The
European Emissions Trading Scheme under Imperfect Competition

An Economic Analysis of the Institutional Framework

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Referent:	Prof. Dr. S. Berninghaus
Korreferent:	Prof. Dr. M. Uhrig-Homburg
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To Ying.

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Contents

Chapter 1

Introduction

The European Union established the largest greenhouse gas emissions trading scheme in the world. The need for such regulatory frameworks to reduce greenhouse gas emissions became evident, at the latest, when the Intergovernmental Panel on Climate Change published its fourth assessment report in 2007. According to this report, an uncontrolled anthropogenic production of greenhouse gases will lead, with almost absolute certainty, to climate change. "Continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system."[1] In particular, this would lead to global warming and sea level rises and thus floods, droughts, migration, and negative effects on agriculture and on human health are expectable.[2] The widely noticed Stern Review estimates the global costs of these negative effects of climate change and concludes that the uncontrolled production of greenhouse gases will "reduce welfare by an amount of equivalent to a reduction in consumption per head of between 5 and 20%."[3] Even more problematic, these costs are unevenly distributed and the poorest countries and people will suffer most. According to Stern, the costs of stabilization of greenhouse gas concentrations in the atmosphere, at a level that would prevent the most serious damage, are only around 1% of global GDP if actions are taken immediately. To achieve such a

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[1] See IPCC (2007b).

[2] For a detailed overview of the potential consequences of climate change, see IPCC (2007a).

[3] See Stern (2007).

stabilization of greenhouse gas concentrations, strong abatement efforts are necessary. Since greenhouse gases are uniformly-mixing, i.e., the global effects are independent of the location of emission, only the reduction of aggregate greenhouse gas emissions is relevant.[4]

This inescapable need to mitigate global greenhouse gas emissions calls for combined global efforts. The hitherto most important achievement of the international community is the Kyoto Protocol. The Protocol commits participating industrial and transition countries to reduce emissions to 5.2% below 1990 levels in the period between 2008 and 2012. At the time of writing, the international community is still in negotiations about an environmental agreement for the time beyond 2012.

To achieve the emission reduction target stipulated by the Kyoto Protocol, the European Union launched in 2005 an emissions trading scheme. In the beginning, this scheme only regulates the production of carbon dioxide, which is the most important greenhouse gas. However, only carbon-dioxide-intensive industries take part in emissions trading and need to cover their emissions with an appropriate amount of emission rights, which are freely tradable on a European market. On the contrary, other emitters, e.g. in the traffic or household sectors, are regulated outside of the Emissions Trading Scheme by different policy measures, like taxes or standards. In this approach, a major task for the regulator is to split up the total amount of emissions stipulated by the Kyoto Protocol between the Emissions Trading Scheme and the remaining sectors of the economy in a way that negative effects of emissions reduction on social welfare are minimized.

This allocation of emission rights plays a decisive role for the total costs of the European Union to achieve its reduction target. Various studies suppose that in the first trading period, too many emission rights are assigned to the trading scheme and too few to other parts of the economy, leading to unnecessarily high costs. However, none of these studies consider that major industries in the European Emissions Trading Scheme are oligopolies, i.e., they consist of only a few firms that probably possess market power in their product markets. A prominent example is the German power supply industry, which is dominated by five firms

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[4] See for example Tietenberg (1990).

with a total market share of over 80%.[5] According to Requate's excellent survey on environmental policies under imperfect competition, "Innes et al. (1991) is one of the few papers that studies simultaneous regulation of both a large monopolistic firm and many competitive small polluting firms."[6] This work contributes to this hiatus in literature and analyzes the impact on the optimal allocation of emissions to the different sectors of the economy if some product markets in the European Emissions Trading Scheme are oligopolistic. At this juncture, it combines the existing knowledge on the optimal regulation of negative externalities in oligopolies with the special design of the European regulatory framework. Therefore, the present analysis takes into account that the European approach connects former independent industries via the newly established permit market. Another important issue is that not only industries are regulated, but also households. Thus, a more general approach is used than in existing literature, which usually analyzes partial markets.

