** (0.07)	-0.97** (0.20)	0.08** (0.01)
Spain	-0.03 (0.04)	0.37** (0.09)	-1.46** (0.27)	0.10** (0.02)
Sweden	-0.07* (0.05)	0.21** (0.06)	-0.82** (0.20)	0.04** (0.02)

Note: Standard errors are indicated in parentheses. Asterisks "**" denote significance at the 5 percent critical level or better; "*" indicates significance at the 10 percent critical level.

In addition to our findings on the long-run causality as indicted by the significance of the error-correction terms (Table 13), we conduct a sequence of the tests to examine the short-run causality. The related tests evaluate the individual and joint significance of the lagged differences in the respective ECMs. Focusing on the ECM for petrol prices, evidence from a block exogeneity Wald tests shows that in the short run crude oil prices, carbon costs and exchange rates *jointly* Granger cause petrol prices in most countries. Besides the individual significance of the respective variables in the equation for the EUA – most importantly the impact of crude oil price differences on EUA price differences – we do not find in general an indication for a joint significance of crude oil prices, carbon costs and exchange rates in this equation.

Figure 7 and Figure 8 (Appendix) plot the variance decompositions and the impulse-response functions (using a standard Cholesky decomposition) for a horizon of 50 weeks.[35] The impulse-response analysis largely reinforces the previous findings, particularly, that all prices typically respond positively to innovations with the exception of carbon costs. The impulse-response analysis shows that the one-time innovation has a permanent impact on petrol prices and that the long-run equilibrium in this equation is reached roughly 20 weeks after the innovation at the latest (Figure 8). According to the Figure 7, variations in petrol prices primarily occur due to their own innovations and innovations in crude oil prices. However, in Austria, Germany, France, Spain, the Czech Republic and Hungary a large fraction of petrol price changes can be explained by changes in EUA prices.

The results in this basic specification are in general found to pass the misspecification and stability tests.[36] In order to additionally test the robustness of the results in this basic model set-up, we run an alternative model specification. Moving from the four-variable model ($p_t^{pet}, p_t^{oil}, p_t^{car}, p_t^{ex}$) to the three-variable model ($p_t^{pet}, p_t^{oil}, p_t^{car}$) with p_t^{ex} as exogenous variable, the results presented for the basic model in general remain very robust. Although we do not observe any drastic variation in sensitivity of petrol prices to crude oil prices and carbon costs, we find that the estimated models do not pass (or pass very narrowly) the

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[35] The following variable ordering is assumed: POIL → PEX → PCAR → PPET. This ordering is consistent with studies using similar variables (Hüfner and Schröder, 2002; Beirne and Bijsterbosch, 2009). Crude oil prices are ordered first as the most exogenous variable in the scheme, while petrol prices are ordered as the last variable. While checking the alternative ordering (between PEX and PCAR), we found that this did not significantly change the results.

[36] See footnote 32.

misspecification tests for heteroscedasticity. We therefore conclude that the three-variable model specification with exchange rates as an exogenous variable might suffer from the misspecification problems.

3.3 Conclusions

This chapter analyses the ability of the refining sectors to pass-through carbon costs to the consumers by estimating a sequence of vector error correction models covering 14 EU member states. In comparison to the stationary VAR models, this framework allows using information "hidden" in the levels and enabling to deal with non-stationarity of the data in a proper vein. We add to the literature body by revealing that carbon costs were entering the cointegration space with petrol price, crude oil prices and exchange rates in the first trading period of the EU ETS. The estimation of the long-run pass-through coefficients for the carbon costs is thereby essential in both assessing the effects of the trial phase of the EU ETS and in designing the trading scheme in the future phases.

Our results suggest that petrol prices are elastic with respect to crude oil prices and exchange rates but inelastic with respect to the EUA prices in the long-run. The increase of the EUA prices by 1 percent typically leads to an increase of the petrol prices by 0.01-0.09 percent across the EU member states. The relatively low elasticity of the petrol prices with respect to the EUA prices is due to the fact that carbon costs account for a tiny share in the total costs of production of petrol (roughly 2 percent). The full pass-through is therefore rather likely for the respective estimates. As to the short-run implications, the refining sector is found to pass-through costs to the consumers rather rapidly. In 10 out of 15 countries, the refineries are found to pass-through 50 percent or more of crude oil price increases to the consumers within two weeks. Roughly in half of the analysed countries, producers are capable to increase petrol prices facing decreasing EUA prices over the same time horizon.

We apply a sequence of tests to examine the long-run and short-run dynamic causal relationships among the variables of interest. Focusing on the ECM for petrol prices, evidence from a block exogeneity Wald tests – in addition to the evidence available on the individual significance of the lagged differences in this equation – shows that in the short run crude oil prices, carbon costs and exchange rates *jointly* Granger cause petrol prices in most countries.

The variance decomposition indicates thereby that carbon costs play a significant role in explaining the variance of differenced petrol prices in Austria, Germany, France and Spain (between 10 percent and 20 percent of variance in petrol prices). In the ECM for the EUA prices, the lagged differences for crude oil prices, petrol prices and exchange rates are individually significant at the country level in the short, but the block exogeneity Wald tests cannot in general reject the hypothesis that EUA prices are *jointly* not Granger-caused by other variables. In contrast, the lagged error-correction terms in the equations for both petrol prices and carbon costs are significant and have an expected (negative) sign. This finding provides a robust indication for the existence of the long-run causal relationships running from crude oil prices, carbon costs and exchange rates to petrol prices, on the one hand, and from crude oil prices, petrol price and exchange rates to the EUA prices, on the other hand. The impulse-response analysis shows that – as expected (Lütkepohl and Reimers, 1992) – shocks do not fade away and that the long-run equilibrium in the equation for petrol prices is reached 20 weeks after the one-time innovation at the latest.

Albeit the relatively small sample poses some limitations on our analysis, we consider the results to be valid as they pass several misspecification and stability tests. The sensitivity analysis which treats the exchange rate as an exogenous variable reaffirms our conclusions on the proper specification of the basic model at the country level.

Analysing both long-term and short-term elasticities of petrol prices, we detect some heterogeneity across the EU member states in terms of how strongly and rapidly the net retail prices of Euro-95 unleaded petroleum react to changes in carbon costs. Notwithstanding this heterogeneity, our results suggest the existence of significant adverse distributional implications in the refining sector during the first trading period of the EU ETS. This is due to the generous allocation of allowances free of charge. Our central finding thereby questions the policy outcome in which emissions from the refining sector will be largely benefiting from free allocation of allowances from 2013 onwards, whereas the power sector falls fully under the auctioning regime.

By evaluating how the international trade flows respond to European climate policy, the next chapters 4 will go beyond the industry-distributional analysis presented in this chapter. Furthermore, it will evaluate the inter-sectoral CO_2 price differentiation strategies and assess their potential to mitigate the associated risks to lose competitiveness advantage faced by energy-intensive industries in Europe.

3.4 Appendices to chapter 3

3.4.1 List of tables

Table 14a: Testing for a unit root (Phillips-Perron test)

	Levels		**First-differences**	
Model, Variables	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
Retail prices for Euro-95 unleaded petrol[37]				
$p_{pet,AT}$	-1.28	-1.36	-4.88***	-4.84***
$p_{pet,BE}$	-1.69	-1.73	-6.99***	-6.92***
$p_{pet,CZ}$	-1.10	-1.25	-3.60***	-3.56**
$p_{pet,DE}$	-1.44	-1.61	-8.26***	-8.20***
$p_{pet,DK}$	-1.79	-1.69	-7.55***	-7.51***
$p_{pet,ES}$	-1.39	-1.46	-4.65***	-4.61***
$p_{pet,FI}$	-2.59	-2.52	-11.98***	-12.25***
$p_{pet,FR}$	-1.55	-1.55	-4.84***	-4.80***
$p_{pet,GR}$	-1.55	-1.63	-5.97***	-5.93***
$p_{pet,HU}$	-0.96	-0.95	-5.04***	-4.94***
$p_{pet,IE}$	-1.20	-1.80	-8.42***	-8.20***
$p_{pet,IT}$	-1.07	-1.18	-5.05***	-5.05***
$p_{pet,LT}$	-1.25	-1.39	-5.13***	-5.04***
$p_{pet,NL}$	-1.96	-1.95	-9.12***	-9.06***
$p_{pet,PL}$	-1.45	-1.63	-2.26	-2.24
$p_{pet,PT}$	-0.95	-1.10	-4.98***	-5.01***
$p_{pet,SE}$	-1.59	-1.38	-6.82***	-6.79***
$p_{pet,UK}$	-0.99	-1.18	-3.07**	-3.05

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[37] Prices for petroleum products are in national currencies.

Table 14b: Testing for a unit root (Phillips-Perron test)

	Levels		**First-differences**	
Model, Variables	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
Exchange Rates				
$p_{ex,US/EU}$	-0.88	-3.31*	-9.63***	-9.58***
$p_{ex,US/CZ}$	-0.78	-3.56**	-9.61***	-9.54***
$p_{ex,US/DK}$	-0.91	-3.37*	-9.80***	-9.75***
$p_{ex,US/HU}$	-1.39	-2.27	-8.12***	-8.24***
$p_{ex,US/LT}$	-0.81	-3.24*	-9.58***	-9.56***
$p_{ex,US/PL}$	-1.55	-3.62**	-8.50***	-8.45***
$p_{ex,US/SE}$	-0.88	-3.26*	-8.45***	-8.38***
$p_{ex,US/UK}$	-0.73	-3.75**	-9.13***	-9.08***

Table 14c: Testing for a unit root (Phillips-Perron test)

	Levels		**First-differences**	
Model, Variables	**Constant**	**Constant & trend**	**Constant**	**Constant & trend**
Crude oil price				
$p_{oil,\$US}$	-1.68	-1.65	-7.97***	-7.95***
Carbon costs[38]				
p_{car}	6.29	2.28	-6.87***	-7.50***

Note: The MacKinnon critical values across the sample are -3.52*** / -2.90**/ -2.59* for the model with a constant and -4.09*** / -3.47** / -3.16* for a model with a constant and a trend at the 1 percent / 5 percent / 10 percent levels of significance.

The notation * (**, ***) means the rejection of the hypothesis at the 10 percent (5 percent or 1 percent) significance level, respectively.

Acronyms of the variables: AT Austria, **BE** Belgium, **CZ** Czech Republic, **DK** Denmark, **FI** Finland, **FR** France, **DE** Germany, **GR** Greece, **IE** Ireland, **IT** Italy, **HU** Hungary, **LT** Lithuania, **NL** Netherlands, **PL** Poland, **PT** Portugal, **SE** Sweden, **SK** Slovakia, **ES** Spain and **UK** United Kingdom.

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[38] To save the space we report only carbon prices which apply to the Euro countries; its counterparts in non-Euro EU member states are also found to be integrated of order one at usual significance levels.

Table 15: Number of cointegrating relations

	Cointegration test specification	**VAR lags**
Regions	Intercept and trend in CE, no trend in VAR	
Austria	1 [57.46]**	2
Belgium	1 [59.43]**	2
Czech Republic	1 [41.04]**	1
Denmark	1 [36.60]**	1
Finland	0 [27.80]	1
France	1 [56.81]**	2
Germany	1 [61.86]**	2
Greece	1 [42.44]**	1
Ireland	1 [39.23]**	2
Italy	1 [57.73]**	2
Hungary	1 [42.66]**	1
Lithuania	1 [48.60]**	2
The Netherlands	1 [64.27]**	2
Portugal	1 [49.48]**	2
Spain	1 [62.67]**	2
Sweden	1 [32.55]**	1

Note: In parentheses, we indicate the maximum eigenvalue statistics. In 15 out of 16, the null hypothesis of no cointegrating vector against the specific alternative of a unique cointegrating vector is rejected at 5 percent significance level (“**”). The critical value at the 5 percent significance level is 32.11832. We do not include any exogenous variables into the tests.

3.4.2 List of figures

Figure 5: Estimated coefficients of past changes in crude oil prices in the ECM for petrol prices[39]

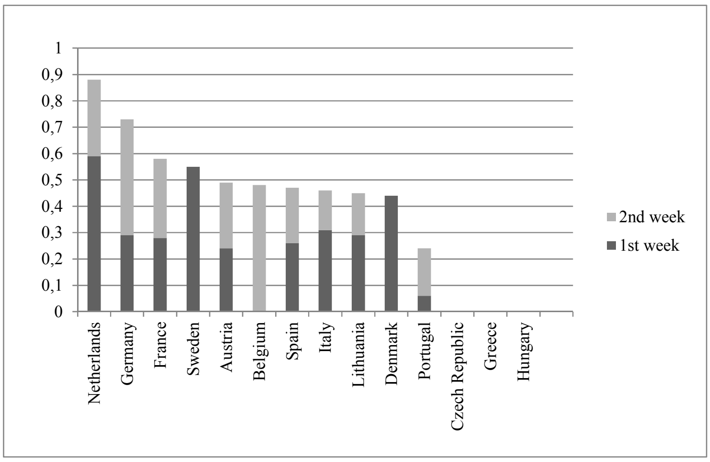
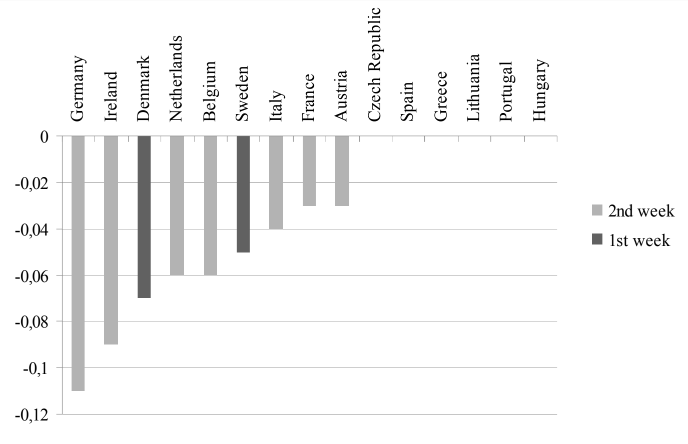


Figure 6: Estimated coefficients of past changes in EUA prices in the ECM for petrol prices[40]



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[39] We plot only statistically significant estimates with the expected positive sign (10 percent significance level or better) to capture the indication of (plausible) short-run causality. This is the case in all countries, except for Greece and Hungary.

[40] We plot only statistically significant estimates (10 percent significance level or better) to capture the indication of short-run causality.

Figure 7: Variance decomposition (in the equations for petrol prices)

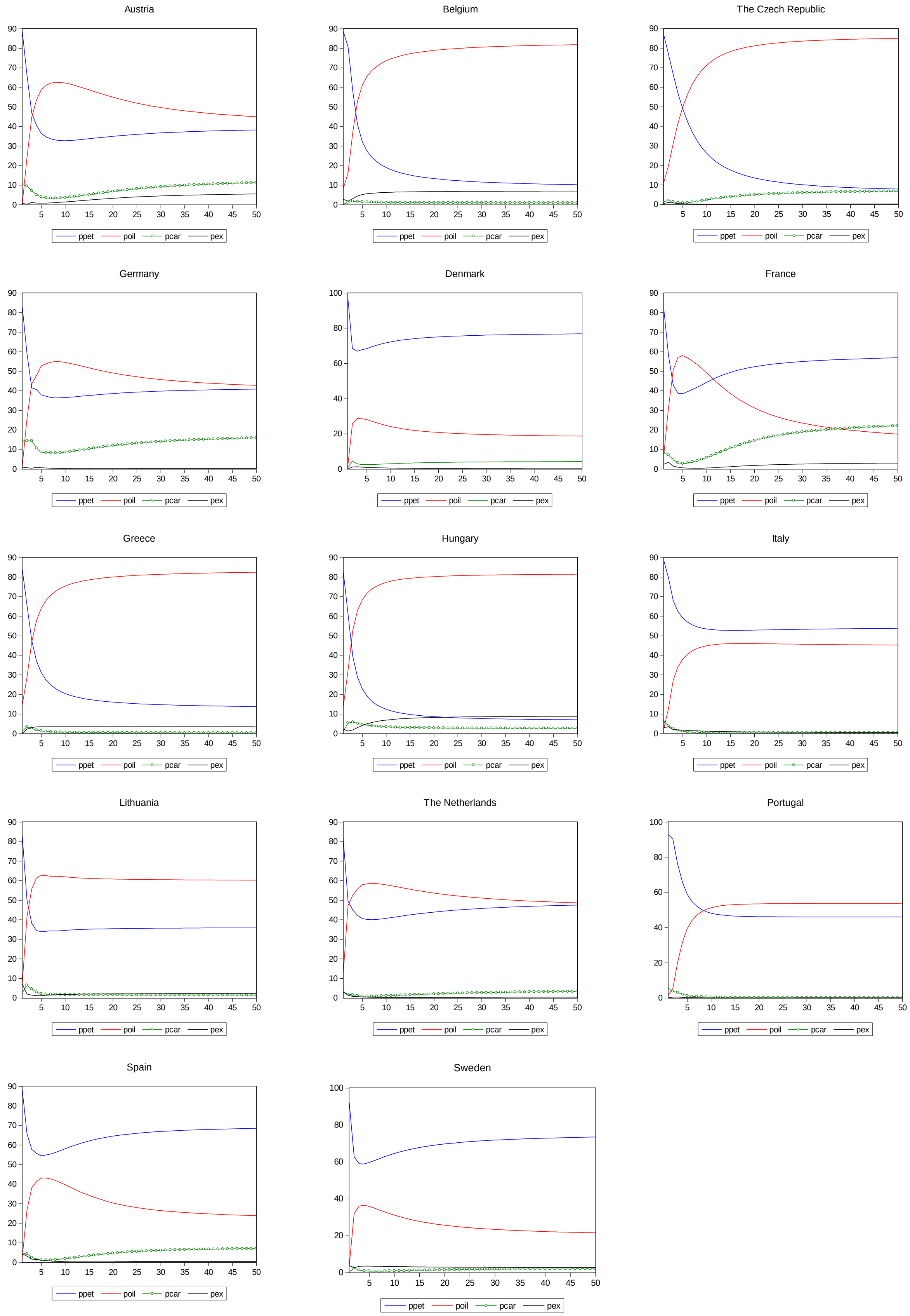
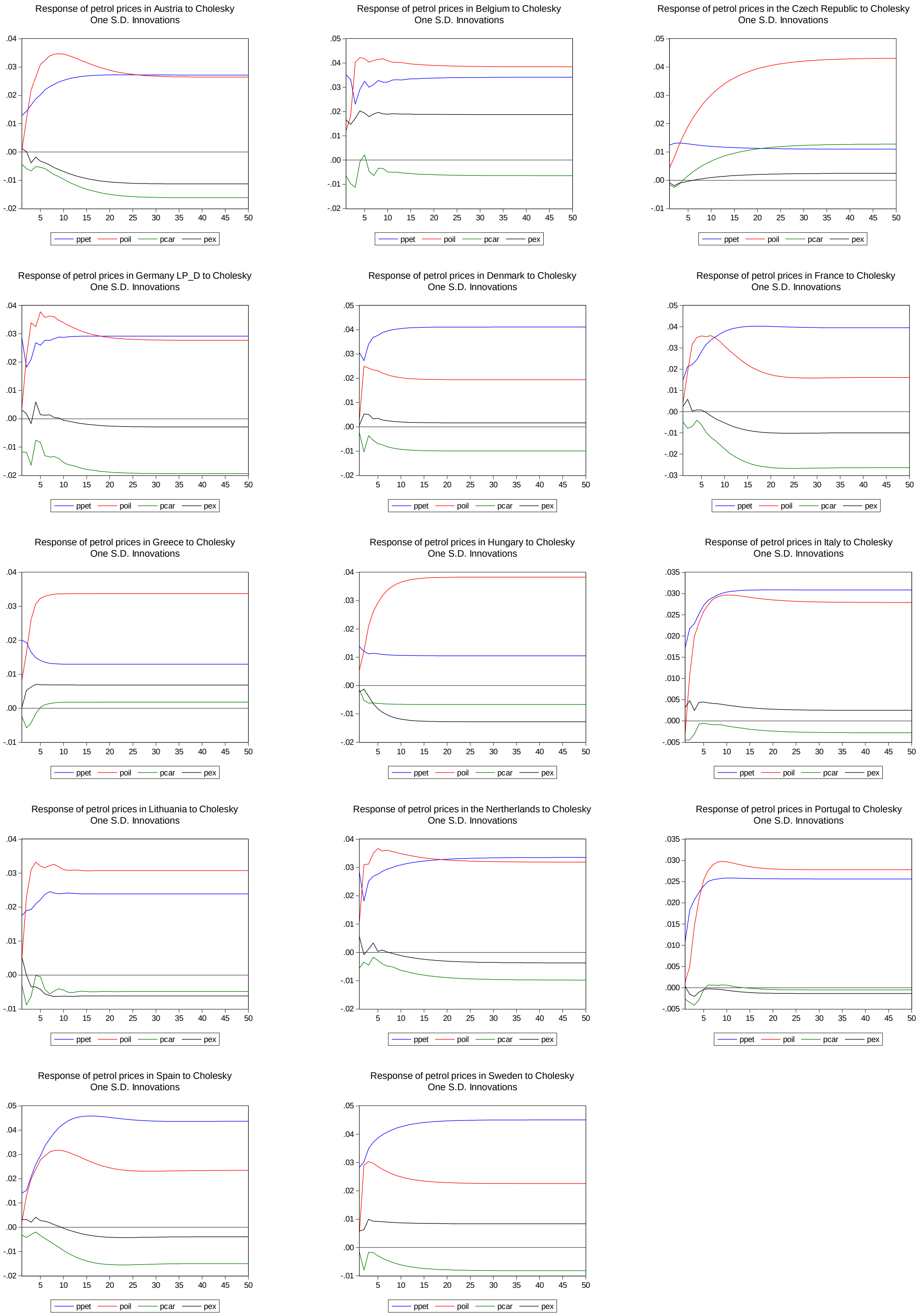


Figure 8: Impulse-response functions (in the equations for petrol prices)



Part II:

Economic Impacts of Alternative Climate Policy Designs

4 Unilateral Climate Policy and Competitiveness: Differential Emission Pricing from a Sectoral, Regional and Global Perspective[41]

At the sixteenth United Nations Climate Change Conference in Cancún, the world community committed itself to the objective of limiting the rise in global average temperature to no more than 2° Celsius above pre-industrial levels in order to hedge against dangerous anthropogenic interference with the climate system. According to scientific knowledge assessed by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (IPCC, 2007), this implies that global greenhouse gas emissions must decline within the next two decades and be reduced by roughly a half vis-à-vis 1990 emission levels. To date, however, prospects for a Post-Kyoto agreement covering all major emitting countries are bleak. Even in the case of a broader follow-up agreement to the Kyoto Protocol, it is much likely that emission reduction targets will be quite unevenly spread across the signatory regions with OECD countries taking a lead role reflecting their historical responsibility and a higher ability to pay.

One-sided commitments to ambitious emission reduction targets raise competitiveness and emission leakage concerns in all major economies implementing or proposing unilateral responses to the threat of climate change. At the fore of climate policy discussions, competitiveness and leakage concerns refer in particular to the performance of energy-intensive and trade-exposed (EITE) industries. Obviously, unilateral emission pricing of domestic industries where emission-intensive inputs represent a significant share of direct and indirect costs will put these sectors at a disadvantage compared to competing firms in countries abroad which lack comparable regulation. The loss in competitiveness is to some extent associated with the potential for emission leakage, i.e. the change of emissions in non-abating regions as a reaction to the reduction of emissions in abating regions (e.g. Hoel, 1991; Felder and Rutherford, 1993).

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[41] This chapter is based on the paper: C. Böhringer and V. Alexeeva-Talebi (2011), Unilateral Climate Policy and Competitiveness: Differential Emission Pricing from a Sectoral, Regional and Global Perspective.

Leakage can arise when energy-intensive and trade-exposed industries in emission-constrained regions lose competitiveness, thereby increasing emission-intensive production in unconstrained regions. A second important leakage channel works through international energy markets: Emission constraints in larger open economies depress the demand for fossil fuels, thereby depressing world energy prices which in turn lead to an increase in the level of energy demand in other regions. Competitiveness and leakage concerns have motivated claims for special treatment of energy-intensive and trade-exposed sectors ranging from reduced emission prices or output-based emission allocation to border carbon adjustments (see Böhringer et al., 2010a).

A prime example of the competitiveness and leakage issues at stake in unilateral climate policy is provided by the European Union (EU) which considers itself as a leading force in the battle against anthropogenic climate change. During the Spring Summit in March 2007, the European Council has agreed upon an ambitious climate policy with unilateral greenhouse gas emissions reductions in 2020 by at least 20 percent compared to 1990 levels (EU, 2010a). At the same time, the EU is strongly committed to the objective of increasing competitiveness, economic growth and enhancing job creation alongside the so-called Lisbon Strategy (EU, 2006).[42] The simultaneous pursuit of environmental and competitiveness objectives has led to the preferential treatment of EITE industries in EU climate policy. The aggregate EU emission reduction is divided between energy-intensive sectors – of which EITE industries are a subset – covered through an EU-wide emission trading system (the so-called EU ETS) and the remaining parts of the EU economy (without trade linkages). As a consequence of competitiveness and leakage concerns, the emission reduction requirements for ETS sectors have been chosen relatively lax compared to the reduction targets for non-ETS segments of the EU economy (Convery and Redmond, 2007) which effectively boils down to preferential emission pricing of EITE industries.

While the issue of competitiveness ranks high and has tangible implications for the design of unilateral emission regulation, the climate policy debate misses a rigorous clarification of competitiveness notions and a comprehensive quantitative analysis of policy proposals that respond to competitiveness concerns of specific industries. In the assessment of unilateral EU climate policy, the bulk of “competitiveness research” is skewed towards a partial equilibrium perspective focusing on EITE industries which are directly affected by the EU ETS (e.g. Ponssard and Walker, 2008; Meunier and Ponssard, 2010; Monjon and Quirion, 2010). The sector-specific partial equilibrium framework does neither allow for a comparison of competitiveness implications across different industries nor a simultaneous assessment of economy-wide performance in terms of an overarching welfare metric. General equilibrium analysis of EU climate policies based on multi-sector, multi-region computable general equilibrium (CGE) models put the emphasis on the excess cost of emission abatement induced by emission market segmentation and overlapping regulatory measures (see Böhringer et al., 2009b, for a summary assessment of the EU climate and energy package) rather than competitiveness and leakage aspects.

This chapter provides an impact assessment of EU leadership in climate policy to illustrate the potential pitfalls of climate policy design that narrowly focuses on competitiveness concerns about EITE branches. Based on quantitative simulations with a large scale computable-general equilibrium model of global trade and energy we show that sector-specific gains of preferential regulation in favour of EITE branches must be traded off against the additional burden imposed on other industries to meet an economy-wide emission reduction target. Beyond burden shifting between industries, our results highlight the scope for substantial excess cost in emission reduction at the regional level as policy grants lower carbon prices to EITE industries and thereby foregoes relatively cheap abatement options in these sectors. From the perspective of *global cost-effectiveness*, however, preferential emission pricing for domestic energy-intensive and trade-exposed sectors can reduce leakage and thereby lower overall cost of cutting global emissions as compared to uniform emission pricing.

The remainder of this chapter is organised as follows: Section 4.1 discusses alternative indicators that can be used to quantify specific aspects of competitiveness at the level of sectors and countries. Section 4.2 lays out a computable general equilibrium model complemented with selected competitiveness indicators to facilitate the comprehensive impact assessment of unilateral climate policies. Section 4.3 presents a quantitative impact assessment of EU leadership in climate policy. Section 4.4 summarises and concludes.

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[42] Focusing on the "pressing challenge for competitiveness", the European Commission has initiated a permanent monitoring of competitiveness developments in the EU on the basis of selected competitiveness indicators in order to detect divergences between member states and provide timely policy reactions (EU 2010d).

4.1 Defining and measuring competitiveness

Competitiveness has become one of the most prominent catchwords in economics. Yet, the notion of competitiveness misses a well-defined conceptual framework and remains rather susceptible for ambiguities. As a basic orientation, scientific research distinguishes between competitiveness determinants governing the ability to compete and competitiveness indicators describing the outcome of competitiveness such as international trade performance or profitability (Reichel, 2002; Aiginger, 2006). For our impact assessment of climate policy interference, we adopt the outcome-based competitiveness notion and review the literature on appropriate sectoral and economy-wide competitiveness indicators.

4.1.1 Competitiveness notions and measurement concepts at the sectoral level

The most widespread definition of sectoral competitiveness refers to a sector's "*ability to sell in international markets*" (Jaffe, et al. 1995; Jenkins, 1998; Xu, 2000; Babool and Reed, 2010). International competitiveness, defined in terms of foreign trade performance, is thereby closely linked with international trade theory in general and the concept of comparative advantage in particular. According to the latter, countries are likely to export those goods and services in which they have a comparative cost advantage. The concept of a (revealed) comparative advantage has been interpreted as a "revealed competitive advantage" where industries with a comparative (cost) advantage are considered as internationally competitive (Jenkins, 1998; Fertö and Hubbard, 2003; Ahrend et al., 2007; Cai and Leung, 2008).

An alternative definition of sectoral competitiveness refers to a sector's "*ability to be profitable*" (Sell, 1991; EU, 2005a). This definition reflects the capacity to sell profitably in national and international markets. Cost pressure may not be (immediately) reflected in increasing prices as profits could play a buffer role to keep the market shares constant.

Table 16 provides a list of sectoral competitiveness indicators for measuring the "*ability to sell in international markets*" and the "*ability to be profitable*". Indicators on international trade performance are either based on trade data or a combination of trade and production (consumption) data. Contrary to indicators of international trade performance, the empirical implementation of indicators to measure profitability is more difficult due to limited availability of appropriate data (EU, 2005a). Harvey (2003) suggests three types of profitability indicators at the industrial level using national accounts data: profit margin (profit over sales), rates of return (profit over capital stock) and profit shares (profit over total factor expenditures).

Table 16: List of competitiveness indicators at the sectoral level

International trade performance	Profitability performance
• **Revealed comparative advantage** References: Balassa (1965), Ballance et al. (1987), Gorton et al. (2000), Fertö and Hubbard (2003), Abidin and Loke (2008)	• **Earnings before interests, tax, debt and amortisation (EBITDA)** References: Smale et al. (2006), Sato et al. (2007), Demailly and Quirion (2006, 2008a)
• **Export (import) ratio in world's total exports (imports)** References: Kravis and Lipsey (1992), Carlin et al. (2001), Reichel (2002)	• **Gross operating rate** References: EU (2005a), Peltonen et al. (2008)
• **Constant market share index** References: Koopmann and Langer (1988), Holst and Weiss (2004)	• **Rate of return** References: Rossi et al. (1986), Wang (1995), Manne and Barreto (2004)
• **Intra-industry trade index (Grubel-Lloyd)** References: EU (2005a), Havrila and Gunawardana (2003)	• **Profit share** References: Torrini (2005)
• **Ratio of exports (imports) to production (consumption)** References: Ballance et al. (1987)	

4.1.2 Competitiveness notions and measurement concepts at the economy-wide level

At the economy-wide level the concept of competitiveness is discussed controversially. One of the most prominent opponents, Paul Krugman, argues that „competitiveness is a meaningless word when applied to national economies" (Krugman, 1994). Contrary to such fundamental criticism, competitiveness concepts at the economy-wide level are widely used in scientific studies (see Porter, 1990, for an early contribution) and the public policy debate. There are meanwhile numerous surveys of competitiveness notions at the economy-wide level (see e.g. Reichel, 2002; Aiginger, 2006, or Siggel, 2007).

The conventional interpretation of national competitiveness – analogous to the "ability to sell" notion at the sectoral level – focuses on a country's international trade performance (Durand

and Giorno, 1987; Fagerberg, 1988; Nielsen et al., 1995). The traditional focus on "ability to sell" has shifted in the recent literature towards more general measurement concepts linked to normative economics. The argument behind this shift is that the emphasis on international trade can be misleading as trade may represent only a small fraction of GDP and one-sided export orientation is not sustainable. Furthermore, expansion of exports – as an indicator of competitiveness – might have its origin in low wages, subsidies or weak currency resulting in lower standards of living in the country. The real matter then becomes "the ability to earn", i.e. the ability to create wealth or high standards of living as a central dimension of national competitiveness (Jenkins, 1998; EU, 2004a; Grilo and Koopman, 2006; Aiginger, 2006). Grilo and Koopman (2006) argue that international trade performance is only an appropriate competitiveness indicator at the sectoral level, whereas competitiveness at the national level should be rigorously linked to welfare metrics such as GDP per capita or real consumption.

Dollar and Wolff (1993), Auerbach (1996), Reichel (2002), Hildebrandt and Silgoner (2007) and ECB (2009) take an intermediate position referring to both "*ability to sell*" and "*ability to earn*". They suggest that changes in competitiveness at the economy-wide level measured by international performance indicators shall not be interpreted in isolation, but rather in combination with a country's economic development and/or standards of living. The underlying argument is that the rise in living standards can be attributed to improved competitiveness at the national level as measured by the international trade performance indicators. Table 17 provides a summary of economy-wide competitiveness indicators.

Table 17: List of competitiveness indicators at the economy-wide level

International trade performance	**Ability to create welfare**
• **Terms of trade** References: Riley (1980), Di Bartolomeo (2005), Hildebrandt and Silgoner (2007) • **Trade balance (current account)** References: Nielsen et al. (1995), Deutsche Bundesbank (2007) • **Export market share** References: Fagerberg (1988), Amable and Verspagen (1995), ECB (2005), Danninger and Joutz (2007) • **(Real effective) exchange rate** References: Vitek (2009)	• **GDP per capita** References: Grilo and Koopman (2006), Aiginger (2006) • **Real consumption** References: Grilo and Koopman (2006), Aiginger (2006)

The final conclusion which can be drawn from literature on competitiveness indicators to measure international trade performance is that it is not possible to identify a single valid measure from a theoretical (including normative) and empirical perspective.

4.2 Method for quantitative impact assessment

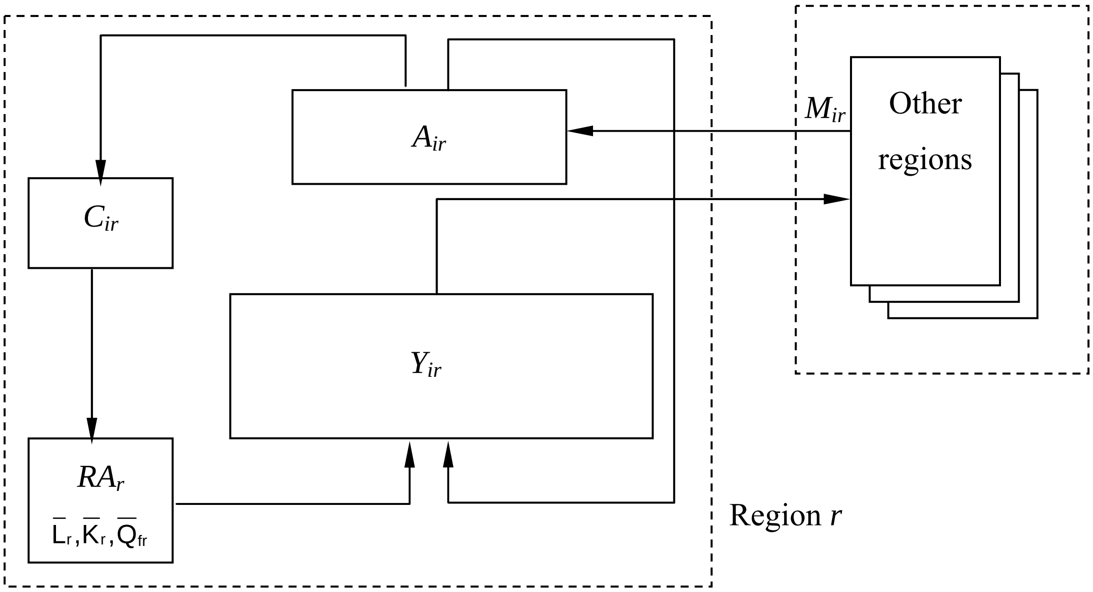
To quantify the economic implications of unilateral climate policies on competitiveness and welfare, we make use of a multi-sector, multi-region computable general equilibrium (CGE) model of global trade and energy use. CGE models build upon general equilibrium theory that combines behavioural assumptions on rational economic agents with the analysis of equilibrium conditions. They provide counterfactual ex-ante comparisons between a reference situation without policy intervention and the outcome triggered by policy reforms. The main virtue of the CGE approach is its comprehensive micro-consistent representation of price-dependent market interactions. The simultaneous explanation of the origin and spending of the agents' income makes it possible to address both economy-wide efficiency as well as distributional impacts of policy interference. The disaggregation of macroeconomic production, consumption and trade activities at the sector level based on national input-output accounts accommodates a coherent cross-comparison of economic performance between sectors and a trade-off analysis with economy-wide welfare. Changes in economic welfare are usually expressed in terms of the Hicksian equivalent variation (HEV) in income. Beyond an appropriate sectoral disaggregation, a multi-region setting is indispensable for the economic impact analysis of climate policy interference: In a world which is integrated through trade, policy interference in larger open economies not only causes adjustment of domestic production and consumption patterns but also influences international prices via changes in exports and imports. The changes in international prices, i.e., the terms of trade, imply secondary effects that can significantly alter the impacts of the primary domestic policy (Böhringer and Rutherford, 2002). The international dimension is also a prerequisite to track sectoral and economy-wide competitiveness implications related to the international trade performance.

Section 4.2.1 provides a non-technical overview of the basic CGE model structure adopted for our impact analysis of unilateral climate policies (for an algebraic summary see: Böhringer and Rutherford, 2010). Section 4.2.2 lays out the data sources in use for empirical parameterisation. Section 4.2.3 describes the CGE implementation of selected competitiveness indicators at the sector level – i.e. relative world trade shares (RWS) and revealed comparative advantage (RCA) – and the economy-wide level, i.e. the terms of trade (ToT) and real consumption. These competitiveness indicators are used in our numerical simulations in order to illustrate the meaningfulness and potential pitfalls of competitiveness analysis.

4.2.1 Model structure

Figure 9 provides a diagrammatic structure of the static multi-sector, multi-region CGE model in use for our numerical analysis. A representative agent RA_r in each region r is endowed with three primary factors: labour $\overline{L}_r$, capital $\overline{K}_r$ and specific resources $\overline{Q}_{fr}$ (the latter used for the production of fossil fuels f such as coal, gas and crude oil).

Figure 9: Diagrammatic overview of the model structure



Labour and capital are assumed to be intersectorally mobile within a region but immobile between regions. Fossil-fuel resources are specific to fossil fuel production sectors in each region. Production Y_{ir} of commodity i in region r is captured by three-level constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labour, energy and material in production. At the top level, a CES composite of intermediate material demands trades off with an aggregate of energy, capital and labour subject to a constant elasticity of substitution. At the second level, a CES function describes the substitution possibilities between demand for the energy aggregate and a value-added composite of labour and capital. At the third level, capital and labour substitution possibilities within the value-added composite are captured by a CES function, whereas different energy inputs (coal, gas, oil and electricity) enter the energy composite subject to a constant elasticity of substitution. In the production of fossil fuels all inputs, except for the sector-specific fossil fuel resource, are aggregated in fixed proportions. This aggregate trades off with the sector-specific fossil fuel resource at a constant elasticity of substitution. The latter is calibrated to be generally consistent with empirical estimates for the supply elasticity of the specific fossil fuel.

Final consumption demand C_r in each region is determined by the representative agent who maximises utility subject to a budget constraint with fixed investment (i.e. a given demand for savings) and exogenous government provision of public goods and services. Total income of the representative household consists of net factor income and tax revenues. Consumption demand of the representative agent is given as a CES composite which combines consumption of non-electric energy and composite of other consumption goods. Substitution patterns within the non-electric energy bundle are reflected by means of a CES function; other consumption goods trade off with each other subjected to a constant elasticity of substitution.

Bilateral trade is specified following the Armington approach of product heterogeneity, i.e. domestic and foreign goods are distinguished by origin (Armington, 1969). All goods used on the domestic market in intermediate and final demand correspond to a CES composite A_{ir} which combines the domestically produced good (Y_{ir}) and the imported composite (M_{ir}) from other regions. Domestic production is split between input to the formation of the Armington good and exports to other regions subjected to a constant elasticity of transformation. The balance of payment constraint which is warranted through flexible exchange rates incorporates the base-year trade deficit or surplus for each region.

Carbon emissions are linked in fixed proportions to the use of fossil fuels. Thereby, carbon coefficients are differentiated by the specific carbon content of fuels. Restrictions to the use of carbon emissions in production and consumption are implemented through carbon taxes or exogenous emission constraints which keep carbon emissions to a specified limit. Carbon emission abatement then takes place by fuel switching (inter-fuel substitution) and energy savings (either by fuel-non-fuel substitution or by a scale reduction of production and final demand activities).

4.2.2 Data

The model is based on the most recent consistent accounts of region- and sector-specific production, consumption, bilateral trade and energy flows as provided by the GTAP 7 data base for the year 2004 (Badri and Walmsley, 2008). The GTAP data base features rudimentarily initial tax distortions. In our numerical analysis, we therefore abstain from the explicit representation of initial taxes. As to the sectoral and regional model resolution, the GTAP database is aggregated towards a composite dataset which accounts for the specific requirements of international climate policy analysis. At the sectoral level, the model captures details on sector-specific differences in factor intensities, degrees of factor substitutability and price elasticities of output demand in order to trace the structural change in production induced by policy interference. The energy goods identified in the model are coal, crude oil, natural gas, refined oil products and electricity. This disaggregation is essential in order to distinguish energy goods by carbon intensity and degree of substitutability. The model then incorporates explicitly carbon-(energy-)intensive commodities with significant shares of international trade that are potentially most affected by unilateral climate policies and are subject to competitiveness and leakage concerns: paper, pulp and print; chemical products; mineral products; iron and steel; non-ferrous metals and air transport. These sectors together with refined oil products are referred to as EITE industries in our numerical analysis below. The remaining sectors are summarised through a composite of all other industries and services. With respect to the regional disaggregation, the model includes the European Union (EU) together with other major industrialised and developing regions that are key players in international climate negotiations and at the same time intertwined through bilateral trade links: the United States of America, Japan, Russia, the rest of OECD, China, India, Brazil, the organisation of oil exporting countries (OPEC) and a composite region for the rest of the developing world. Table 18 summarises the regional, sectoral and factor aggregation of the model, respectively.

Elasticities in international trade (Armington elasticities) are based on empirical estimates reported in the GTAP7 database. Substitution elasticities between production factors capital, labour, energy inputs and non-energy inputs (material) are taken from the econometric study by Okagawa and Ban (2008) who use the most recent panel data across sectors and industries for the period 1995 to 2004.

Table 18: Model dimensions: Regions and sectors

Production sectors	**Regions and primary factors**
Energy	*Regions*
Coal	European Union
Crude oil	United States of America
Natural gas	Japan
Electricity	Russia
Refined oil products	Rest of OECD
	China
Non-Energy	India
Paper, pulp and print	Brazil
Chemical products	OPEC
Mineral products	Rest of the developing world
Iron and steel	
Non-ferrous metals	*Primary factors*
Air transport	Labour
Other industries and services	Capital
	Fixed factor resources for coal, oil and gas

4.2.3 CGE implementation of competitiveness indicators

For our illustrative analysis of competitiveness effects triggered by unilateral climate policy, we implement a set of widely used competitiveness indicators: relative world trade shares (RWS) and revealed comparative advantage (RCA) in order to measure sectoral competitiveness effects and terms of trade (ToT) as well as real consumption to measure economy-wide competitiveness effects.

Letting *X* denote exports, P^x export prices, *r* the region and *i* the sector, the RWS index for sector *i* in region *r* can be written as follows (Balassa 1965; Reichel, 2002):

$$RWS_{ir} = \frac{P_{ir}^x X_{ir} / \sum_r P_{ir}^x X_{ir}}{\sum_i P_{ir}^x X_{ir} / \sum_r \sum_i P_{ir}^x X_{ir}} .$$

This index compares the ratio of a country’s exports in a certain sector to the world’s exports in this sector with the ratio of a country’s overall exports to the world’s exports in all sectors. If the sectoral export-import ratio is identical to the economy-wide ratio, the RWS index takes the value of one ($RWS_{ir} = 1$). A region *r* is said to have a comparative advantage in sector *i* if the RWS index exceeds unity ($RWS_{ir} > 1$). Conversely, a region *r* has a comparative disadvantage in sector *i* if the RWS index takes the values between zero and one ($0 \le RWS_{ir} < 1$).

The validity of RWS as a general indicator for international trade performance is sometimes questioned because import flows are not taken into account. As an alternative metric, we therefore consider the revealed comparative advantage (RCA) indicator. The RCA index provides a measure for competitiveness of different industries within an economy. With the additional notations of P^m for import prices and *M* for imports, the RCA index for sector *i* in region *r* is defined as follows (Balassa, 1965; Reichel, 2002):

$$RCA_{ir} = \frac{P^x_{ir} X_{ir} / P^m_{ir} M_{ir}}{\sum_i P^x_{ir} X_{ir} / \sum_i P^m_{ir} M_{ir}} .$$

For a particular region and sector, this index compares the ratio of exports by a specific sector to its imports with the ratio of exports to imports across all sectors of the region. The RCA indicator ranges from $0 \le RCA_{ir} \le \infty$ and can be interpreted regarding the range for comparative (dis-)advantage similarly to the RWS indicator.