Furthermore, it is important to keep in mind that the European institutional framework is a multinational approach. In the primary design, the participating EU member states could decide individually on the partitioning of the total amount of emissions between the Emissions Trading Scheme and the remaining sectors of the economy. Of course, this modus operandi immediately raises the question whether there is room for strategic behavior by individual member states. It is reasonable to propose that member states may abuse the allocation of emissions to affect the permit market, such that national welfare is maximized. Moreover, this additional degree of freedom may be employed as a replacement for abolished trade policies on the integrated European commodity markets. Finally, it is also questionable whether such strategic behavior of individual member states allows for greenhouse gas reductions at lowest cost or whether it in fact results in an inefficient outcome.

However, exploitation of the regulatory framework is not only conceivable at the international, but also at the interfirm level. According to Requate (2006):

> [I]t would be interesting to investigate whether there are incentives

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[5] See for example WWF (2006) and Hirschhausen et al. (2007).

[6] See Requate (2006).

> for firms to (ab)use voluntary environmental agreements and commitments in order to bypass anti-trust laws.

On this account, the present work also investigates whether the European Emissions Trading Scheme enables oligopolistic firms to tacitly collude on commodity markets. In this vein, the Emissions Trading Scheme could facilitate firms' coordination to corporately reduce their output levels, which in turn would raise consumers' prices and lead to welfare losses.

In the course of this thesis, microeconomic and particularly game theoretic methods are employed to address the above questions. Due to the fact that the European approach to reducing greenhouse gas emissions affects major parts of the economy, a general equilibrium approach with imperfect competition is applied. In part, the analysis is constrained to partial markets in order to be able to derive more precise results on particular effects.

The main contribution of this thesis is to establish formal proof that imperfect competition can significantly affect the European approach to regulate emissions. Firstly, it is shown that under the assumption of imperfect commodity markets, an optimal regulation must discriminate between the emitters assigned to the Emissions Trading Scheme and the emitters outside of the Emissions Trading Scheme. Based on empirical data, it can be shown that the oligopoly structure of the German power supply market probably requires a significantly stricter regulation of emitters outside of the Emissions Trading Scheme.

Secondly, extending the scope of the analysis and considering the multinational framework of the European system reveals that the participating states have an incentive to act strategically. If member states are given the power to allocate emission rights themselves, the European system provides loopholes to replace missing trade policies. For instance, it is shown that states affect their terms-of-trade via influencing the emission permit market, which is also supported by a numerical example.

Thirdly, the outcome of an Emissions Trading Scheme with decentralized decision-making of strategically acting member states is compared to the welfare optimal outcome, which could be implemented by a central decision maker, such as the European regulator. It is shown that the individual strategic incentives are not aligned with the incentives of a central decision maker, resulting in welfare inefficiencies, i.e., the emission reduction target is achieved at excessive costs. Thus, the finding of the present analysis supports the plan of the European Union to centralize the allocation of emissions in the future. However, even if a central authority decides on the partitioning of emissions between the trading scheme and other emitters, discrimination of emitters is inevitable for a cost-efficient solution. Interestingly, an optimal differentiation would not only call for a differentiation between the emitters assigned to the Emissions Trading Scheme and the remaining sectors, but also between different emitters outside the Emissions Trading Scheme. Hence, it could well be that households in different states have to pay different emission taxes in order to achieve cost-efficient emission abatement.

Moreover, the insights from this analysis also support the presumption that firms have incentives to abuse the regulatory framework. In fact, it is shown that firms can even benefit from a stricter regulation, which in turn can lead to a situation where firms voluntarily commit themselves to pay higher prices for emissions. The existing Emissions Trading Scheme provides possibilities for such misuse. Furthermore, in the current trading scheme, there exists an option by which firms can pool their emissions, which facilitates firms' tacit collusion on the output market.

In conclusion, this thesis highlights the many aspects by which imperfect competition enriches previous analyses of the European Emissions Trading Scheme and provides further insights on an optimal regulatory framework. The following findings provide strong evidence that the regulator cannot neglect the existence of imperfect markets when the goal of regulatory intervention is to guarantee emission abatement at lowest cost. Finding solutions to abate emissions as cheaply as possible is of major importance for creating acceptance and ensuring sustainability of the European approach to mitigate climate change.