While both sectoral indicators, RWS and RCA, purport to measure comparative advantage of a particular industry, they vary with respect to the point of reference: The RWS indicator measures how the relative performance of a particular sector in the country *r* changes compared to the relative performance of the same sector across the world. The RCA indicator compares the performance of a particular sector with performance of all sectors within the same region. In a partial equilibrium perspective, increases in exports X_{ir} of sector *i* in region *r* result ceteris paribus in increasing competitiveness according to RCA_{ir} and RWS_{ir} indicators. Vice versa, increasing imports will ceteris paribus decrease sectoral competitiveness. While RCA and RWS provide information on the quality and intensity of competitiveness implications at the sector level, they cannot be used as a general indication of economy-wide welfare effects.

At the economy-wide level, we implement a terms-of-trade (ToT) indicator to monitor competitiveness implications for international trade performance. The ToT indicator is defined as a Laspeyres index measuring the ratio of the price index of exports to the price index of imports in which prices are weighted by the base-year quantities of exports $\overline{X_{ir}}$ and imports $\overline{M_{ir}}$ (see e.g. Krueger and Sonnenschein, 1967):

$$ToT_r = \frac{\sum_i P_{ir}^x \overline{X}_{ir} \Big/ \sum_i \overline{P}_{ir}^x \overline{X}_{ir}}{\sum_i P_{ir}^m \overline{M}_{ir} \Big/ \sum_i \overline{P}_{ir}^m \overline{M}_{ir}},$$

whereas P_{ir}^x and $\overline{P}_{ir}^x$ (P_{ir}^m and $\overline{P}_{ir}^m$) represent current and base-year export (import) prices, respectively. Terms of trade deteriorate as the indicator decreases; terms of trade improve as the indicator increases.

Finally, the level of real consumption – as our alternative competitiveness indicators at the economy-wide level – is incorporated as an explicit activity variable in the CGE model. It directly captures welfare implications based on the CES expenditure function for final consumption goods.

4.3 Impact assessment of unilateral EU climate policies

Our standard CGE framework, complemented with competitiveness indicators at the sectoral and economy-wide level, facilitates a comprehensive impact assessment of unilateral climate policies. The major drivers of economic impacts triggered by emissions constraints include (i) the stringency of the emissions reduction target, (ii) the policy implementation, (iii) the ease of emission abatement in production as well as consumption and (iv) spillover and feedback effects from international markets that emerge from policy action of larger economies.

We capture dimensions (i) and (ii) in the specification of our climate policy scenarios reflecting the ongoing debate on the stringency of emission reduction pledges and preferential treatment of emission-intensive and trade-exposed (EITE) industries. Firstly, we vary the unilateral reduction target of the EU between 5 percent, 10 percent, 15 percent, 20 percent, 25 percent and 30 percent as compared to the reference emission level without climate policy action (the so-called business-as-usual, BaU). Higher reduction targets thereby go along with a more ambitious role of EU leadership in the fight against climate change. Secondly, we allow for differential emission pricing in favour of EITE industries, thereby mimicking actual policy legislation to ameliorate adverse competitiveness effects for these sectors.[43] In our simulations, the emission price ratio between the remaining segments of the economy, on the one hand, and the EITE industries, on the other hand, ranges from unity (i.e. uniform emissions pricing), via factors of 2, 5, 10 and 20 to full exemption of EITE industries. Ratios higher than one indicate that emissions prices are discriminated in favour of EITE sectors – for example, a ratio of 20 implies that the carbon price in the rest of the economy is twenty times higher than that for the EITE industries. The emission price level is thereby endogenously adjusted to warrant overall compliance with the exogenous EU-wide emission reduction target.

The remaining dimensions (iii) and (iv) are inherent to our CGE model framework: The ease of emission substitution in production and consumption is implicit to the top-down representation of technologies and preferences. That is through continuous functional forms that describe trade-offs between inputs (outputs) based on empirically estimated substitution (transformation) elasticities. The international spillover effects are captured through explicit bilateral trade relations between key trading partners at the sectoral level. Policy-induced changes in international prices, i.e. the terms of trade, may allow a country to shift part of its domestic abatement cost to trading partners or conversely suffer from a deterioration of its terms of trade (on top of purely domestic adjustment cost in the absence of terms-of-trade effects). International spillover effects furthermore provide the background for leakage concerns in the case of unilateral climate policies and the claim for preferential treatment of EITE sectors to reduce emission leakage.

For our graphical exposition of simulation results, we use bar diagrams along the different unilateral emissions abatement targets and the alternative emission price ratios. Note that in the graphs we refer to the case of full emission price exemptions in favour of EITE sectors with the label “ex”. The primary interest of our quantitative analysis is to highlight the pending trade-offs between economic performance across sectors (in terms of output and competitiveness indicators) and overall economic efficiency (in terms of real consumption) as a function of environmental stringency and preferential treatment of EITE industries. In this way, we can complement the often narrowly focused debate on competitiveness effects for EITE industries with insights on cost shifting to other segments of the economy and potential

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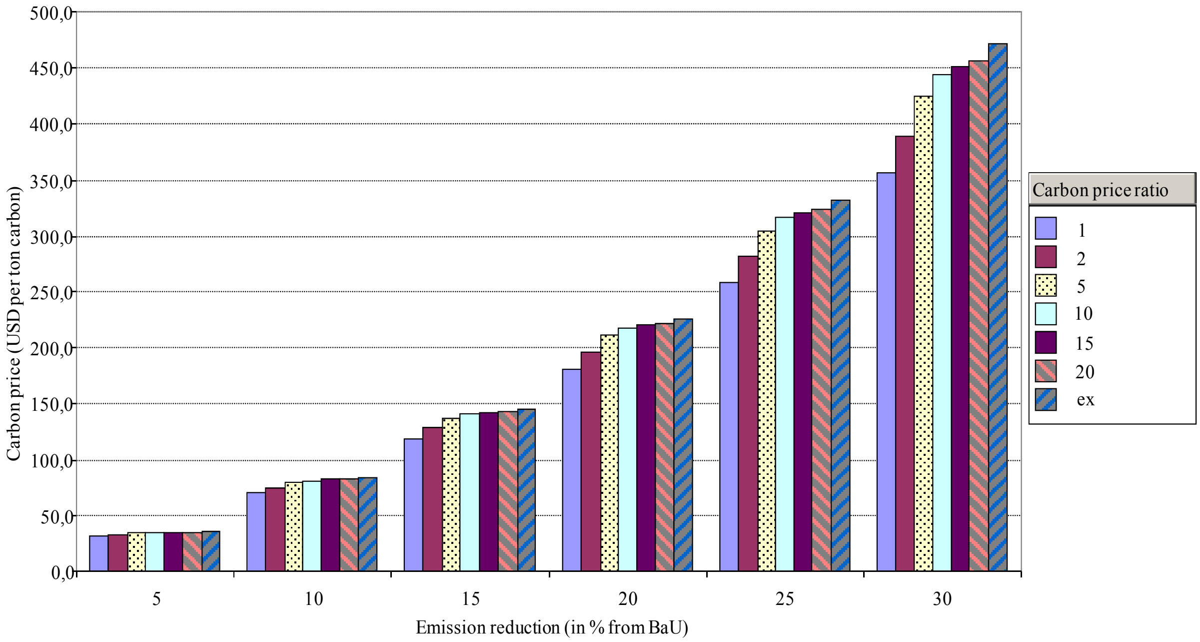
[43] As mentioned before, differential emissions pricing between EITE sectors and the rest of the economy corresponds to the hybrid EU climate policy legislation where energy-intensive industries covered under the EU

excess cost of environmental regulation. As it is customary in applied equilibrium analysis most of our results are reported in terms of percentage changes in economic indicators compared to a reference situation without climate policy interference – the BaU. Our reference situation is one without climate policies, i.e. the historical outcome of the base year of the model 2004. Note that this was before the EU emissions trading system has been implemented and before the Kyoto Protocol entered into force.

We start the interpretation of results with the marginal abatement cost for non-EITE segments of the economy. The marginal abatement cost for EITE industries then directly follow as a function of the imposed emission price ratio: For a carbon price ratio of 1, the marginal abatement cost are by definition uniform across all segments of the unilateral abating region.

Figure 10 clearly illustrates that marginal abatement cost increase towards higher emission reduction targets as carbon emission abatement options through fuel switching (inter-fuel substitution) or energy savings (either via energy efficiency improvements or the scale reduction of production and final demand activities) become more and more expensive.

Figure 10: Marginal abatement cost in non-EITE segments of the EU economy (USD2004 per ton of carbon)



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emission trading scheme face a different emission price that the remaining segments of the EU economy.

Under uniform emission pricing marginal abatement cost rise from roughly 30 USD per ton of carbon at a 5 percent unilateral emission reduction to more than 350 USD per ton of carbon at a 30 percent emission reduction. When policy grants preferential treatment of EITE sectors through relatively lower emission prices it is clear that marginal abatement cost for the remaining segments of the economy must increase above the carbon value in the case of uniform emission pricing.

The increase in the absolute carbon price for non-EITE sectors (compared to the uniform carbon value) remains relatively moderate even for the case of total EITE exemption. The reasoning behind is that the EITE sectors are only responsible for a smaller share (less than 15 percent) of overall carbon emissions in the domestic economy. Yet, the additional price tag on non-EITE sectors towards higher emission reduction targets becomes more and more pronounced indicating the potential for substantial increases in direct abatement cost as the gap in marginal abatement cost between EITE and non-EITE sectors widens.

We next turn to the implications of unilateral climate policy on competitiveness at the sector level. Emission pricing has a direct impact on those sectors where emission-intensive inputs (fossil fuels) represent a significant share of direct and indirect cost. With uniform unilateral emission pricing, these sectors lose in comparative advantage not only against domestic emission-extensive industries; at the international level they are also at a disadvantage compared to competing energy-intensive industries which are not subject to emission regulation. Figure 11 and Figure 12 depict the implications for competitiveness of EITE industries as well as for the bulk of non-EITE industries (summarised within the composite sector “Other industries and services”, OTH). Both trade-based indicators confirm competitiveness concerns for EITE sectors in the case of unilateral climate policy: EITE industries lose in competitiveness if we compare its trade performance with the average trade performance across all sectors of the unilateral abating region (RCA). Likewise, EITE industries suffer from a loss in competitiveness if we track the trade performance of this sector in the abating region compared to the performance of the same sector in other non-abating regions (RWA). The higher the emission reduction target and thus the implied emission price is, the higher are ceteris paribus the losses in EITE competitiveness. As policy discriminates emission pricing in favour of EITE industries, these losses can be ameliorated to some extent.

Figure 11: EU sectoral competitiveness effects – revealed comparative advantage (% change from BaU)

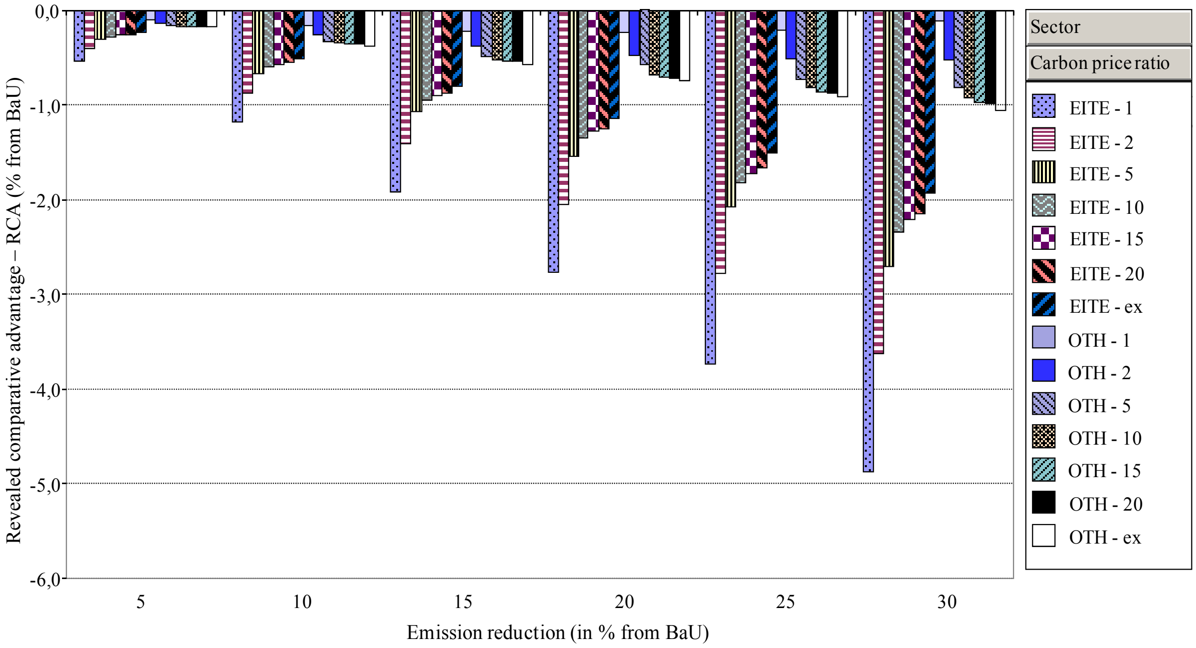
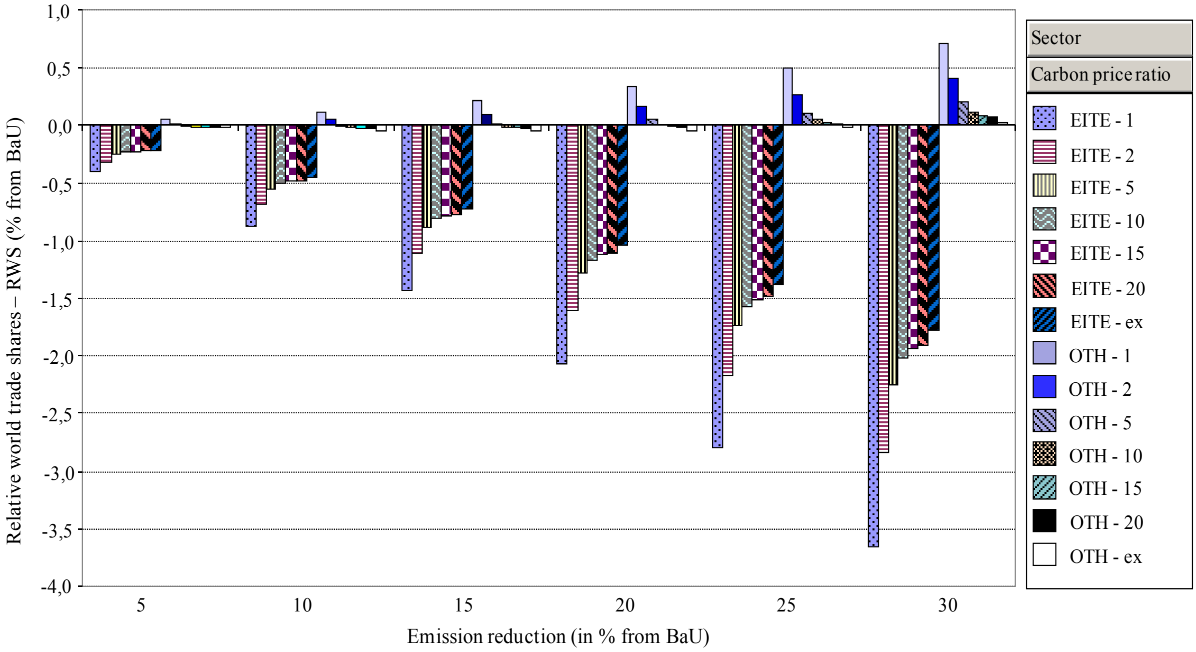
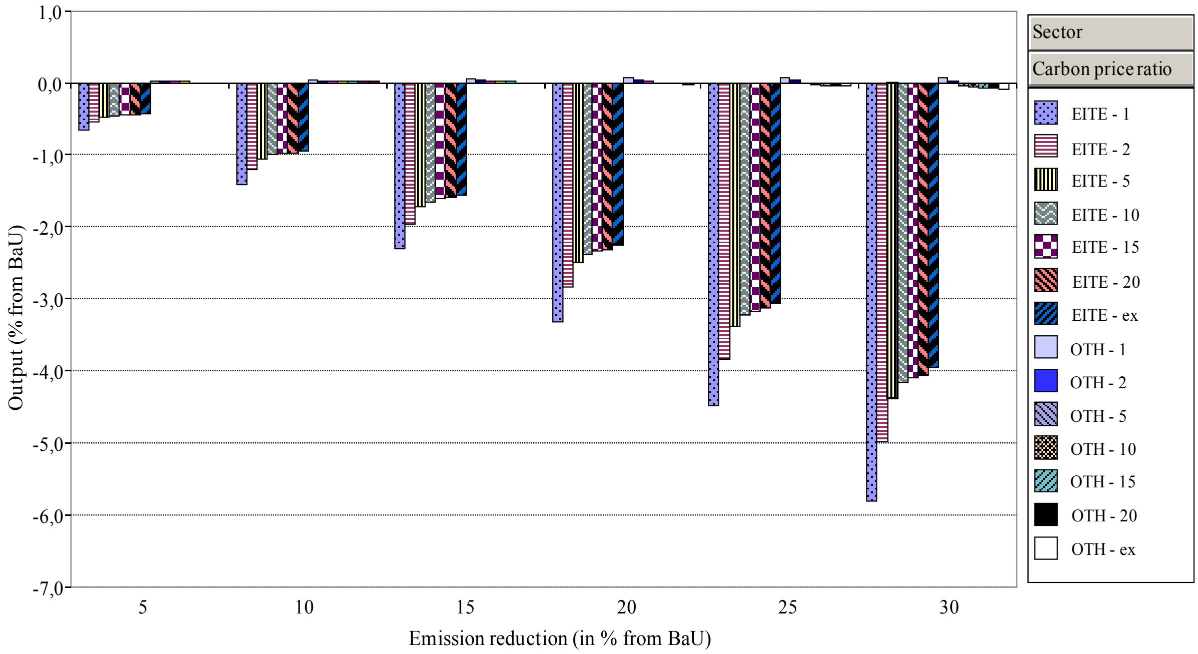


Figure 12: EU sectoral competitiveness effects – relative word trade shares (% change from BaU)



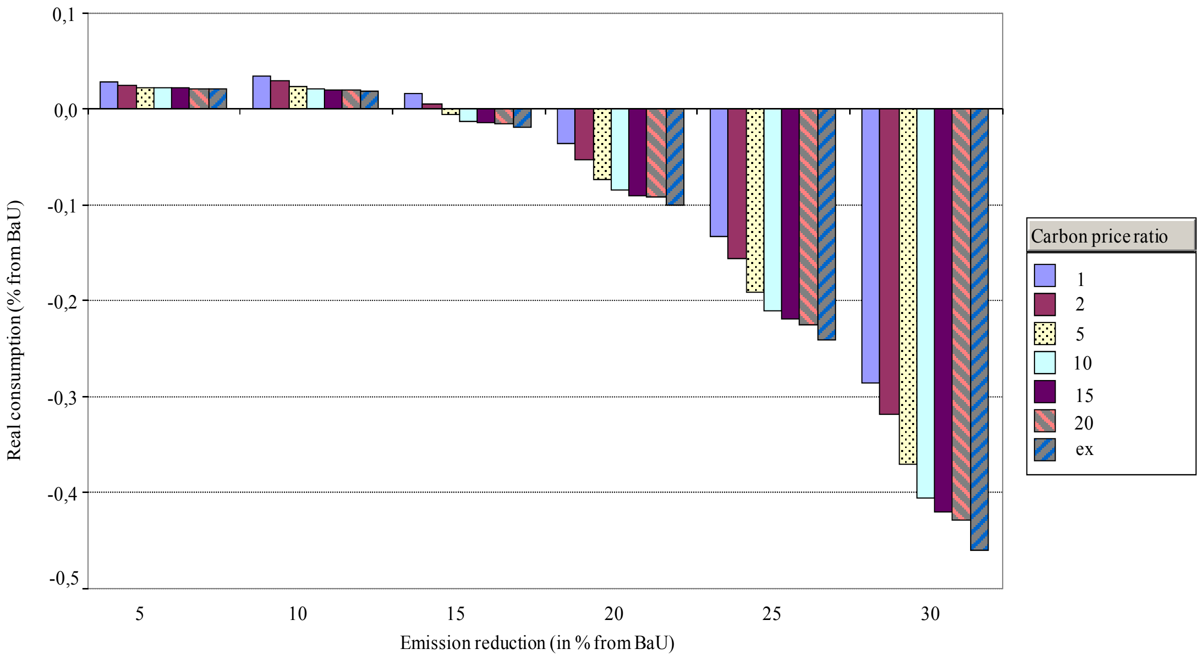
However, Figure 11 and Figure 12 also illustrate that preferential policies in favour of EITE sectors go at the expense of other industries whose competitiveness decrease towards higher carbon price ratios. While the specific changes in competitiveness RCA and RWS indicators provide a useful cardinal information on competitiveness implications at the sectoral level, it becomes obvious that a balanced view calls for the simultaneous assessment across various sectors of the domestic economy rather than focusing on a very narrow segment of the economy which might be most adversely affected by policy-induced structural change. The trade-off between performances of sectors for differential emission pricing can be further visualised through the output effects in the different industries. Figure 13 indicates that EITE industries (with a BaU production share of slightly more than 10 percent) suffer from substantial production losses due to emission constraints, while the rest of non-energy industries and services (OTH) industries with a much higher BaU production share may even slightly increase their output above BaU levels. The losses in EITE production can be substantially attenuated through differential emission pricing (up to roughly one-third for the extreme case of full exemption) but this works at the disadvantage of production in OTH industries.

Figure 13: Output effects in the EU (% change from BaU)



We now discuss the economy-wide implications of unilateral emission abatement. The common metric in general equilibrium analysis to report aggregate welfare changes is the Hicksian equivalent variation in income. In our analytical framework where we abstain from quantifying the (uncertain) benefits from emission reduction and keep savings demand constant, the policy-induced change in real income can be readily translated in changes of real consumption. In other words: The change in real consumption provides a consistent metric for cost-effectiveness analysis across alternative emission price ratios to reach the same level of unilateral emission abatement (for the discussion of global effectiveness incorporating leakage effects see below). Figure 14 reveals that the EU is able to achieve moderate emission reductions at negative costs as the direct costs of emission abatement are more than compensated through welfare gains from improved terms of trade. Towards higher emission reduction requirements the direct abatement costs dominate secondary terms-of-trade gains and the EU encounters non-negligible losses in real income. As climate policy deviates from uniform emission pricing in favour of EITE industries, there is an economy-wide excess burden of discriminatory climate policy. The latter becomes quite pronounced towards higher reduction targets where broader dispensation of cheap abatement options in the EITE sectors causes much higher abatement costs in the remaining segments of the economy. More generally, the EU experiences terms-of-trade gains from unilateral emission reductions but there is no scope for additional net welfare gains (taken as the difference between direct abatement cost and indirect terms-of-trade gains) through lower emission pricing to EITE sectors.

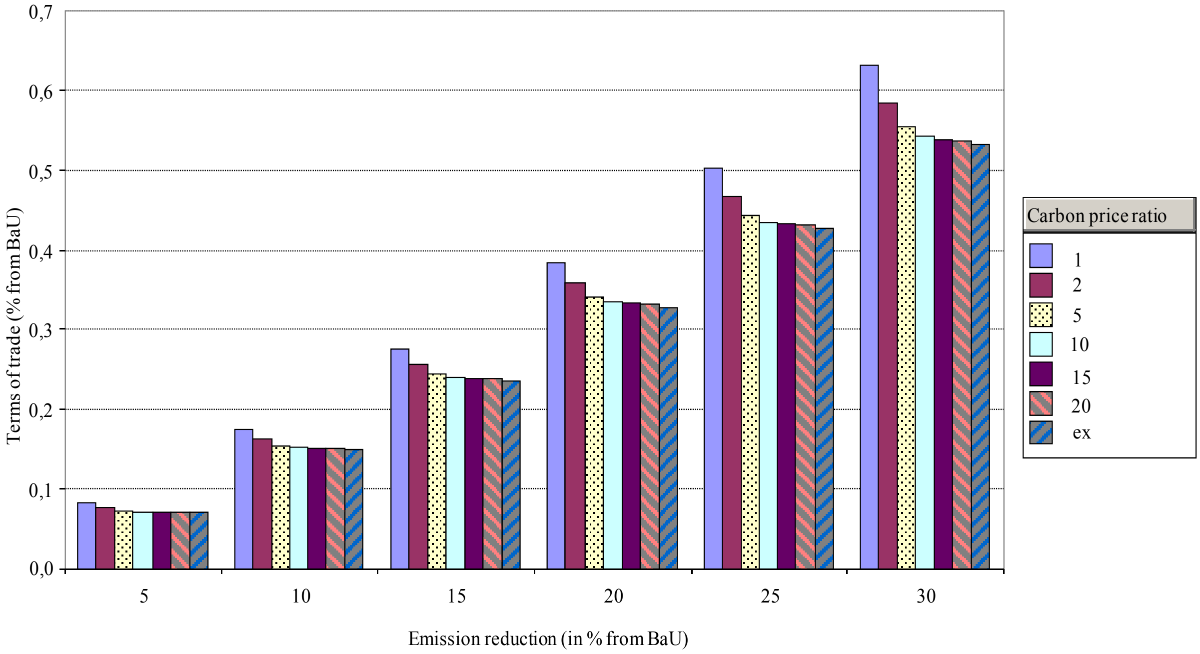
Figure 14: Changes in real consumption in the EU (% change from BaU)



In this context, it is useful to distinguish international spillovers from fossil fuel markets, on the one hand, and from non-energy markets, on the other hand. Regarding spillovers on fossil fuel markets, cutbacks in international fuel demand of large open economies depress international fuel prices which in turn reduce the energy bill of the EU as a large fuel importer. The terms-of-trade effects on fossil fuel markets thereby dominate additional spillover effects on non-energy markets where emission price discrimination between EITE sectors and the remaining segments of the unilaterally abating region only has a secondary welfare impact (Böhringer et al., 2010b). Taking real consumption as an appropriate economy-wide competitiveness indicator we can conclude that preferential treatment of EITE sectors rather worsens than alleviates the "national" competitiveness impact of unilateral climate policy for the EU.

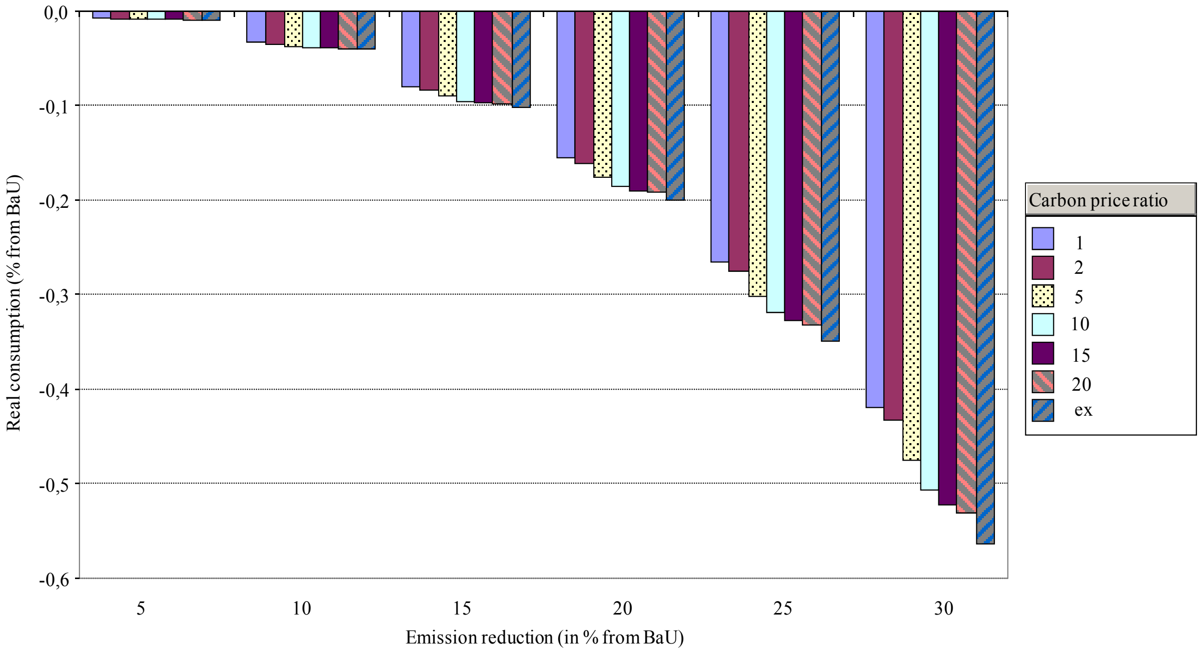
Figure 15 provides supplemental information on terms-of-trade changes for the EU triggered by unilateral climate policy. There are terms-of-trade gains for the EU from unilateral emission abatement (predominantly on international fuel markets) but these gains decrease with differential emission pricing in favour of EITE industries.

Figure 15: Terms of trade in the EU (% change from BaU)



It is possible to decompose the welfare implications of secondary terms-of-trade effects by applying a simple decomposition technique described in Böhringer and Rutherford (2002b). The total economic effect of unilateral abatement is thereby broken down into a so-called domestic market effect (i.e. the domestic adjustment holding international prices constant) and the international spillover effect (i.e. the residual effect accounting for changes in the terms of trade). Figure 16 quantifies the primary domestic market effect at constant international prices for the EU economy.

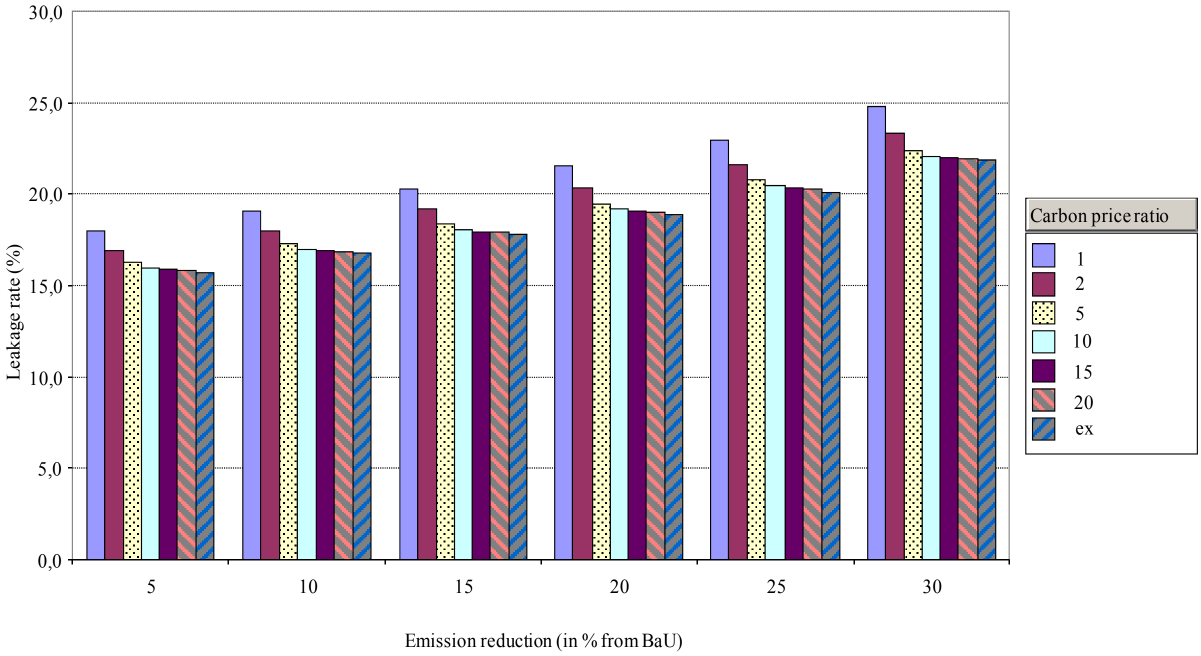
Figure 16: Changes in real consumption neglecting terms-of-trade changes in the EU (% change from BaU)



Without terms-of-trade effects, unilateral emission reduction triggers overall adjustment cost for the EU economy right away. Compliance cost increase towards higher unilateral emission reduction pledges as well with differential emission pricing. Note that the difference in economy-wide adjustment cost between Figure 14 and Figure 16 are equivalent to the welfare gains for the EU from policy-induced shifts in the terms of trade.

So far we have not addressed the issue of emission leakage and global cost-effectiveness of unilateral climate policy design. Compliance to regional emission targets at minimum cost for the domestic economy appeals as a realistic policy objective of the unilateral abating country. However, the focus on unilateral emission reduction neglects the different impacts of alternative policy implementations (in our case: differential emission pricing of EITE versus non-EITE sectors) on the level of global emissions via carbon leakage. In fact, claims for preferential treatment of EITE sectors not only stem from concerns of politically influential lobbies on adverse adjustment (competitiveness) effects in these industries but may be justified as second-best strategies to reduce leakage and thereby potentially increase global cost-effectiveness of unilateral abatement. In this vein, we must investigate the question how compliance cost of the unilateral abating region change with preferential emission pricing as we consider a global emission reduction target rather than the domestic emission pledge. The global emission reduction target that goes along with unilateral abatement is thereby defined as the leakage-compensated unilateral emission reduction pledge. To achieve this, we endogenously scale the domestic reduction target of the unilaterally abating regions in order to offset adverse leakage impacts from non-abating regions on the global emission level. While leakage compensation does not seem particularly relevant for actual policy practise of unilaterally abating regions, it provides a meaningful benchmark for judging the cost-effectiveness of unilateral action without the need for evaluating the benefits from emission reduction. Against this background, Figure 17 confirms basic economic reasoning that preferential treatment of emission-intensive and trade-exposed industries will reduce leakage which is conventionally defined as the change in foreign emissions as a share of the domestic emissions reductions.

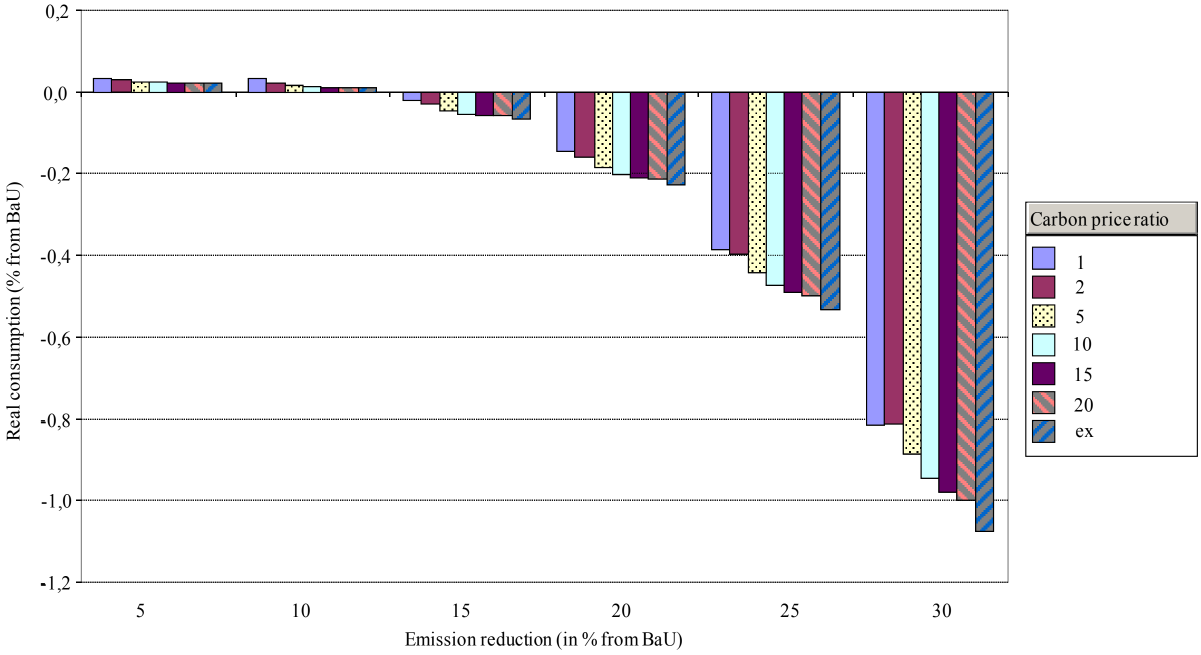
Figure 17: Emission leakage rates (in %) in the case of unilateral leakage compensation



Notwithstanding, it also becomes obvious that emission pricing in favour of EITE industries is only a weak instrument to counteract leakage since the main part of leakage comes from fossil fuel reduction which is more or less fixed through the global emission reduction target. Figure 18 confirms the poor performance of differential emission pricing as a second-best strategy compared to uniform emission pricing across all segments of the domestic economy.

The domestic compliance cost for the EU to achieve a given global emission reduction through unilateral abatement is very likely to increase with non-uniform emission pricing, i.e. the gains from reduced leakage are more than offset through the increase in additional direct abatement cost for the case of differential emission pricing.[44]

Figure 18: Changes in the EU real consumption (% change from BaU) in the case of leakage compensation



Finally, our results show that non-uniform pricing strategy offers some prospects for improving global cost-effectiveness of unilateral emission reduction actions. Centring the discussion around global instead of regional (European) welfare perspective, Figure 19 demonstrates that moderate carbon price differentiation (up to factor 5 in favour of EITE industries) slightly reduces losses in global real consumption compared with a simple rule of uniform emission pricing. Gains from reduced leakage and improved terms of trade in non-abating regions are sufficient in magnitude to offset the increase in additional direct abatement cost for the case that Europe pursues climate policy with some degree of preferential treatment in favour of EITE industries.[45]

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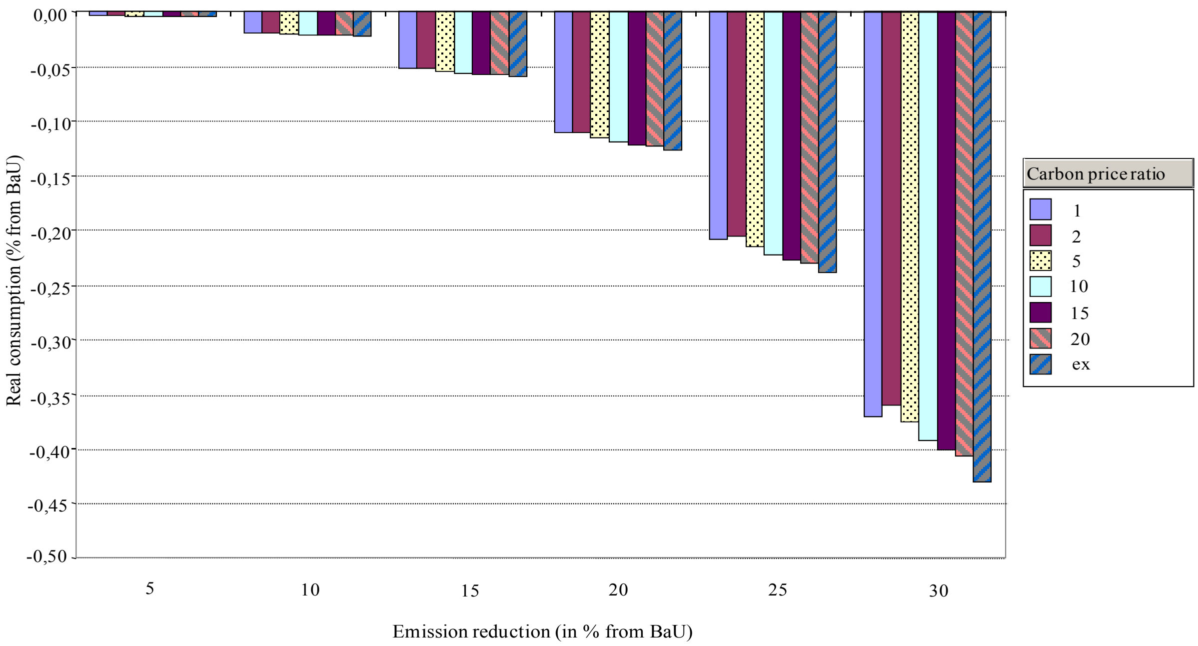
[44] In the numerical simulations reported in Figure 18 there is only one exception for the case of high emission reduction targets and moderate preferential treatment of EITE industries.

[45] They are mirror-inverted to the EU implications as shown in Figure 15.

Figure 19: Changes in global real consumption (% change from BaU)



4.4 Conclusions

In response to the challenges posed by climate change and the lack of a global greenhouse gas reduction treaty, individual OECD countries are in the process of legislating unilateral emission reduction strategies. As a primary example, the European Union has already committed itself to substantial unilateral greenhouse emissions reductions within the EU Climate and Energy Package. The prospect of rising carbon prices, however, fosters concerns on adverse competitiveness impacts for domestic energy-intensive and trade-exposed (EITE) industries compared to foreign competitors that are not constrained by comparable regulation. These competitiveness concerns joint with the potential for emission leakage provide the background for preferential treatment of EITE industries in unilateral climate policy legislation. While the climate policy debate is very much dominated by the issue of "competitiveness", it misses a rigorous clarification of competitiveness notions and a comprehensive impact assessment of policy proposals that respond to competitiveness concerns of particular industries.

In this chapter, we have first discussed alternative indicators that can be used to quantify specific aspects of competitiveness at the level of sectors and countries. We subsequently have elaborated on a computable general equilibrium model complemented with selected competitiveness indicators to facilitate the comprehensive impact assessment of EU leadership in climate policy. In order to reinforce industrial competitiveness, price discrimination in favour of EITE sectors is warranted. Notwithstanding, our analysis has clearly revealed potential trade-offs to be faced by European policy makers narrowly focusing on competitiveness concerns about energy-intensive and trade-exposed branches. In particular, the sector-specific gains of preferential regulation in favour of these branches must be trade-off against the additional burden imposed on other industries to meet an economy-wide emission reduction target. The concomitant effect is that marginal benefits of improved economy-wide terms of trade changes in a large open economy such as EU pursuing unilateral climate actions decrease with differential emission pricing in favour of EITE industries. Sectoral competitiveness of those branches in turn is directly linked to and largely driven by changes in terms of trade which work predominantly through adjustments on international fuel markets. Via this channel carbon price discrimination has adverse repercussions for energy-intensive and trade-exposed branches facing higher energy prices on international markets as under uniform pricing rule. Beyond these insights, our results highlight the scope for substantial excess cost in the EU in emission reduction as price discriminating policy grants lower carbon levies to EITE industries and thereby foregoes relatively cheap abatement options in these sectors.

Krugman (1994) has condemned the obsession with competitiveness as “both wrong and dangerous”. Our assessment of competitiveness issues in unilateral climate policy is somewhat more differentiated. The notion of competitiveness at the sectoral level should not be mixed up with the broader issue of structural change towards a low-carbon economy. The commitment to reduce emissions in a cost-effective manner shifts comparative advantage towards emission-extensive industries which makes the loss in competitiveness of emission-intensive branches rather a desired feature than a feared outcome of rational climate policy. Competitiveness concerns of emission-intensive and trade-exposed industries are legitimate to the extent that competing firms abroad face an undue comparative advantage because of a lack of comparable regulation. However, second-best responses to the problem of emission leakage must be carefully assessed. Despite the potential pitfalls of price differentiation at the regional level, our findings lower concerns on these pricing strategies when global cost-effectiveness is taken into consideration: The moderate non-uniform emission pricing which is erected to protect energy-intensive industries in the EU will barely hurt global real consumption, while it will to some extent enhance environmental effectiveness of unilateral actions.

While this chapter assessed policy options aiming at levelling down carbon costs for the EU producers of energy-intensive goods, the next chapter will focus on measures which aim at levying carbon costs on non-carbon constrained EU competitors. It will thereby consider highly controversial policy measures that have been proposed to tackle the adverse impacts on competitiveness and carbon leakage: border tax adjustments and integrated emissions trading.

5 Climate Policy and the Problem of Competitiveness: Border Tax Adjustments or Integrated Emission Trading?[46]

The European Union has repeatedly underlined the principle of common but differentiated responsibilities as an essential element to effective and efficient framework for post-2012 global actions to combat climate change. The commitment to reduce GHG emissions by 20 percent by 2020 has been reaffirmed in mid-2010. But in the world with uneven carbon constraints, climate change actions envisaged by the EU may lead to the relocation of European installations to countries with less strict emissions regulation (EU, 2010a).