The remainder of this thesis is organized as follows. Chapter 2 introduces the current European Emissions Trading Scheme and briefly describes the relevant international agreements, most prominently the Kyoto Protocol. Chapter 3 provides a survey on the economics of emissions trading. With respect to the following analyses, the focus of the survey is mainly on the effects of imperfect competition. Chapter 4 investigates the optimal allocation of emission rights for a single country scenario when some commodity markets are imperfectly competitive. The analysis is extended in Chapter 5 to a multi-country scenario, which considers both a central planner and strategically acting states. In Chapter 6 the focus is shifted from an overall perspective to the impacts of emissions trading on firms' profits. It is investigated whether firms can abuse the European Emissions Trading Scheme. Finally, Chapter 7 concludes and gives a short outlook on further research possibilities.

Chapter 2

The European Emissions Trading Scheme

2.1 Foundations in International Law

The European Emissions Trading Scheme (ETS) has its groundwork in the United National Framework Convention on Climate Change (UNFCCC) and especially in the Kyoto Protocol. It is also linked to these conventions via different mechanisms. Therefore, the following subsections give a brief survey of the essential international agreements for the European approach to reduce greenhouse gas emissions.

2.1.1 The United National Framework Convention on Climate Change

The foundation for the United National Framework Convention on Climate Change was laid in the 1970s, when scientists began to understand that an uncontrolled anthropogenic production of greenhouse gas emissions would lead to climate change. As a result of this discussion, the World Climate Programme (WCP) was launched after the first World Climate Conference in Geneva, Switzerland in 1979. The WCP is a scientific program to improve the understanding of the world climate system and man-made climate change. The next big step forward on the way to an international climate convention was the foundation of the Intergovernmental Panel on Climate Change (IPCC) after the world climate conference in Toronto, Canada, in 1988. The IPCC has the objective to accumulate and evaluate all information about climate change. Due to the alarming results of the first assessment report of the IPCC in 1990 on future climate change and its consequences, 154 states ratified the UNFCCC at the Earth Summit in Rio de Janeiro, Brazil, in 1992.[1][2] In 2007 over 190 states participated in the UNFCCC.[3]

The main objective is to "achieve (...) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system".[4] Therefore, the level of greenhouse gas emissions should be reduced to a level that allows ecosystems to adapt naturally to climate change. Most participating member states of the Organisation for Economic Co-operation and Development (OECD) and central and east European transition countries committed themselves to formulate and implement emission abatement measures to protect the climate system and to mitigate adverse effects of climate change.[5] The result of these measures is regularly examined through the Conferences of the Parties (COP).

2.1.2 The Kyoto Protocol

At the third COP in Kyoto, Japan, in 1997 the so-called Kyoto Protocol was drafted, which commits participating industrial and transition countries to quantified reductions of their greenhouse gas emissions (i.e., carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)).[6] This protocol is the center-piece of the hitherto efforts of the UNFCCC to mitigate climate change.

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[1] The fourth and latest assessment report on the risk of climate change of the IPCC was published in 2007.

[2] For a detailed description of the events, see for example Lucht (2005).

[3] See UNFCCC (2007).

[4] See Article 2 in UNFCCC (1992).

[5] See Annex I in UNFCCC (1992).

[6] See Annex A of the Kyoto-Protocol (Kyoto, 1998).

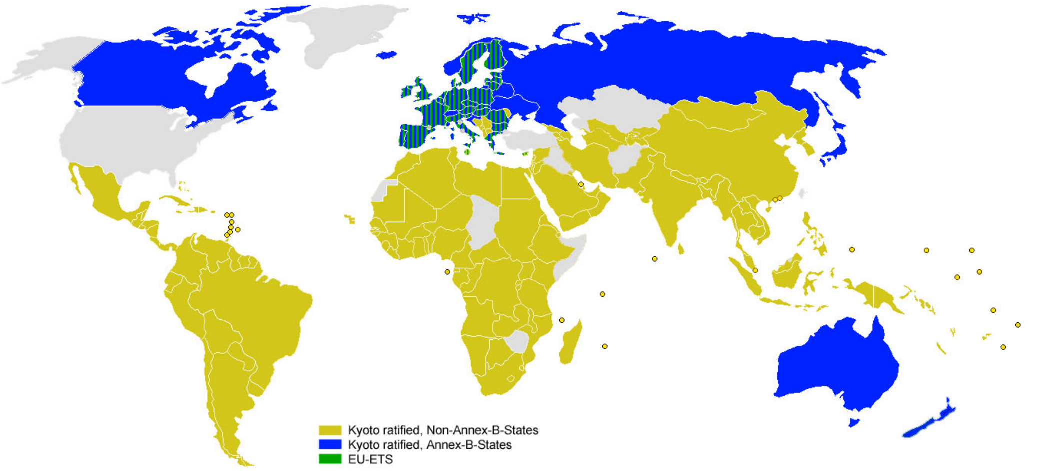

Figure 2.1: *Annex B and Non-Annex B States; states participating in the EU ETS as of Dec 2008.*