Trade policy measures as a remedy to address the risk of carbon leakage and competitiveness concerns are ranked prominently on the European political agenda. In 2007, the European Parliament called on the European Commission to consider border tax adjustments for third countries which are not bound by the Kyoto Protocol (EU, 2007b). French President Nicolas Sarkozy echoed the invocation to impose a European tax on commodities imported from countries with less stringent environmental laws.[47] An alternative trade policy measure – the integration of importers into the EU Emissions Trading Scheme (ETS) – was recommended by the President of the European Commission Jose Manuel Barroso: “I think we should also be ready to [...] require importers to obtain allowances alongside European competitors, as long as such a system is compatible with WTO requirements.”[48] In the wake of the failed Copenhagen negotiations, the European Commission reinforced the inclusion of importers into the EU ETS as an effective option to address carbon leakage (EU, 2010a).

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[46] This chapter is based on the paper: Alexeeva-Talebi et al. (2008), Climate Policy and the Problem of Competitiveness: Border Tax Adjustments or Integrated Emission Trading?, *ZEW Discussion Paper* 08-061, ZEW, Mannheim (co-authored by A. Löschel and T. Mennel). The paper has been submitted to *The Word Economy*.

[47] In the speech of September 10, 2009, Sarkozy argued: ”I am in favour of environmental protection but I want to keep our industry.” (cf. http://www.euractiv.com/en/climate-change/sarkozy-renews-pressure-co2-border-tax/article-185387).

[48] In the speech “Europe's Climate Change Opportunity” of January 21, 2008, (cf. http://europa.eu/rapid/pressReleasesAction.do?reference=SPEECH/08/26).

Border tax measures played also a prominent role in the context of the climate change policy in the United States. All bills on climate policy that were put forward in the federal legislative process including the American Clean Energy and Security Act of 2009 (Waxman-Markey-Bill) contained provisions on border tariffs. In this connection, van Asselt and Brewer (2010) emphasised that given the influence of energy-intensive industry on policy making process in the US no carbon regulation will be enacted in the future without accompanying trade measures.

Referring to current political trends, this chapter compares two alternative trade-based policy regimes that are discussed in the EU: border tax adjustments (BTA) and integrated emissions trading (IET). It thus extends the literature body by adding the concept of IET and highlighting its advantages and drawbacks in comparison to BTA. Border tax adjustments consist first of tariffs on imported goods mimicking an (environmental) tax on domestic commodities and second of rebates on domestic tax for exported varieties. In contrast, under an integrated emissions trading regime foreign producers purchase emissions allowances for imports according to the factually embodied emissions. Thereby, domestic exporters do not participate in the emissions trading scheme. In other words, the former regime levies a quantity-based; the latter an emission-based duty on imports from non-abating countries and compensates domestic exporters accordingly. Given the GATT (General Agreement on Tariffs and Trade) treaty on free trade and the absence of official carbon registers in many countries both BTA and IET raise legal and practical questions. We briefly address these issues in the conclusions.

Early research contributions demonstrated the ability of border measures to guarantee trade neutrality in a world with differentiated taxation (Bhagwati and Srinivasan, 1973; Meade, 1974; Grossman, 1980), distinguishing between origin and destination principle. Barthold (1994) and Poterba and Rotemberg (1995) introduced BTA into the field of environmental economics. Mathiesen and Maestad (2004) and Babiker and Rutherford (2005) quantified allocative effects of BTA for abating and non-abating countries in the context of climate policy under the Kyoto Protocol. Few papers focused on the introduction of border measures into the EU ETS: Based on a partial equilibrium model, Ismer and Neuhoff (2007) demonstrated that BTA can effectively prevent European climate policy from negatively affecting competitiveness of energy-intensive industry in Europe. One main caveat in their formal set-up is that the energy efficiency decision of firms is not modelled explicitly.

Sectoral studies by, among others, Demailly and Quirion (2008b) and Monjon and Quirion (2010) are in line with these findings. Peterson and Schleich (2007) emphasised in general equilibrium set-up the importance of alternative benchmarks for the BTA level and corresponding economic implications. Employing a CGE model, Alexeeva-Talebi et al. (2010a) showed that even restricted access to the Clean Development Mechanism (CDM) may damp adverse impacts on energy-intensive sectors in the same vein as the most ambitious BTA regime. Finally, Fischer and Fox (forthcoming) analysed the potential of border tax adjustments to address carbon leakage concerns in the U.S. climate policy.

The contribution of this chapter to the existing literature is threefold: First, it introduces and formalises the concept IET as distinct from BTA. Second, it compares the economic and environmental implication of both instruments by means of a stylised theoretical model, identifying the economic channels driving main results. Third, it demonstrates the limitations of a partial equilibrium analysis by studying the effects of both regimes in a computable general equilibrium set-up.

The main results from our stylised model are that the BTA regime is more effective in mitigating the negative effects of unilateral climate policy on the production level of the domestic industry, while the IET scheme achieves a greater reduction in foreign emissions in respective sectors. These results are confirmed by a multi-regional multi-sectoral computable general equilibrium analysis. Our results also show that countries introducing BTA and IET for energy-intensive sectors end up with higher emissions allowance prices compared to the unilateral abatement policy without any complementary measures. Under an efficient implementation, this is due to the emissions abatement shifting from covered energy-intensive industries with relatively low abatement costs to non-energy-intensive sectors with relatively high abatement costs. This shifting is particularly pronounced under the BTA regime with a strong negative impact on the production level of the non-energy intensive sectors and the overall production level in the EU. The latter result stresses the importance of applying a general equilibrium framework (instead of partial equilibrium one) for the analysis of BTA and IET.

This chapter is organised as follows: Section 5.1 defines and explains two stylised policy options – i.e. BTA and IET – in a stylised two-country set-up. Section 5.2 develops computational analysis. After defining the policy scenarios in section 5.3, the subsequent section 5.4 discusses main numerical results. Section 5.5 concludes. Appendices to this chapter can be found in section 5.6.

5.1 Theoretical preliminaries

This section introduces a simple two-country model to study the basic differences between border tax adjustments and integrated emissions trading. It builds on the partial equilibrium analysis in Böhringer and Lange (2005a,c) who discuss alternative abatement policies in a closed economy context. Our stylised framework reveals the basic mechanisms at work and serves as a prerequisite for the numerical study. For the ease of the analysis, possible impacts of policies on government revenues, labour supply and welfare are neglected.

5.1.1 Formal set-up

The model encompasses two countries (commonly denoted by *r*), the domestic country *d* and the foreign country *f*. The representative household in each country disposes of initial wealth w_r, $r \in \{d, f\}$. It derives utility from consumption only. In order to establish consistency with the subsequent numerical framework, we adopt the Armington assumption of product heterogeneity in international trade (Armington, 1969): The standard goods produced in d and in f are imperfect substitutes in household preferences. Prices for these goods $p_{r_c}^{r_p}$ form on competitive markets, including imports and exports.[49] The representative firm in country *r* chooses the quantity of the good produced for the domestic market q_d^r, for the foreign market q_f^r and emissions intensity of production μ^r. Quantities and emissions intensity determine the total level of emissions $E = \mu^r (q_f^r + q_d^r)$ in country *r*.

Costs of production $C(\mu, q) = c(\mu)q$ are constant returns to scale with respect to quantity and decreasing and concave in emissions intensity, i.e. $c_1(\mu) < 0, c_2(\mu) > 0.$ By c^r we denote

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[49] In the notation for prices $p_{r_c}^{r_p}$, producer's country is denoted in the exponent r_p and consumer's country as an index r_c.

marginal cost function in region r, its (first and second) derivatives are expressed by c_1^r and c_2^r, respectively.

The government of the domestic country introduces emissions trading with full auctioning to achieve a certain emissions target $\overline{E}$ for its country. In this simple deterministic set-up such an emissions trading system is equivalent to a carbon tax τ. Furthermore, the domestic government can impose a tariff κ on imported goods and pay a tax rebate for exported commodities (border tax adjustment) or, alternatively, it can sell emissions allowances to the foreign producers (integrated emissions trading).

To keep the model tractable, the household disposes of a fixed income (no labour supply decision) and thus maximises its utility in consumption only. Marshallian demand by the household in country r_c for the good produced in r_p is given by:

$$q_{r_c}^{r_p} = d_{r_c}^{r_p}(p_{r_c}^d, p_{r_c}^f, w_{r_c}). \tag{1}$$

Utility maximisation with Cobb-Douglas (CD) utility functions:

$$u_{r_c}(q_{r_c}^d, q_{r_c}^f) = k(q_{r_c}^d)^{\alpha_{r_c}}(q_{r_c}^f)^{1-\alpha_{r_c}}$$

yields the following demand functions:

$$q_d^d = \frac{\alpha_d w_d}{p_d^d} \qquad q_d^f = \frac{(1-\alpha_d)w_d}{p_d^f},$$

$$q_f^d = \frac{\alpha_f w_f}{p_f^d} \qquad q_f^f = \frac{(1-\alpha_f)w_f}{p_f^f}.$$

As the demand functions are separable, price increase for one good has no effect on the absolute demand for the other good. This is a special feature of CD preferences which is not present in a CES (constant elasticity of substitution) framework. Thus, we abstract from income effects of taxation and concentrate on substitution effects. Finally, we assume that the following restrictions hold: $0 < \alpha_d < 1$ and $0 < \alpha_f < 1$.[50]

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[50] Otherwise, demand for one of the goods breaks down and an analysis of demand effects of the policies becomes senseless.

Now, the problem of the representative firm in the domestic and in the foreign country can be formally stated: The firm maximises profits by choosing emissions intensity and quantities produced, taking prices for its products as given. As a first benchmark for a later comparison of policies, the problem of the firm in the absence of carbon abatement policy is referred to as ”laissez-faire” (LF).

The profit function of the domestic firm is given by:

$$\Pi^d = p_d^d q_d^d + p_f^d q_f^d - c^d(\mu^d)(q_d^d + q_f^d)$$

and the one of the foreign firms is:

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f).$$

Profit maximisation leads to the first order conditions of the firm (with $r \in \{d, f\}$):

$$p_d^d - c^d(\mu^d) = 0, \tag{2}$$

$$p_f^d - c^d(\mu^d) = 0, \tag{3}$$

$$c_1^d(\mu^d) = 0. \tag{4}$$

The first two conditions state that prices for goods that are consumed domestically and abroad are equal to marginal costs of production. The last condition makes clear that emissions intensity will increase to the point that its marginal costs are zero.

Thereby, it holds $p_d^d = p_f^d =: p^d$ and $p_d^f = p_f^f =: p^f$. The production of goods in the domestic country results in emissions:

$$E^{LF} = \mu^d(q_f^d + q_d^d).$$

Subsequently it will be assumed:

Assumption 1 (Emissions Cap): *The emissions cap* $\overline{E}$ *imposed by the domestic government is lower than* E^{LF} *, i.e.* $0 < \overline{E} < E^{LF}$.

One important feature of the specification of the production technology is the following: Although the standard good is produced for two different markets (home and abroad), the choice of energy efficiency is the same for both quantities. The implicit assumption that industries do not build separate production lines for different markets is standard.

5.1.2 Defining abatement policies

Unilateral Abatement Policy: We use unilateral abatement policy (UAP) as a second benchmark in our comparison of the domestic carbon policies that address the problems of competitiveness and carbon leakage. The government of the domestic country auctions emissions allowances to ensure that total emissions of the domestic production do not exceed $\overline{E}$. This corresponds to the government setting a carbon tax τ (where τ is equivalent to the price of allowances). We state now the profit functions and the first order conditions of both firms under UAP.[51]

Under UAP, the profit function of the domestic firm is given by:

$$\Pi^d = p_d^d q_d^d + p_f^d q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau\mu^d(q_d^d + q_f^d).$$

From this, the associated first order conditions can be derived as:

$$p_d^d - c^d(\mu^d) - \tau\mu^d = 0, \tag{5}$$

$$p_f^d - c^d(\mu^d) - \tau\mu^d = 0, \tag{6}$$

$$c_1^d(\mu^d) + \tau = 0. \tag{7}$$

Again, it holds: $p_d^d = p_f^d =: p^d$.

The profit function of the foreign firm is:

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[51] All variables used in this and the next section should have indices indicating the policy case, as they take different values across the three scenarios. For ease of exposition, this additional index has been dropped here, but will be set in the next section.

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f)$$

and, consequently, the first order conditions are given by:

$$p_d^f - c^f(\mu^f) = 0, \tag{8}$$

$$p_f^f - c^f(\mu^f) = 0, \tag{9}$$

$$c_1^f(\mu^f) = 0. \tag{10}$$

As above: $p_d^f = p_f^f =: p^f$. Hence, the first order conditions of the foreign firm remain unchanged in comparison to the laissez-faire case.

The government sets τ so that in equilibrium emissions remain below the cap:

$$\overline{E} \geq \mu^d(q_d^d + q_f^d). \tag{11}$$

Border Tax Adjustment: In the second policy scenario the government uses border tax adjustments to offset differences in taxation for imported and exported goods. A quantity-based tariff κ is levied on the imported good. It is set to match the tax on the average carbon content of the good. With BTA, the carbon content of the import good is measured as if it had been produced domestically.[52] Characteristically for a tariff, information on foreign emissions is not required.

Formally stated:

$$\kappa = \tau\mu^d. \tag{12}$$

Exporters receive a tax refund of κ per quantity sold which matches their emissions in production.

The profit function of the domestic firm is given by:

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[52] In fact, the measurement of emissions which are related to imports is critical for the implementation of BTA, both from a legal and a practical perspective.

$$\Pi^d = p_d^d q_d^d + p_f^d q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau\mu^d(q_d^d + q_f^d) + \kappa q_f^d$$

and the first order conditions are:

$$p_d^d - c^d(\mu^d) - \tau\mu^d = 0\,, \tag{13}$$

$$p_f^d - c^d(\mu^d) - \tau\mu^d + \kappa = 0\,, \tag{14}$$

$$c_1^d(\mu^d) + \tau = 0\,. \tag{15}$$

Condition (13) states that the price for the domestic good is equal to marginal production costs plus the tax on emissions times emissions intensity (which amounts to a tax on quantities produced). Condition (14) states that the price for the export good is marginal costs plus tax on emissions minus the rebate. Condition (15) says that marginal costs of emissions intensity are equal to minus the tax on emissions.

The profit function of the foreign firm is given by:

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f) - \kappa q_d^f\,.$$

and the first order conditions are:

$$p_d^f - c^f(\mu^f) - \kappa = 0\,, \tag{16}$$

$$p_f^f - c^f(\mu^f) = 0\,, \tag{17}$$

$$c_1^f(\mu^f) = 0. \tag{18}$$

Condition (16) says that the price for the import good is equal to marginal production costs plus the environmental tariff. According to the condition (17), the price for the foreign good to be sold in foreign market is equal to marginal production cost, as in the LF and UAP case. Similarly, condition (18) states that marginal cost of emissions intensity is zero in equilibrium.

As before, the government sets τ so that the emissions cap is achieved:

$$\overline{E} \geq \mu^d (q_d^d + q_f^d). \tag{19}$$

Note that κ applies to quantities of goods, not to emissions. This is the systematic difference with respect to the third policy scenario.

Integrated emission trading: In the third policy scenario the government designs an integrated emissions trading (IET) scheme: Foreign producers have to purchase emissions allowances for their imports into the domestic country at a price τ. In contrast to an emissions trading with BTA, it is emissions that are targeted by the IET, not consumption quantities. Goods exported to the foreign country are exempt from the environmental duty.

The profit function of the domestic firm is given by:

$$\Pi^d = p_d^d q_d^d + p_f^d q_f^d - c^d(\mu^d)(q_d^d + q_f^d) - \tau\mu^d q_d^d$$

and the first order conditions are:

$$p_d^d - c^d(\mu^d) - \tau\mu^d = 0, \tag{20}$$

$$p_f^d - c^d(\mu^d) = 0, \tag{21}$$

$$c_1^d(\mu^d)(q_d^d + q_f^d) + \tau q_d^d = 0. \tag{22}$$

Condition (20) states that the price of the domestic good is equal to marginal production costs plus the tax on quantities – it is identical to the BTA case. Condition (21), in contrast, makes clear that the price for exports is equal to marginal cost, as in the LF case. Other than in the BTA case, the firm internalises the effect of the emissions intensity decision on the carbon price. Condition (22) says that marginal cost of emissions intensity is equal to the tax times the fraction of the domestic good over total domestic output.

The profit function of the foreign firm is given by:

$$\Pi^f = p_d^f q_d^f + p_f^f q_f^f - c^f(\mu^f)(q_d^f + q_f^f) - \tau\mu^f q_d^f.$$

Note the difference with the profit function under BTA: Under IET, the actual emissions of the foreign firm are taxed, and thus its emissions intensity is the basis for the duty.

The first order conditions are given by:

$$p_d^f - c^f(\mu^f) - \tau\mu^f = 0\,, \tag{23}$$

$$p_f^f - c^f(\mu^f) = 0 \tag{24}$$

$$c_1^f(\mu^f)(q_d^f + q_f^f) + \tau q_d^f = 0. \tag{25}$$

Condition (23) states that the price for the export good is equal to marginal costs minus the emission tax (on quantities), mimicking condition (20) for the domestic firm. Condition (24) says that price of the foreign good to be sold on the foreign market is equal to marginal production costs. As in the case of the domestic firm, condition (25) says that marginal cost of emissions intensity is equal to the tax times the fraction of exports over total foreign output.

Note that the same emissions cap across all three policy scenarios was chosen. Thus, the domestic government sets a cap on domestic emissions, i.e. emissions caused by the domestic production:

$$\overline{E} \geq \mu^d(q_d^d + q_f^d). \tag{26}$$

However, taxes τ can vary across scenarios.

Quite importantly, in the integrated emissions trading scheme presented in our analysis the importers do not participate in the domestic market for emissions allowances directly. Their allowances are “set aside”, i.e. the domestic government issues additional allowances at the domestic carbon price. We assume that these suffice to satisfy the demand. One might object that this specification of IET is not very general. Indeed, a logical extension of IET would be a cap on emissions caused by the domestic consumption: Both domestic producers and importers would have to compete for emissions allowances to sell their products in the domestic market. This would change the trade paradigm, abandoning the origin in favour of the destination principle. Consumption, not production, would be the basis for a carbon levy. The problem with such an altered version of IET is that it cannot be compared directly to BTA and UAP because foreign emissions remain unregulated under these policies. In contrast, in our set-up the environmental regulation of the three regimes has a common denominator: the cap on emissions. For the sake of analytical clarity, we leave the study of other specifications of IET to future research.

5.1.3 Finding equilibrium conditions

This section aims at deriving equilibrium conditions and proving the existence of equilibrium.

Utility maximisation by households yields demand functions that specify quantities as function of prices. Profit maximisation by firms yields first order conditions that determine prices as function of all other variables. The government sets taxes and tariffs to enforce its rules, in particular, the emissions cap.

Formally, equilibrium conditions take the following form:

1. Zero-Profit (FOCs of the firms):

$$p_{r_c}^{r_p} = P(q_d^{r_p}, q_f^{r_p}, \mu^{r_p}, \tau, \kappa),$$

$$\mu^{r_p} = M(q_d^{r_p}, q_f^{r_p}, \tau, \kappa).$$

2. Utility maximisation (FOCs of the households):

$$q_{r_c}^{r_p} = d_{r_c}^{r_p}(p_{r_c}^{d}, p_{r_c}^{f}, w_{r_c}).$$

3. Emissions cap:

$$\overline{E} \geq E(q_d^d, q_f^d, q_d^f, q_f^f, \mu^{r_p}).$$

The functional form of the conditions has been derived in the previous subsection. In order to guarantee the existence of equilibrium we impose the standard assumption on the marginal cost functions $c^d(.)$ and $c^f(.)$ to avoid corner solutions.

Assumption 2 (Inada condition): *The marginal cost functions* $c^r(.)$ *satisfy:*

$$\lim_{\mu \to 0} c_1^r(\mu) \to -\infty.$$

Moreover, there exist unique $\hat{\mu}^d$ *and* $\hat{\mu}^f$ *such that:*

$$c_1^d(\hat{\mu}^d) = c_1^f(\hat{\mu}^f) = 0.$$

From this assumption we derive:

Proposition 1: *Under assumptions 1 and 2 unique equilibria exist in all three scenarios.*
Proof: See Appendix (5.6).

5.1.4 Discussing policy outcomes

In this section, we use the model of the preceding section to analyse economic and environmental impacts of alternative policy options in climate policy.

Emissions Intensities: The first step in the analysis of policy outcomes is the comparison of equilibrium emissions intensities. The equilibrium choice of emissions intensity is important for the understanding of the policy outcome in general.

Proposition 2 (Comparison of emissions intensities): *In equilibrium, emissions intensities in the domestic and the foreign country satisfy the following inequalities:*

$$(\mu^d)^{UAP} > (\mu^d)^{BTA} \qquad (\mu^f)^{UAP} = (\mu^f)^{BTA} \quad ,$$

$$(\mu^d)^{UAP} = (\mu^d)^{IET} \qquad (\mu^f)^{UAP} > (\mu^f)^{IET},$$

$$(\mu^d)^{BTA} < (\mu^d)^{IET} \qquad (\mu^f)^{BTA} > (\mu^f)^{IET}.$$

Concerning the domestic country, proposition (2) states that emissions intensity is equal under UAP and IET, whereas compared to them, BTA lowers it. This is a somewhat surprising result. Generally speaking, carbon abatement leads to an increase in energy efficiency – this is part of the economic answer to making emissions costly. BTA anchors the incentives to increase energy efficiency in both parts of production, i.e. for domestic and foreign consumption, even if pressure is more shifted towards the former. IET affects only the part of production which is sold on domestic market. Under both regimes, producers trade off, however, the adjustment of output against the need to improve energy-efficiency. As under BTA the demand for goods is higher than under IET the pressure for the producers under the former regime is more pronounced to increase emissions intensity in order to comply with the emissions reduction target. This kind of pressure does not exist under IET (see below).

The results for the emissions intensity of the foreign country are straightforward: Neither UAP nor BTA affect equilibrium emissions intensity which remains at its maximum laissez-faire level. In contrast under IET, by levying a duty on the carbon content of the import good the domestic country exerts an abatement influence on the foreign firm, inducing it to increase its energy efficiency.

Prices and Quantities: The next proposition presents a comparison of equilibrium prices and quantities under the three policies. While the comparison of UAP, on the one hand, and BTA and IET, on the other hand, is straightforward, comparing BTA and IET turns out to be somewhat difficult. This is due to the fact that the duty levied on the import good depends on the domestic production function in the case of BTA and on the foreign production function in the case of IET. Thus, with some variables being directly comparable, a full comparison requires an additional assumption on the two cost functions. We assume that they are identical.

Assumption 3 (Cost Symmetry): *The marginal cost function is equal for both countries* $c^d(.) \equiv c^f(.)$.

Subsequently, all inequalities that require assumption (3) are labelled by an index *s*.

Proposition 3 (Comparison of prices and quantities): *In equilibrium, quantities and prices chosen under UAP and under BTA compare as follows:*

$$(p_d^d)^{UAP} < (p_d^d)^{BTA} \qquad (p_f^f)^{UAP} = (p_f^f)^{BTA},$$

$$(p_f^d)^{UAP} > (p_f^d)^{BTA} \qquad (p_d^f)^{UAP} < (p_d^f)^{BTA} \quad ,$$

$$(q_d^d + q_f^d)^{UAP} < (q_d^d + q_f^d)^{BTA} \qquad (q_d^f + q_f^f)^{UAP} > (q_d^f + q_f^f)^{BTA} \quad .$$

Under UAP and IET, the comparison yields:

$$(p_d^d)^{UAP} < (p_d^d)^{IET} \qquad (p_f^f)^{UAP} < (p_f^f)^{IET},$$

$$(p_f^d)^{UAP} > (p_f^d)^{IET} \qquad (p_d^f)^{UAP} < (p_d^f)^{IET},$$

$$(q_d^d + q_f^d)^{UAP} = (q_d^d + q_f^d)^{IET} \qquad (q_d^f + q_f^f)^{UAP} > (q_d^f + q_f^f)^{IET}.$$

Under BTA and IET equilibrium prices and quantities compare as follows:

$$(p_d^d)^{BTA} < (p_d^d)^{IET} \qquad (p_f^f)^{BTA} < (p_f^f)^{IET},$$

$$(p_f^d)^{BTA} > (p_f^d)^{IET} \qquad (p_d^f)^{BTA} <_s (p_d^f)^{IET},$$

$$(q_d^d + q_f^d)^{BTA} > (q_d^d + q_f^d)^{IET} \qquad (q_d^f + q_f^f)^{BTA} >_s (q_d^f + q_f^f)^{IET}.$$

Proposition (3) states central economic implications of alternative policy options in our theoretical framework that shall be explained in a greater detail. As for the domestic production, in comparison to UAP, both BTA and IET lead to an increase in the (gross) price for the domestic good (sold on the domestic market) and to a decrease in the price for the export good. The price decrease under both regimes for the export good follows directly from the rebate. The price increase for the domestic good is a consequence of a higher abatement effort under BTA and IET which is necessary to reach the emissions target. Both effects are more pronounced under IET than under BTA. This is due to the fact that exporters under the latter regime are fully exempt from carbon regulation, while the emissions reduction burden is completely born by the part of production that is sold on domestic market.

Now, we turn to the discussion of price effects for foreign producer. The price for the foreign good sold in the foreign market remains unaltered in comparison to LF under both UAP and BTA. In contrast, the energy efficiency effort induced by IET leads to more costly production and thus a higher price. The price of the export good increases under BTA and IET, a plausible result of the duties levied. Higher energy efficiency under IET in the foreign country makes the effect more pronounced for this policy as long as we assume symmetry of cost functions.

The output effects of the policies are driven by price changes. Thereby, IET is more effective in protecting international competitiveness of domestic exporters than BTA: Indeed, due to the full exemption from the carbon regulation domestic producers export more under the former regime. However, the proof (Appendix) shows that an increase in exports under BTA offsets a decrease in the consumption of the domestic good resulting in higher total production level vs. UAP. The same two effects apply to IET. In this case, however, they offset each other: Domestic production is equal under IET and UAP. Consequently, BTA is more effective in protecting domestic industry than IET.

Clearly, the foreign country produces more under UAP than it does under BTA and IET. Production is higher under BTA than under IET (assuming symmetry of cost functions), as imports are cheaper and the price of the foreign good remains unchanged under BTA.

One word concerning assumption (3): It is a sufficient, not a necessary condition. In fact a glance at the proof of proposition (3) shows that all assertions hold as long as marginal costs of production abroad are not much lower than at home. A change in the results is conceivable only when the foreign country has much cheaper abatement options than the domestic one.

Emissions: Finally, we turn to the environmental implications. Corollary 4 shows that policies have a different impact on foreign emissions.

Corollary 4 (Comparison of foreign emissions): *Emissions in the foreign country relate to each other as follows:*

$$(E^f)^{UAP} > (E^f)^{BTA} \qquad (E^f)^{UAP} > (E^f)^{IET},$$

$$(E^f)^{BTA} >_s (E^f)^{IET}.$$

Corollary 4 shows that both BTA and IET lead to a reduction in foreign emissions compared to the case of UAP. Under BTA, this is a mere quantity effect: A decrease in imports to the domestic country leads to a decrease in output. In the case of IET, higher energy efficiency adds up with reduced sales abroad. As for the comparison of foreign emissions under BTA and IET, we need assumption (3) to achieve an unambiguous result which is that under the IET policy in the domestic country the induced abatement in the foreign country is larger. Symmetry of cost functions is only a sufficient condition: The results hold as long as marginal costs of production are higher abroad. This is plausible because under IET foreign producers increase their energy efficiency which under BTA they do not. Only if their costs of doing so are very small, much smaller than in the domestic country, (then) the larger output under IET could offset the effect of increased energy efficiency and foreign emissions would be higher than under BTA.

To sum up, both BTA and IET achieve the target of mitigating negative effects of unilateral climate policy on competitiveness and leakage. In a broader sense, if competitiveness considerations are related to the total production level, BTA is more effective in the former. Under IET exports are higher for the domestic industry and emissions abroad are lower.

5.2 Numerical model framework

While our stylised theoretical framework provides basic insights into economic and environmental implications of alternative domestic policy options, a numerical analysis can take real-world complexities into consideration.

For a comprehensive policy analysis, this section applies a standard multi-sector, multi-region CGE model of international energy use and global trade. Since trade-off measures have been proposed to protect selected industries only, the analysis of spillover effects to and market interactions with remaining industries is important. Such an analysis was not possible within our one-sector theoretical framework in the previous section.

This section introduces the numerical approach with a non-technical summary of the model framework. Subsequently, we present policy scenarios and discuss numerical results contrasting them with our theoretical findings.

For comparative-static impact analysis of BTA and IET we use the open-economy CGE model. For details and an algebraic formulation of the core model see Böhringer and Lange (2005b). A representative agent in each region is endowed with labour, capital and fossil-fuel resources which may be used for fossil fuel production. The representative agent maximises utility from consumption of a composite good which combines demands for energy and non-energy commodities at a constant-elasticity-of-substitution (CES). Production of commodities in region is described by nested separable CES functions with the price-dependent use of capital, labour, energy and material in production. Carbon emissions are linked to the emission-relevant use of fossil fuels, while carbon abatement occurs by fuel switching or energy savings in production and final consumption.

The modelling of (bilateral) international trade is based on the Armington approach of product heterogeneity, so that domestic and foreign goods of the same variety are distinguished by their origin (Armington, 1969). All goods used in the domestic market in intermediate and final demand correspond to a CES composite that combines the domestically produced variety and imports of the same variety from other regions. Domestic production either enters the formation of the Armington good or is exported to other regions to satisfy their import demand. Trade with other regions is represented by a set of export demand and import supply functions at exogenous world import and export prices.

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). Forward calibration of the 2001 economies to the target year 2020 is based on energy trends for EU member states (EU, 2003b) and on international energy projections for non-European economies (US Department of Energy, 2005).

Table 19: Model dimensions

Production sectors		**Countries and Regions**	
Energy		*EU regions*	
COA	Coal (REI)	EU15	Old Member States
CRU	Crude oil (REI)	EU12	New Member States
GAS	Natural gas (REI)		
OIL	Refined oil products (REI)		
ELE	Electricity (REI)		
Energy-intensive sectors		*Non-EU countries and regions*	
ORE	Ferrous metals (EII)	OOE	Rest of OECD
PPP	Paper products and publishing (EII)	RUS	Former Soviet Union
NMM	Mineral products nec (EII)	SMA	Rest of South and Middle America
NFM	Metals nec (EII)	CHN	China (including Hongkong)
ATP	Air transport (REI)	SEA	Rest of South and East Asia
CRP	Chemicals, rubber and plastics (EII)	OPC	OPEC
		XRW	Rest of the World
Non-energy-intensive sectors			
ROI	Rest of industry (NEI)		
CGD	Savings good		

Table 19 summarises regional and sectoral aggregation of the model. The aggregation of the GTAP database includes nine regions that are central in the climate policy debate on competitiveness and leakage. The member states of the European Union are aggregated to two major regions, EU15 (old member states) and EU12 (new member states). The sectoral aggregation in the model has been chosen to distinguish energy-intensive sectors from the rest of the economy. It captures key dimensions in the analysis of greenhouse gas abatement, such as differences in carbon intensity and the degree of substitutability across carbon-intensive goods. The primary and secondary energy goods identified in the model are coal, natural gas, crude oil, refined oil products and electricity. The remaining sectors are aggregated to a composite industry that produces a non-energy-intensive macro good.

In order to assess economic and environmental implications of complementary measures (i.e. BTA and IET), the EU is assumed to impose a unilateral emission cap and to apply offsetting measures to (five) energy-intensive and export-oriented sectors, i.e. ferrous metals (ORE), non-ferrous metals (NFM), chemicals (CRP), mineral industries (NMM) and paper products and publishing (PPP).

Numerical modelling of both regimes is consistent with our theoretical approach in previous section: Under BTA, both the duty levied on imports and the rebate for the EU exports from the covered sectors are quantity-based, i.e. the BTA level is determined by the *EU average carbon content* in the production of the corresponding energy-intensive goods *in the specific sector*. Thus, no information about emissions intensities of foreign producers is necessary under the BTA regime. Under IET, the EU exporters and the EU importers face the allowance price which is applied to the actual carbon content of the respective energy-intensive industry. For importers into the EU, the price of emissions allowances is exogenous. The allowances are from a set-aside budget. BTA and IET do *not* apply to energy-producing, remaining energy-intensive and non-energy-intensive sectors. Partial sectoral coverage of the BTA and IET regimes is the major characteristic distinguishing the numerical analysis from the theoretical one. Below we refer to energy-intensive and export-oriented industries under BTA and IET in an aggregate manner as *EII* sectors. To account for relevant market interactions, results for remaining energy-intensive and energy-producing sectors (REI) as well as non-energy-intensive sectors (NEI) are displayed. Obviously, there are no border adjustments between the EU-12 and EU-15.

5.3 Policy scenarios: BTA vs. IET

Numerical application illustrates economic and environmental implications of BTA and IET regimes using three stylised policy scenarios for the year 2020. Across all scenarios, the unilateral emissions reduction target of the EU-27 is set at 20 percent versus Business-as-Usual (BaU) emissions levels in 2020. Efficient implementation of the emissions reduction target is assumed through unrestricted intra-EU emissions trading between energy-intensive and non-energy-intensive industries. Revenues from the auctioned allowances are rebated as lump-sum transfers to the representative agent in the EU. All non-EU regions are assumed – consistent with theoretical approach – not to have committed to binding emissions reduction targets in 2020.

As a reference case, scenario UAP reflects the efficient emissions trading scheme thereby abstaining from any offsetting measures to mitigate negative competitiveness implications on covered energy-intensive and export-oriented industries. In scenarios BTA and IET, border tax adjustments and integrated emissions trading, respectively, are introduced into the emissions trading scheme. Under the BTA regime, both tax compensation for the EU exports from the covered sectors and tariffs for the respective EU imports are quantity-based, while the sector-specific level of BTA is determined by the EU average carbon content in the production of the corresponding energy-intensive goods. Under the IET regime, the EU exporters and the EU importers face the allowance price which is applied to the actual carbon content of the respective energy-intensive industry (see previous section for more details).

5.4 Simulation results

In this section we discuss effects of both trade measures on industrial production in the EU and non-EU regions (Table 20) and emissions level (Table 21) which are reported in Appendix (section 5.6). The effects are measured with respect to the BaU situation in which no policy measures are undertaken.

Unilateral carbon abatement policies in the EU-27 induce adjustments of production and consumption patterns towards less carbon intensity and associated energy use. This section starts by reporting production level implications for both European and non-European economies (Table 20). Referring to the central topic of this chapter, both offsetting regimes are suitable to mitigate detrimental effect of unilateral abatement policy on production of those European sectors that are covered by trade measures. Thereby, these sectors are best off under the BTA regime. EU27 is even capable to slightly increase output level of the covered sectors versus BaU by 0.1 percent, while under IET the production losses in targeted energy-intensive sectors are only slightly smaller than under UAP (-1.9 percent and -2.0 percent vs. BaU, respectively). This outcome is in accordance with the assertion from our theoretical set-up.

The theoretical model predicted higher domestic production level of the covered sectors under BTA than under IET and identified driving forces of this outcome by decomposing the implications of both policies on prices and quantities. First, trade measures such as BTA and IET let domestic prices increase for goods that are sold on domestic markets (in comparison to the UAP case), but to a lesser extent under the former regime. The economic rationale behind this outcome is the fact that, since abatement is no longer necessary for the exported goods, the abatement pressure increases for domestic goods, leading to an increase in energy efficiency. Second, export prices are expected to decrease under both regimes (in comparison to the UAP case), but this effect is more pronounced under the IET regime. Price adjustments on both domestic and international markets determine the overall production level. Increased export performance of domestic firms under BTA regime is more than sufficient to compensate for production losses on domestic markets. In contrast, consumption of domestic goods decreases on domestic markets too strongly to be offset by increasing export level under IET. To sum up, this mechanism leads to higher overall production level of domestic firms under BTA than under IET and UAP.[53]

However, from a general equilibrium perspective, the introduction of the BTA and IET scheme in selected energy-intensive sectors leads to production level adjustments in the non-covered sectors. Table 20 reports production level implications for (i) energy-producing and remaining energy-intensive sectors (*REI*), (ii) non-energy-intensive sectors (*NEI*) and (iii) the total output level. In the EU-27, *REI* sectors are able to slightly extend production level due to

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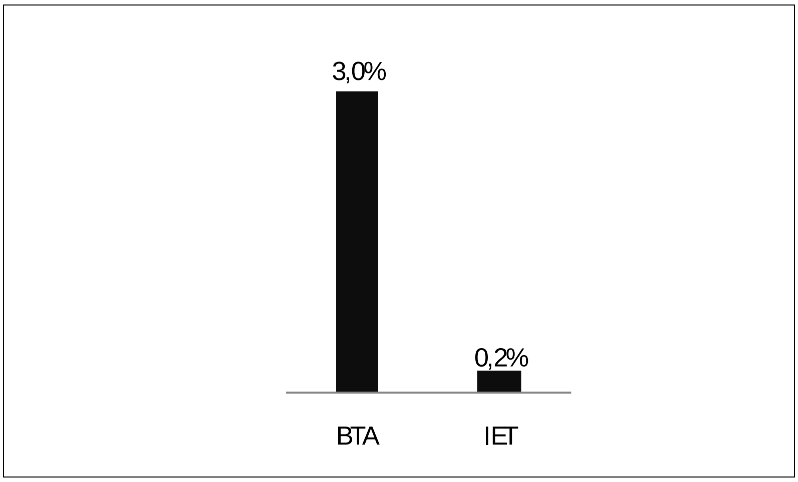
[53] In the theoretical framework, under IET overall domestic production remains unaltered in comparison to UAP. This somewhat surprising result can be explained by the change in domestic abatement. Since exports are exempt from the emissions duty, the pressure on domestic consumption increases. Gross prices of output sold on domestic markets are raised by both BTA and IET. While the rising energy efficiency under BTA leaves domestic producers with a net increase of production, under IET the increase of exports and the decrease of domestic sales offset each other. In a numerical framework, the quantitative results in terms of production level adjustment are not identical for IET and UAP but are very similar. One explanation for that might be the presence of general equilibrium effects.

lower energy prices, while non-energy-intensive sectors (*NEI*) decrease output to comply with the total emissions reduction target. The increase in production level in energy-intensive sectors, however, does not outweigh the output decrease in the non-energy intensive sectors which results in overall output losses for the EU-27. These losses are particularly pronounced under the BTA regime. While confirming theoretical results for the covered energy-intensive sectors, the multi-sectoral analysis thus reverses the insight of the theoretical analysis for the aggregate production level.

Focusing now on the non-EU regions, the EII sectors are worse off under the BTA scenario as this (quantity-based) regime does not allow the respective industries to adjust energy intensity in the production process and makes imports to the EU more expensive. For OECD countries (OOE), South and Middle America (SMA), China (CHN) and the Rest of South and East Asia (SEA), the output implications of trade measures are unambiguously negative. Under the IET regime, output losses for all regions are thereby less pronounced than under BTA. These results suggest that *EII* sectors in the EU appear to be least exposed to international competition and therefore better protected under the BTA regime.

In the reference scenario UAP, the allowance price imposed to reduce carbon emissions by 20 percent vs. BaU in the EU-27 ranges up to $37 US per ton CO_2. Cost-effective implementation of the target suggests that emissions reduction is undertaken where it is cheapest. The multi-sectoral modelling approach allows accounting for potentially important general equilibrium interactions: The introduction of the BTA and IET regimes partially shifts emissions abatement from covered energy intensive sectors (*EII*) with relatively low abatement costs to non-energy intensive sectors (*NEI*) with relatively high abatement costs (Table 21). This shift is particularly pronounced under the BTA regime, as the allowance price increases by roughly three per cent compared to the reference scenario UAP. The introduction of the IET scheme let the allowance price rise by less than one per cent (vs. UAP scenario) (Figure 20).

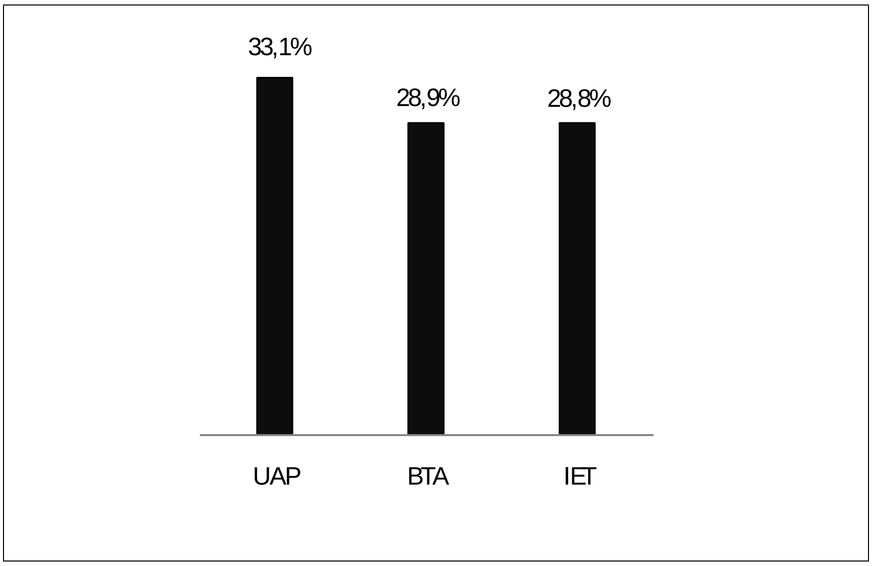
Figure 20: Emissions allowance price under scenario BTA and IET (% vis-à-vis UAP scenario) in 2020



Hence, countries with the BTA and IET regimes in energy-intensive sectors are likely to end up with higher marginal abatement costs compared to the unilateral abatement policy without any complementary measures.

Unilateral abatement policy (UAP) leads to an increase in emissions in non-abating regions (Table 21). The leakage rate of about 33 percent reduces thereby the global environmental effectiveness (Figure 21). Corollary 4 in theoretical section of this chapter showed that trade measure such as BTA and IE could provide a remedy against carbon leakage. But numerical results demonstrate that both BTA and IET lead to a modest reduction of carbon leakage compared to the case of UAP. The leakage rate drops by roughly four percentage points to 29 percent under BTA and IET due to the fact that export intensities of the EU production and import intensities of the EU consumption are relatively small. Thereby, from the global perspective the IET regime does not impede carbon leakage more effectively compared to the BTA regime. Two effects working in opposite directions explain this outcome: On the one hand, the central insight from the theoretical and numerical analysis is that the IET scheme induces a considerably lower emissions level in EII sectors outside Europe than the BTA scheme in all model regions (except OOE). Under the latter, the emissions level decrease is due to the production level adjustment – BTA does not affect the energy intensity decision of the foreign producers, so that it remains at its maximum level. Under the former, higher energy efficiency and output adjustment let the emissions level decrease by a much higher extent. In all countries, the IET regime provokes the effective emissions reduction in comparison to the BaU of up to roughly 5 percent, except for China that reverts to the BAU. By levying a duty on the carbon content of the import good, the EU hence exerts an abatement impact on foreign firms, leading to an increase in energy efficiency. On the other hand, emissions in energy-intensive sectors not subjecting to trade measures increase more under IET than BTA regime in all countries outside Europe.

Figure 21: Leakage rates (% change from BaU)



From the perspective of the European Union, impacts of both trade regimes on environmental performance constitutes the central trade-off with pure competitiveness considerations of covered energy and trade-intensive sectors: As shown above, BTA better protects production level of domestic industries that intensively employ energy, while IET is superior in terms of emissions reduction in foreign energy intensive industries subjecting to trade measures. At the aggregate level, however, both trade measures are fairly equal in terms of restricting carbon leakage consequences.

Finally, neglecting economic benefits from improved environmental quality, carbon constraints decrease real income and macroeconomic consumption, thereby generating welfare losses. Simulation results for the EU-27 indicate that efficient implementation of the given emission reduction target in the reference case (UAP) is consistent with fairly small welfare losses – expressed by the Hicksian Equivalent Variation (HEV) – as compared to the unconstrained BaU situation. Introduction of the BTA and IET regimes has thereby a negligible impact (-0.04 percent) on social welfare in the EU-27.[54]

5.5 Conclusions

This chapter assesses two trade-based policies that have been proposed to mitigate competitiveness losses and carbon leakage: Border tax adjustments (BTA) and integrated emission trading (IET). The contribution of this chapter to the literature body is to characterise both policies, to analyse the channels affecting their economic and environmental effectiveness and to quantify the outcome. Theoretical framework shows that energy-intensive sectors in the EU are best off under the BTA regime, while the IET scheme reduces more strongly emissions in non-EU regions than the BTA scheme. The numerical analysis puts this view into perspective: While the prior conclusions hold true for sectors participating in either BTA or IET (i.e. selected energy-intensive sectors), the presence of non-participating sectors can lead to a reversion of the result on production level. The carbon rebate for exports granted under both BTA and IET means that a part of the abatement burden is shifted from energy-intensive industries to non-energy-intensive sectors increasing the overall costs of abatement. Finally, the numerical analysis confirms some global environmental effectiveness of both policies, with little difference in the impacts of BTA and IET.

These results show the importance of a careful implementation of both policies. In the sequel we briefly discuss the related legal and practical problems. By imposing a duty on imports both BTA and IET interfere with free trade policies. It is a legal matter whether and to what extent the policies are compatible with the GATT treaty on international free trade. In their analysis of BTA, Ismer and Neuhoff (2007) conclude that BTA do not violate the treaty if they are based on the "best-available technology" assumption, i.e. the assumed carbon content of imported goods must correspond to goods produced with the least carbon intensive technology. The macroeconomic models applied in this chapter do not of course allow for a precise description of the full spectrum of available technologies. By fixing the carbon

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[54] We report the welfare implications for EU-27 only since a direct comparison of the welfare impacts for other regions or globally would be misleading. This is due to the fact that environmental effectiveness of alternative policy options for these regions differs across three scenarios.

content of imported goods to the energy efficient European production level we are, however, broadly in line with the 'best-available technology' assumption.

As for the practical implementation, the ultimate choice of an appropriate offsetting measure should be based on two considerations, concerning the institutional arrangements and the degree of international cooperation. The implementation of both instruments is likely to go along with considerable administrative efforts in the domestic or foreign country, respectively. Additional to the domestic environmental administration (national carbon registers) authorities must be established to define benchmarks, to measure and to report carbon content of the imported goods. While the BTA regime calls for a home-based authority defining carbon standards, IET requires international cooperation to run comparable institutions (branch offices) abroad. Thereby, BTA is per-se a non-cooperative policy option. Its introduction may cause retaliatory measures by trading partners resulting in the welfare-decreasing trade wars. The study of such a scenario requires a game-theoretic setup. It would be an interesting research question to study the effect of partial cooperation in such a multi-country-framework where two countries that have climate policies do not impose BTA on each other’s imports, but just on those of other countries. However, such a study is clearly beyond the scope of this chapter.

The IET represents in principle an intermediate step in multilateral cooperation on climate change issues. The introduction of the IET regime could result in launching emissions reduction schemes with binding constraints abroad which could then be linked with the domestic scheme. The next chapter addresses these issues in a more detail.

5.6 Appendices to chapter 5

5.6.1 Mathematical appendix

The appendix presents the proofs of propositions (1) to (3) and corollary (4). All proofs build on transformations of the first order conditions of the firms and the emissions cap. We start by presenting the transformed first order conditions which give rise to equations determining prices.

P-UAP: We eliminate the emissions tax τ with the help of the first order condition for μ_d, equation (7) and thus obtain the following set of price equations:

$$p_d^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d \qquad p_f^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d,$$

$$p_d^f = c^f(\mu^f) \qquad p_f^f = c^f(\mu^f).$$

P-BTA: As before, eliminating τ and κ by equations (15) and (12) yields a set of price equations:

$$p_d^d = c^d(\mu^d) - c_1^d(\mu^d)\mu^d \qquad p_f^d = c^d(\mu^d),$$

$$p_d^f = c^f(\mu^f) - c_1^d(\mu^d)\mu^d \qquad p_f^f = c^f(\mu^f).$$

P-IET: In the case of IET, we use the definition of Cobb-Douglas demand functions of private households as well as the first order conditions for μ^d and μ^f, equations (22) and (25), to obtain:

$$p_d^d = \frac{c^d(\mu^d)}{c^d(\mu^d) + \gamma^d c_1^d(\mu^d)\mu^d}\left[c^d(\mu^d) - c_1^d(\mu^d)\mu^d\right] \qquad p_f^d = c^d(\mu^d),$$

$$p_d^f = \frac{c^f(\mu^f)}{c^f(\mu^f) + \gamma^f c_1^f(\mu^f)\mu^f}\left[c^f(\mu^f) - c_1^f(\mu^f)\mu^f\right] \qquad p_f^f = c^f(\mu^f)$$

with $\gamma^d = \dfrac{\alpha_f w_f}{\alpha_d w_d}$ and $\gamma^f = \dfrac{(1-\alpha_f)w_f}{(1-\alpha_d)w_d}$.

From assumption (1) we infer that the emissions caps, i.e. constraints, are binding. Thus, they give rise to one more equation respectively. Both the transformed first order conditions above and Cobb-Douglas demand functions enter into their transformation. They take the form of fix-point equations.

$$(\mu^d)^{UAP} = \frac{\overline{E}}{\alpha^d w^d + \alpha^f w^f}\left[c^d(\mu^d) - c_1^d(\mu^d)\mu^d\right], \tag{27}$$

$$(\mu^d)^{BTA} = \frac{\overline{E}}{\alpha^d w^d + \alpha^f w^f\left(1 - \frac{c_1^d(\mu^d)\mu^d}{c^d(\mu^d)}\right)}\left[c^d(\mu^d) - c_1^d(\mu^d)\mu^d\right], \tag{28}$$

$$(\mu^d)^{IET} = \frac{\overline{E}}{\alpha^d w^d + \alpha^f w^f}\left[c^d(\mu^d) - c_1^d(\mu^d)\mu^d\right]. \tag{29}$$

We are now prepared for the proofs.

Proposition 1 (Existence of Equilibria):

The existence of equilibria is guaranteed by general equilibrium theory. Uniqueness of equilibria follows from the unique determination of μ^d and μ^f y by equations (27) and (10) for the UAP case, (28) and (18) for the BTA case, (29) and (25) for the IET case. For equations (10), (18) and (25) this is a direct consequence of the properties of the marginal cost function $c(.)$. For equations (27), (28) and (29) this follows from the fact that the right-hand side of the equations is falling, starting from infinity as μ^d goes to zero, leading to a unique crossing point with the left-hand side.

Proposition 2 (Emissions intensities):

Emissions intensities μ^d under UAP, BTA and IET can be compared by virtue of equations (27), (28) and (29). The equality of $(\mu^d)^{UAP}$ and $(\mu^d)^{IET}$ is obvious. The inequality $(\mu^d)^{BTA} < (\mu^d)^{UAP} = (\mu^d)^{IET}$ follows from the fact that the denominator of the RHS of equation (28) is larger than that of (27) and (29).

To understand why $(\mu^f)^{IET}$ is smaller than $(\mu^f)^{BTA}$ we have to derive equations characterising μ^f. In case of BTA this is simply (18). In case of IET, we use (25), P-IET and (4) to obtain:

$$c_1^f(\mu^f) = -\tau \frac{c^f(\mu^f)}{c^f(\mu^f) + (\gamma^d(c^f(\mu^f) + \tau\mu^f)}.$$

As τ is implicitly determined by (29) as a positive number and given our assumption on c^f,we may infer that $c_1^f(\mu^f) < 0$ which yields the claim. The equality of $(\mu^f)^{UAP}$ and $(\mu^f)^{BTA}$ is a trivial consequence of the first order conditions (10) and (18).

Proposition 3 (Competitiveness):

The proof of proposition (3) resembles the one of proposition (2). Essentially, we use equations P-UAP, P-BTA, P-IET, the emissions constraints and the results on emissions intensities μ^d and μ^f from proposition (2) to compare prices. Subsequently, we move from the comparison of prices to comparison of quantities. We will concentrate on the case of p_d^d as before and then explain the need of the symmetry assumption (3) in the comparison of the BTA and IET policy.

The functional form of the equation for p_d^d under P-UAP and P-BTA is identical. The inequality $(p_d^d)^{UAP} < (p_d^d)^{BTA}$ is a direct consequence of the one we have proved above, $(\mu^d)^{UAP} > (\mu^d)^{BTA}$ and the fact that the RHS of P-UAP p_d^d and P-BTA p_d^d is a decreasing function of μ^d (compare the proof of proposition 2). The inequality $(p_d^d)^{UAP} < (p_d^d)^{IET}$ is due to the factor $\frac{c^d(\mu^d)}{c^d(\mu^d) + \gamma^d c_1^d(\mu^d)\mu^d} > 1$ in front of $c^d(\mu^d) - c_1^d(\mu^d)\mu^d$ (which is identical to the RHS of P-UAP (p_d^d) and the equality $(\mu^d)^{UAP} = (\mu^d)^{BTA}$ as shown before.

The comparison of $(p_d^d)^{BTA}$ and $(p_d^d)^{IET}$ is trickier. First, we have to show that $(p_f^d)^{BTA} > (p_f^d)^{IET}$. This follows from $(\mu^d)^{BTA} < (\mu^d)^{IET}$ and the fact that the $c(.)$ is a decreasing function (cf. P-BTA and P-IET). From the comparison of the p_f^d and the definition of the demand functions, we conclude that $(q_f^d)^{BTA} < (q_f^d)^{IET}$. Now, given that the emissions cap $\overline{E}$ is the same under both BTA and IET and that $(\mu^d)^{BTA} < (\mu^d)^{IET}$, we may conclude that domestic production is higher under BTA than under IET. So, in particular, $(q_d^d)^{BTA} > (q_d^d)^{IET}$ and thus $(p_d^d)^{BTA} < (p_d^d)^{IET}$.

A glance at P-BTA(p_d^f) and P-IET(p_d^f) shows the difficulty of a comparison of $(p_d^f)^{BTA}$ and $(p_d^f)^{IET}$ - the two formulae contain different cost functions $c^f(.)$ and $c^d(.)$. Without further assumptions, we cannot expect to obtain an answer to the question how the two prices compare. Assumption (3) is sufficient to establish the relations stated in proposition (3), as is immediate for the case of p_d^f from a comparison of P-BTA(p_d^f) and P-IET(p_d^f) and $(\mu^f)^{BTA} > (\mu^f)^{IET}$.

Corollary 4 (Leakage):

The results on the relation of foreign emissions under the three policies are a direct consequence of the relation of quantities, derived in proposition (3) and of emissions intensities, derived in proposition (2).

5.6.2 List of tables

Table 20: Output effects (% vis-à-vis BaU)

Sectors	**EEI**			**REI**			**NEI**			**TOTAL**		
Regions, Scenarios	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**
EU15	-1.88	0.41	-1.77	-12.78	-12.48	-12.77	-0.15	-0.32	-0.16	-0.16	-0.32	-0.17
EU12	-3.22	-2.37	-3.14	-8.83	-8.73	-8.82	-0.27	-0.37	-0.28	-0.30	-0.40	-0.31
EU27	-2.03	0.10	-1.92	-11.87	-11.62	-11.86	-0.16	-0.32	-0.17	-0.18	-0.32	-0.18
OOE	0.34	-0.19	0.37	0.96	0.90	0.96	-0.02	0.01	-0.03	-0.02	0.01	-0.02
RUS	0.82	0.12	0.68	1.01	0.79	0.97	0.07	0.12	0.07	0.08	0.13	0.08
SMA	0.54	-0.19	0.58	2.13	2.08	2.12	-0.02	0.03	-0.02	-0.02	0.03	-0.02
CHN	0.31	-0.19	0.27	0.65	0.46	0.50	0.00	0.06	0.00	0.00	0.06	0.00
SEA	0.82	-0.42	0.78	1.05	0.87	1.06	-0.03	0.05	-0.03	-0.03	0.05	-0.03
OPC	1.95	0.76	0.90	2.40	2.27	2.29	0.06	0.14	0.10	0.08	0.15	0.11
XRW	1.28	0.03	0.89	3.29	2.82	3.03	-0.05	0.07	-0.01	-0.04	0.08	0.00

Note: EU15 Old member states, **EU12** New member states**, OOE** Rest of OECD, **RUS** Former Soviet Union, **SMA** Rest of South and Middle America, **CHN** China (including Hongkong), **SEA** Rest of South and East Asia, **OPC** OPEC, **XRW** Rest of the World. **EEI** energy-intensive and export-oriented sectors to which the BTA and IET regimes is applied (ORE, PPP, NMM, NFM and CRP), **REI** energy-intensive but not-export oriented sectors to which the BTA and IET regimes are not applied (ATP, ELE and OIL), **NEI** non-energy-intensive sectors (ROI).

Table 21: Environmental effects (% vis-à-vis BaU)

Sectors	**EII**			**REI**			**NEI**			**TOTAL**		
Regions, Scenarios	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**	**UAP**	**BTA**	**IET**
EU15	-10.80	-8.12	-10.70	-32.13	-32.10	-32.10	-7.76	-7.90	-7.75	-19.40	-19.40	-19.40
EU12	-13.40	-11.80	-13.20	-30.00	-30.20	-30.00	-16.20	-16.50	-16.30	-23.10	-23.20	-23.10
EU27	-7.66	-7.50	-7.64	-22.90	-22.90	-22.90	-8.85	-9.00	-8.84	-20.00	-20.00	-20.00
OOE	0.55	-0.07	-0.07	1.04	1.00	1.03	0.32	0.33	0.34	0.74	0.71	0.74
RUS	1.10	-0.09	-0.51	1.66	1.45	1.64	0.51	0.48	0.54	1.22	0.99	1.07
SMA	0.66	-0.20	-0.40	2.22	2.16	2.24	0.06	0.08	0.06	0.98	0.89	0.89
CHN	0.61	0.08	0.00	1.57	1.43	1.56	0.42	0.46	0.41	1.18	1.06	1.13
SEA	0.93	-0.29	-1.06	1.51	1.34	1.54	0.52	0.59	0.54	1.15	0.94	0.96
OPC	1.98	0.45	-1.28	1.58	1.42	1.47	0.54	0.59	0.52	1.15	0.93	0.72
XRW	2.75	-0.31	-5.21	3.87	3.39	3.63	0.11	0.16	0.10	2.41	1.86	1.47

Note: EU15 Old member states, **EU12** New member states**, OOE** Rest of OECD, **RUS** Former Soviet Union, **SMA** Rest of South and Middle America, **CHN** China (including Hongkong), **SEA** Rest of South and East Asia, **OPC** OPEC, **XRW** Rest of the World. **EEI** energy-intensive and export-oriented sectors to which the BTA and IET regimes is applied (ORE, PPP, NMM, NFM and CRP), **REI** energy-intensive but not-export oriented sectors to which the BTA and IET regimes are not applied (ATP, ELE and OIL), **NEI** non-energy-intensive sectors (ROI).

6 Globalisation of the Carbon Market: An Economic Efficiency and International Trade Analysis[55]

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 has simultaneously pursued ambitious emissions reduction targets to limit global warming to 2° Celsius and aimed to become the most competitive economy of the world (EU, 2007a, 2000). Europe's central climate policy instrument is the EU Emissions Trading Scheme (EU ETS) which was established in 2005 and entered its second phase in 2008 (EU, 2003a). In order to increase cost efficiency of EU climate policy, the European Council has proposed to link the EU ETS to compatible mandatory schemes in third countries (EU, 2007a), thereby initialising a process towards a global carbon market.

At present, several non-EU countries are contemplating the set-up of domestic ETS at the national and regional level with the intention of linking up to the European scheme. The already mature emissions trading scheme of Norway has been linked to the EU ETS in March 2009 as the first non-EU scheme. In the short run, the emissions trading scheme of Switzerland – which is designed similarly to the EU ETS – can be expected to be linked up to the European system (Sterk, 2005). In the mid-term perspective up to 2020, several parties having ratified the Kyoto Protocol – such as Canada, Japan and the Russian Federation – may also have incentives to join the EU ETS. Four Canadian provinces are going to participate in the Western Climate Initiative (WCI) cap-and-trade program starting operation in 2012 which will establish a Northern American ETS with seven US States (WCI, 2009). After implementing a pilot project of a domestic emissions trading scheme on a voluntary basis in 2005 with comparatively few participants Japan has started a trial ETS in October 2008 to prepare the economy for a possible mandatory cap-and-trade scheme (Kimura and Tuerk, 2008). Moreover, initial exploratory discussions on the potential linkage of trading schemes have already been held between the EU, Canada and Japan (EU, 2005b; EU-Japan Centre for Industrial Cooperation, 2006). Also Russia may have incentives to develop a domestic

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[55] 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* 07-038, Mannheim.

emissions trading system in order to be linked to the European scheme and to exploit a larger market for the sale of excess emissions permits, the so-called “Hot Air”. Finally, linking the EU ETS to emerging schemes in the United States and Australia could be considered as a first step in integrating both countries into an international climate policy regime. Indeed, Australia and United States are already promoting domestic emissions trading schemes: In the U.S., several regional trading systems have evolved: the Regional Greenhouse Gas Initiative, the Western Climate Initiative and the Midwestern Regional Greenhouse Gas Reduction Accord (Haites, 2009). In Australia, the 2007 elected government is taking major steps towards an Australian emissions trading scheme which takes linking options under consideration (Jotzo and Betz, 2009). To sum up, there are strong signals for various emissions trading schemes to be established in non-EU countries and to be potentially linked to the European scheme by 2020.

Reflecting current political priorities within and beyond the EU, this chapter 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. Böhringer et al., 2005, and Fischer, 2006) and competitiveness implications of European climate policies (Klepper and Peterson, 2004; Kemfert et al., 2005, and Peterson, 2006a,b, Alexeeva-Talebi, 2009) in an applied partial and general equilibrium framework. In a partial-market 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. 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 chapter 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 analyse the macroeconomic welfare impacts of linking the EU ETS and (iii) explicitly assess the sectoral trade-based competitiveness effects of developing supra-European emissions trading schemes in the year 2020.

The chapter 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 summarises our quantitative simulation results. In section 6.5, we conclude. Appendices can be found in section 6.6.

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 analyse the general efficiency aspects of international emissions trading and subsequently assess the emissions market implications of linking alternative trading systems.

Building on the stylised framework of Anger (2008), R regions are assumed ($r=1,...,R$) to commit to individual emissions targets, yielding an absolute emissions budget $\bar{E}_r$ 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 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 minimisation with respect to e_r^{ETS} and e_r^{NETS} yields the following first-order condition:

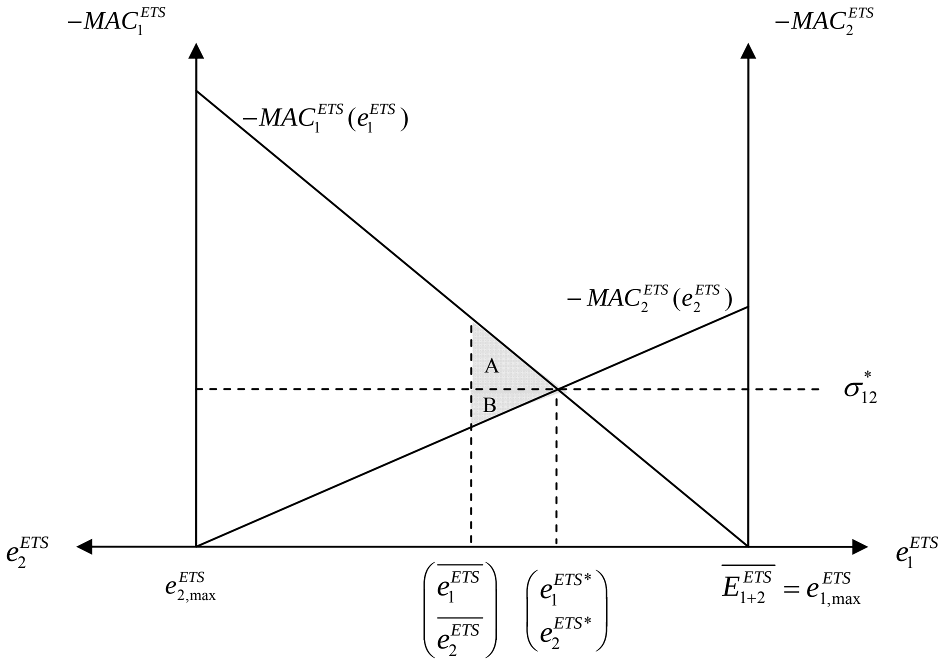
$$\sigma = -\frac{\partial AC_r^{ETS}}{\partial e_r^{ETS}} = -\frac{\partial AC_r^{NETS}}{\partial e_r^{NETS}} = -\frac{\partial AC_r}{\partial (e_r^{ETS} + e_r^{NETS})}. \tag{1}$$

For each region and sector, this cost-efficient solution implies that marginal abatement costs equal the permit price σ and are thus equalised 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 $\bar{E}_r$ and aggregate optimal emissions E_r^* yields the optimal total trade volume in emissions permits.

6.1.1 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 amount to 50 percent of the maximum emissions level, respectively. Figure 22 illustrates the efficiency implications from trading emissions in terms of compliance costs for *ETS* sectors given their permit allocation.

Figure 22: Sectoral efficiency gains in an international emissions trading scheme



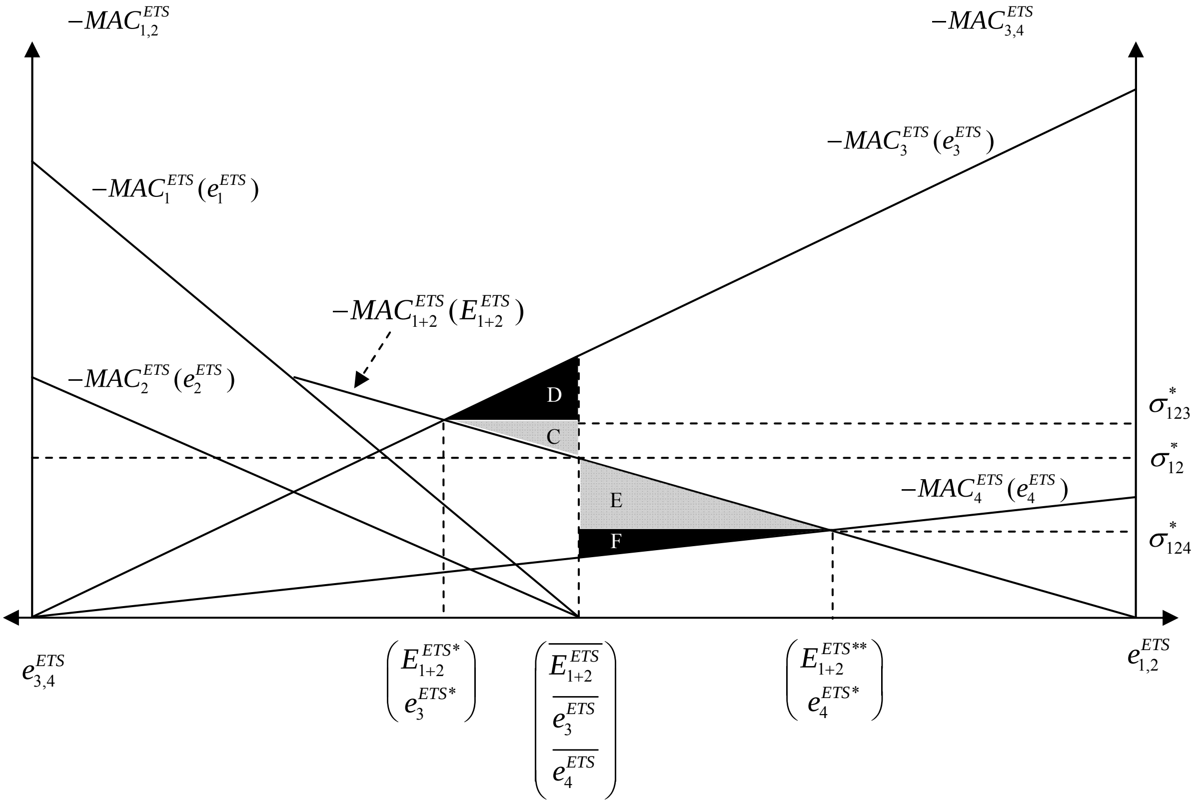
In the figure, the initial regional allocation of emissions permits to the covered *ETS* sectors $(\overline{e_1^{ETS}},\overline{e_2^{ETS}})$ which translates into a total emissions ceiling $\overline{E_{1+2}^{ETS}}$ imply economically inefficient emissions levels of the two regions. This is due to 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}^{*} equalises 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 22 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 23 illustrates the efficiency aspects of linking an additional region to the existing joint trading scheme of regions 1 and 2. In the case of linking the 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 equalised 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).

Figure 23: Additional efficiency gains from linking emissions trading schemes



In contrast, linking to the 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}^*, the optimal emissions levels ($E_{1+2}^{ETS**}, e_4^{ETS*}$) with equalised marginal abatement costs and the 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 a 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 stylised 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 stylised 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 analyse 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 modelling approach and 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, 2005b). 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.[56] 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 $\left(\overline{E}_r - \overline{e_r^{ETS}}\right)$.

In our framework, a representative agent in each region r is endowed with three primary factors: labour, capital and fossil-fuel resources (used for fossil fuel production). The representative agent maximises utility from consumption of a composite good which combines demands for energy and non-energy commodities at a constant-elasticity-of-substitution (CES). Production 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 export 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 that combines the domestically produced variety and imports of the same variety from other regions. Domestic production either enters the formation of the Armington good or is exported 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, 2003b) and on international energy projections for non-European economies (US Department of Energy, 2005). A description of all model

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[56] 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 Eyckmans and Finus (2006).

regions and sectors can be found in Table 22 and Table 23 (all tables in this chapter are compiled in the Appendix).

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 (Clean Development Mechanism) transaction costs and investment risk indicators.

National emissions reduction targets

In order to analyse 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, 2007c). 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 (BaU) emissions levels implies the 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.[57] While having received excess emissions permits under the Kyoto Protocol, we assume Russia to hold its emissions constant under a post-Kyoto

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[57] At the Vienna Climate Change Talks 2007, the Parties to the Kyoto Protocol officially recognised that preventing the threats of climate change would entail emissions reductions in the range of 25-40 percent below the 1990 levels by industrialised countries (UNFCCC, 2007b). 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.[58] The resulting climate policy targets are summarised in Table 24.

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 the 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, 2007d).

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 allowances allocation is decreased by 30 percent as compared to the second trading period.[59] 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

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[58] 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.

[59] Two limitations apply here: Due to the 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.

excess permits to installations covered by a Russian ETS.[60] Table 25 presents the resulting allocation factors for the EU and all linking candidates.

The Clean Development Mechanism

The Kyoto Protocol enables industrialised 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, 2004b). 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.[61] Following Böhringer and Löschel (2002a), 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: Linking up the EU ETS

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.

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[60] 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.

[61] The magnitude of transaction costs is consistent with recent estimations (Michaelowa and Jotzo, 2005).

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.[62] In our analysis, emissions trading at the installation level is thus approximated by 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 26 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 fulfil 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.[63]

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[62] 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.

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

Table 26 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, 2007a). 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 (BaU) where no emissions regulation is imposed.

6.4 Simulation results

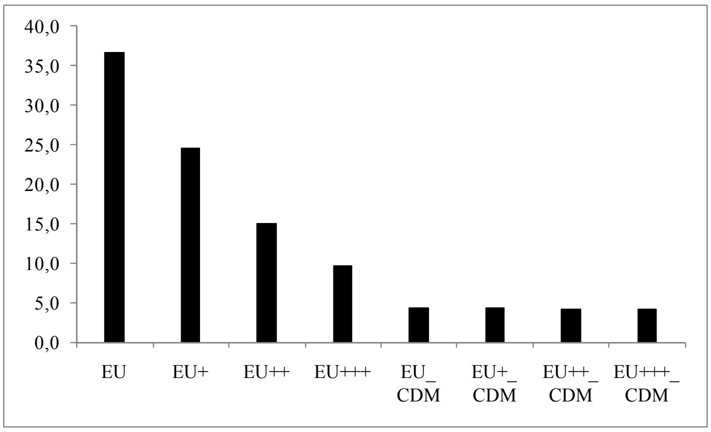
This section presents the simulation results of our model-based assessment of the macroeconomic and competitiveness impacts of linking the EU ETS internationally. The corresponding quantitative simulation results are presented in Table 27 and Table 28. We begin our analysis by reporting the effects of linking the EU ETS on the market for emissions 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 suggests 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 24. 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 of 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$. Despite of the relatively high-cost abatement options of Canada and Japan, the relatively generous allowance allocation in both countries (allocation factors equal to 0.85) implies that sectors in these regions exhibit relatively low marginal abatement cost *levels* as compared to the EU.[64] This is underlined by the low carbon price levels in the domestic ETS of Canada and Japan prior to linking (11 and 4 US$ per ton of CO_2, respectively) 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 27).

Figure 24: CO_2 permit price in ETS sectors within linked schemes by scenario ($US per ton of CO_2)



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$. As we abstract from the allocation of potential excess emissions permits to the covered Russian installations, this lower permit price only originates from relatively low-cost abatement options of permit-exporting Russian *ETS* sectors (which feature a domestic carbon price prior to linking of only 1.5 US$ per ton of CO_2). Table 27 shows that Russian emissions reductions are consequently boosted by linking up to the EU trading scheme, while EU

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[64] For an assessment of marginal abatement costs across OECD countries see: Criqui et al. (1999).

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 of 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 of 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 export 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 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 24 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

(Böhringer and Löschel, 2002b).[65] 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 it also captures 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 27 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 both EU production and welfare losses due to increased where-flexibility of emissions abatement at a *lower* carbon value (i.e. shadow price) of its emissions constraint on the unified carbon market, as compared to the EU ETS. 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 to 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 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 in 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 27. 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 24) by means of domestic emissions trading schemes and complementary regulation of the respective non-covered sectors. Table 27 suggests that

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[65] 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.

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 face a *higher* carbon value (i.e. shadow price) of their emissions constraints on the unified carbon market as compared to their domestic ETS, these industries act as permit exporters by homogenously increasing emissions reductions, thereby decreasing energy use and output. However, this negative production effect can be antagonised 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 27 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 due to a higher carbon value on the unified carbon market 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 which reduces the initial welfare gains of non-EU regions stronger than it recovers production (as opposed to the beneficial effects for the permit-demanding EU economies).

Table 27 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 sectoral 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, 2002). In the following, we assess the trade-based competitiveness effects of linking emissions trading schemes at the sectoral level.

Focusing on the EU-27 region, Figure 25a.-b. (Appendix, all numerical results are reported in Table 28) shows competitiveness effects for the EU at the sectoral level using two well-known indicators: Revealed Comparative Advantage (RCA) and Relative World Trade Shares (RWS).[66] 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 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 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 sectoral

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[66] 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.

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.

Table 28 (Appendix) also summarises the sectoral competitiveness impacts for non-EU regions across policy scenarios. It shows that linking to the EU ETS induces homogeneous competitiveness impacts for non-EU economies: all regions face substantial losses in sectoral competitiveness of *ETS* sectors by linking up. These results relate inversely to the sectoral competitiveness for the EU and are clearly driven by the fact that all non-EU regions face a higher carbon value and 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.

When allowing for CDM access for the covered sectors of the respective trading systems, the competitiveness effects across scenarios are largely levelled out for the EU-27 and non-EU regions. 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.[67] The associated simulation results are presented in Table 29 and Table 30. 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. 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 chapter we presented an efficiency and international trade analysis of developing supra-European emissions trading schemes. A stylised 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 analysed the macroeconomic and trade-based 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

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[67] 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.

constellation the EU represents an importer of emissions allowances, while all non-EU regions export 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 sectoral competitiveness by integrating with emerging ETS outside Europe. However, 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 sectoral 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.

Allowing for permit imports from outside the linked schemes via the Clean Development Mechanism largely neutralises the macroeconomic impacts of linking ETS. The reasons 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 priority for social welfare or international competitiveness.

6.6 Appendices to chapter 6

6.6.1 List of tables

Table 22: 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 23: PACE model sectors

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

Table 24: 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)**	
Year / Region	**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	1240.0	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 (2003b), US Department of Energy (2005), own calculations.

Table 25: 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 (2007d), own calculations.

Table 26: Policy scenarios in 2020 and CDM host countries

Regional scenario	**Regions participating in emissions trading**	**CDM regions**
EU	EU-27	China India Brazil Mexico Korea Rest of World
EU^{+}	EU-27 Canada Japan	
EU^{++}	EU-27 Canada Japan Russian Federation	
EU^{+++}	EU-27 Canada Japan Russian Federation Australia United States	

Table 27: Core 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	-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
	CO_2 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 28: Core allowance allocation – Sectoral competitiveness indicators in 2020

Scenario / **Region**	**EU**		**EU^{+}**		**EU^{++}**		**EU^{+++}**		**EU_CDM**		**EU^{+}_CDM**		**EU^{++}_CDM**		**EU^{+++}_CDM**	
	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 29: 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
	CO_2 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 30: Stricter allowance allocation – Sectoral competitiveness indicators in 2020

Scenario **Region**	**EU**		**EU^{+}**		**EU^{++}**		**EU^{+++}**		**EU_CDM**		**EU^{+}_CDM**		**EU^{++}_CDM**		**EU^{+++}_CDM**	
	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

6.6.2 List of figures

Figure 25a: Sectoral competitiveness indicator by scenario (RCA indicator)

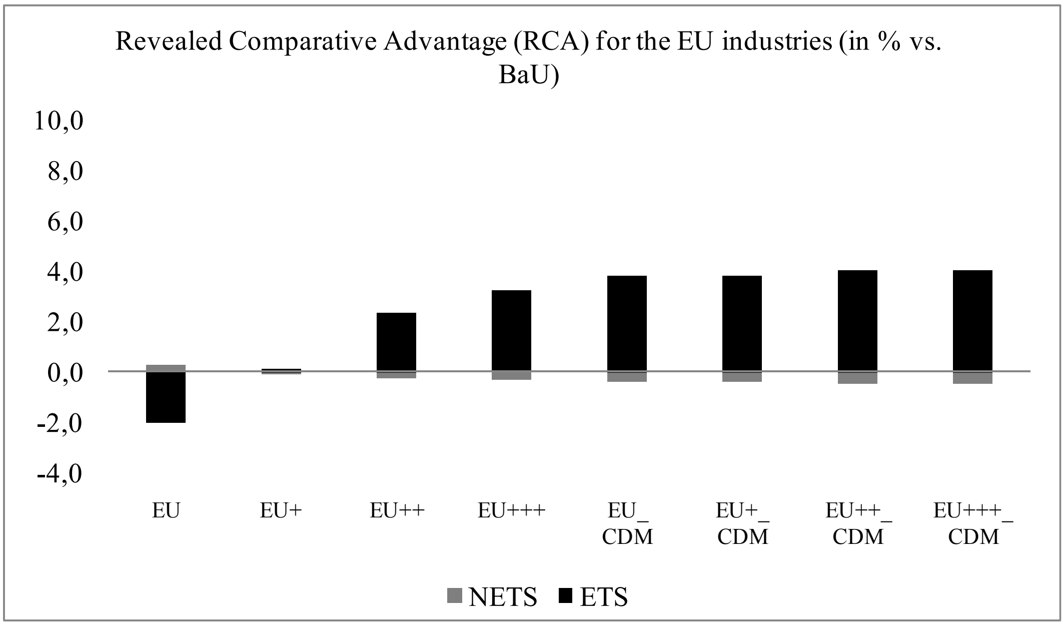
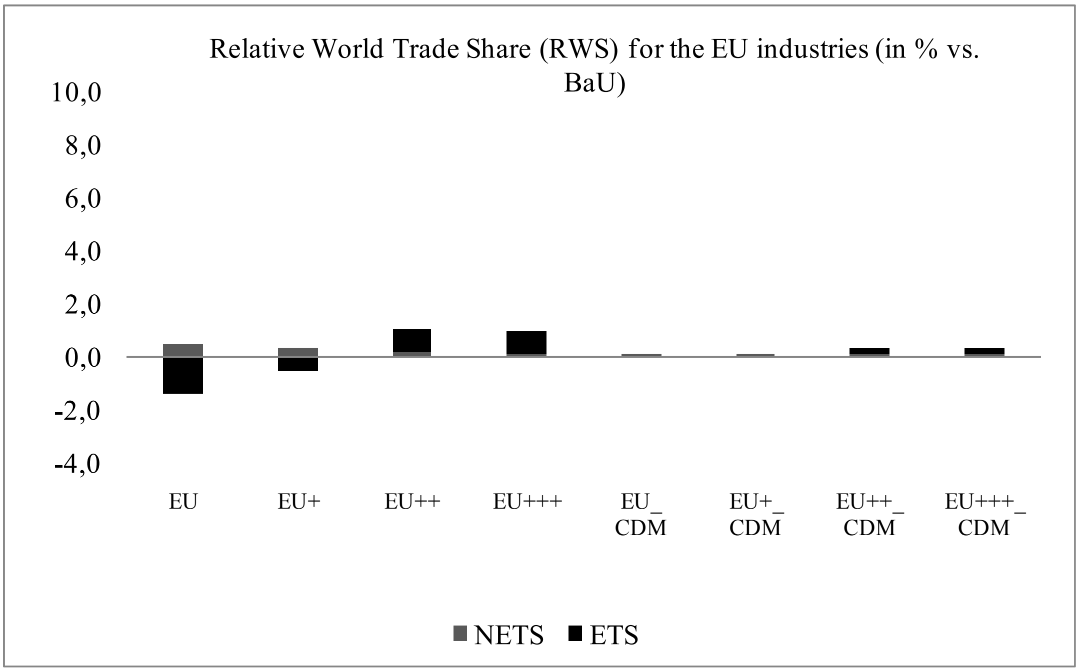


Figure 25b: Sectoral competitiveness indicator by scenario (RWS indicator)



7 General conclusions and policy implications

The EU has repeatedly underlined the principle of common but differentiated responsibilities as an essential element to effective and efficient framework for post-2012 global actions to combat climate change. To ensure the widest possible participation of the nations and to justify those to come forward with proposals on absolute emissions reduction commitments, the EU has taken the lead by committing to a 20 percent reduction in greenhouse gases by 2020 compared to 1990 (EU, 2007a). This commitment has been reaffirmed in mid-2010, as the European Commission rejected stepping up the EU effort to 30 percent as long as the other developed countries disclaim undertaking comparable emissions reductions and the economically more advanced developing countries oppose a contribution commensurate with their respective capabilities (EU, 2010a).

In the world with uneven carbon constraints, commitments to ambitious emissions targets give rise to multiple concerns. A widespread concern is as to what extent nations with stringent climate policies will put domestic industries at a disadvantage relative to competitors in countries with a lower level of ambitions in climate actions. This is a politically contentious issue, in particular if ambitious climate actions result into relocation of emissions instead of their reduction, coupled with local job losses. Not surprisingly, ensuring competitiveness of European energy-intensive industries and retention of global environmental effectiveness have become a guiding principle in the transition to a low carbon economy in Europe. There is a clear perception in the policy arena in the EU that ambitious environmental policy in the mid-term will be politically acceptable only under the premise that European enterprises are able to maintain their competitive position.

Focusing on the assessment of the potential distributional impacts of the EU climate change policy at the sectoral level, this thesis analysed the ability of energy-intensive industries in the EU to pass on additional costs to consumers and demanding sectors. The empirical approach in chapter 2 based on the estimation of a sequence of vector error correction models yielded the cost pass-through potential widely varying across industries in Germany. The pass-through capacity of *domestic* type of cost shocks into sectoral producer prices in the long-run was assessed using price indices for labour, material and energy. For half of sectors in the sample, empirical results give support for medium to high pass-through rates in the long-run equilibrium. The severe risk of carbon leakage working through the decreasing-profit-margin-channel exists thereby in few sectors only. It is mainly concentrated in parts of paper and chemical industry. Profit losses due to the less-than-complete cost pass-through on the part of domestic firms are, however, partly offset as these sectors "capitalise" on the opportunity to increase their own prices if foreign competitors start charging higher prices. Furthermore, the analysis found a significant role for the included industrial characteristics (market concentration, import penetration, degree of product heterogeneity) in explaining the cost pass-through rates in German sectors. The impact on the pass-through is ultimately determined by the interplay of individual effects working in different directions.

Previous research demonstrated that the electricity sector has been largely benefiting from freely allocated allowances in the first trading period 2005–2007 by passing-through opportunity costs to consumers. Focusing on the refining sectors, chapter 3 examined price dynamics in petroleum markets of 14 EU member states over the same time horizon. In contrast to chapter 2, the availability of weakly data from 2005 to 2007 allowed directly exploring the ability of European refineries to pass-through costs associated with the introduction of the EU ETS. By estimating a range of vector error correction models, the analysis found a significant influence of prices for emissions allowances on retail unleaded petrol prices during the trial phase of the EU ETS from 2005 to 2007. Petrol prices are found to be elastic with respect to crude oil prices and exchange rates but rather inelastic with respect to carbon costs. By computing the variance decomposition, the analysis also showed that a significant fraction of petrol price changes in Austria, Germany, France and Spain can be explained by changes in allowance prices (between 10 percent and 20 percent). The overall conclusion of this chapter is that European refineries have been strongly benefiting from the current design of the EU ETS, i.e. free allocation of the allowances in the first trading period. As to the policy implications, these findings question – on grounds of severe adverse distributional impacts – the continuation of a largely free allocation of allowances to the refining sector beyond 2012.

By recognising that international trade is an integral part of the competitiveness notion, chapter 4 evaluated whether competitive distortions on international markets present a realistic danger to European energy-intensive industries in a world with a unilateral climate policy. Rather moderate adverse competitiveness impacts of unilateral actions on these branches in our assessment raises the question on the legitimacy of price discrimination in favour of energy intensive industries as it leads to multiple pending trade-offs: The sector-specific gains of preferential regulation in favour of European energy-intensive branches must be traded-off against the additional burden imposed on other industries to meet an economy-wide emission reduction target in the EU. Beyond these insights, our results highlighted the scope for substantial excess cost in the European Union as price discriminating policy grants lower carbon levies to energy-intensive industries and thereby foregoes relatively cheap abatement options in these sectors. Despite the potential pitfalls of price differentiation at the regional level, our findings lowered concerns on these pricing strategies as a second-best response to the problem of emission leakage. The moderate non-uniform emission pricing in the EU can reduce leakage and thereby lower overall cost of cutting global emissions as compared to uniform emission pricing.

Chapter 5 focused on trade-based measures as a remedy to address competitiveness and carbon leakage concerns in the EU. Theoretical framework showed that energy-intensive sectors in the EU are best off under the border tax adjustment regime, while integrated global emissions trading reduces more strongly emissions in non-EU regions than the BTA scheme. From the perspective of the European Union, impacts of both trade regimes on environmental performance constitute the central trade-off with pure competitiveness considerations. As to the emissions reductions by foreign energy-intensive producers, they are due to the quantity effect under BTA. In the case of IET, higher energy efficiency adds up with reduced sales abroad. The numerical analysis put this view into perspective by introducing real world complexity. If both BTA and IET apply to selected energy-intensive industries only, the latter conclusion on environmental effectiveness still holds true. The presence of non-participating sectors can, however, lead to a reversion of the results on competitiveness. The losses in total production level in the EU 27 almost double under BTA in compassion to IET. This is mainly due to a strong shift in the abatement activities from covered energy-intensive industries to non-covered sectors with relatively high abatement costs.

Chapter 6 assessed the efficiency and international trade aspects of linking the EU Emissions Trading Scheme to emerging trading schemes outside Europe. A stylised partial market analysis suggested that independently of the regional cost characteristics, the integration of emissions trading scheme 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 suggests opposite trade-based incentives of linking ETS: while EU member states improve their competitiveness by integrating with emerging ETS, all non-EU linking candidates face competitiveness losses by linking up. This chapter concluded that for non-EU regions, the attractiveness of developing supra-European ETS is a matter of priority for efficiency or international competitiveness.

As to the policy implications, this study showed that policy makers and industrial associations tend to significantly underestimate the potential of energy-intensive industries to pass-through additional costs to consumers. The less-than-complete pass-through implies that additional costs induced by the EU ETS in the third trading period are likely to be partly absorbed through a reduction of profit margins, but the severe risk of carbon leakage working through this channel exists in few sectors only. Hence, policy makers might consider it appropriate to apply the free allocation provisions to vulnerable sectors, but this shall be done in a very restrictive way to minimise the distortions from the inefficient implementation. In particular, sectors with relatively high cost pass-through rates and relatively low adverse impacts on international competitiveness shall not benefit from generous exposure rules. To reduce political resistance against ambitious climate change policy and to keep compliance costs down, introduction of supportive measures of this type shall be restricted to vulnerable sectors only.

Moreover, the current proposal of the European Commission to possibly introduce “additional and alternative means” to free allocation to address the risk of competitiveness-driven carbon leakage, most notably through the introduction of trade measures, needs to be put into perspective (EU, 2010a). By demonstrating that introduction of border measures is likely to result in decreasing overall production in the EU and to lead to only a moderate reduction of carbon leakage, this thesis opposes the recommendations in some recent contributions to introduce it as a remedy (e.g. Grubb and Droege, 2010).

In contrast, the EU shall pursuit the opportunity to extend the sectoral and the regional scope of the EU ETS to those countries that are not yet participating or participating randomly in the emissions trading (see also: Alexeeva-Talebi et al. 2010b). This option allows realising a cost-efficient and globally effective climate policy while simultaneously minimising the adverse impacts on competitiveness of domestic energy intensive industries. Under currently difficult circumstances in international cooperation on climate change issues, the EU might in particular consider embedding countries like Russia that currently experience a turnaround in its energy and climate policy. Presuming that the hot air controversy is resolved – Russian government has already signalled some flexibility in this respect –, the upcoming negotiations in South Africa in 2011 might be used to make a progress towards a global carbon market as a first-best solution to the climate change problem.

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Ehrenwörtliche Erklärung

Hiermit erkläre ich, dass ich diese Dissertation selbständig verfasst habe. Die benutzten Hilfsmittel sind vollständig angegeben. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle gekennzeichnet. Die Inhalte dieser Arbeit wurden nicht schon für eine Diplom- oder ähnliche Prüfungsarbeit verwendet.

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