With Russia ratifying the Kyoto Protocol in November 2004, it became effective and as of 2008, 183 countries decided to participate. These countries are divided into *Annex B States* and *Non-Annex B States* (see Figure 2.1).[7] The former accepted *quantified emission limitation and reduction commitments* and the latter have no quantified commitments.[8] The Annex B States mainly consist of industrial and transition countries, e.g. the states of the European Union or Russia.[9] The Non-Annex B States mainly consist of developing countries. Since the development of emerging economies should not be endangered by the Protocol, quantified emission reduction commitments for these countries are not stipulated. Thus China and India, as Non-Annex B States, have no quantified emission reduction targets. However, these two states are responsible for a major part of the current anthropogenic production of greenhouse gas emissions, which is one main point of criticism concerning the Kyoto Protocol.

The agreed objective of the Protocol is to reduce overall greenhouse gas emis-

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[7] The states listed in Annex B of the Kyoto Protocol are almost identical to the states listed in Annex I of the UNFCCC. Hence, we will not distinguish between these groups in the following. Turkey is the only Non-Annex B State listed in Annex I of the UNFCCC. Slovenia, Liechtenstein and Croatia are Annex B States, but not listed in Annex I.

[8] See Article 3 and Annex B of the Kyoto Protocol.

[9] The United States, as the largest greenhouse gas emitter, has not ratified the Kyoto Protocol yet. See the Kyoto Protocol Status of Ratification (in UNFCCC, 2008a).

sions of the Annex B States in the period 2008 to 2012 to at least 5% below 1990 levels. Thereby, this overall reduction target is unequally allocated across the different Annex B States. For instance, the European Union (EU) is committed to reducing its greenhouse gas emissions in the period 2008 to 2012 to around 8% below 1990 levels. For achieving this overall reduction goal at lowest cost, different *Flexible Mechanisms* are enshrined in the Protocol. These mechanisms refer to International Emissions Trading (IET), the Clean Development Mechanism (CDM) and Joint Implementation (JI).[10]

International Emissions Trading

Article 17 of the Kyoto Protocol allows Annex B States to trade their rights to emit greenhouse gas emissions among themselves. In accordance with the Kyoto Protocol, each Annex B State gets a certain amount of emission allowances, which are called *Assigned Amount Units* (AAUs). Each AAU entitles an Annex B State to emit 1 ton of CO_2 or an equivalent amount of another greenhouse gas.[11] If a state has a surplus of AAUs, e.g. because of cheap emission abatement measures, it can sell these allowances to Annex B States with higher marginal emission abatement costs. This mechanism should ensure that emission abatement is always conducted in the Annex B States where it is cheapest. In Chapter 3, the economic principles and the theory behind emissions trading are explained in more detail.

Clean Development Mechanism

Another Flexible Mechanism enshrined in Article 12 of the Kyoto Protocol is the CDM. It enables Annex B States to conduct or finance CO_2-reducing measures in Non-Annex B States, e.g. reforestation or transfer of environment-friendly technologies.[12] If these measures are taken in addition to the usual emission reduction

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[10] For a detailed description of the Flexible Mechanisms stipulated in the Kyoto Protocol, see for example Betz et al. (2003).

[11] To make greenhouse gases comparable, the Global Warming Potential (GWP) was introduced. The GWP of a greenhouse gas measures which amount of CO_2 is necessary to create the same impact on the climate system as 1 unit of the regarded greenhouse gas. See Forster et al. (2007).

[12] To be more precise, CDM projects can be conducted in all countries that have ratified or acceded to the UNFCCC and are not included in Annex I of the Convention.

activities of the Non-Annex B State, the amount of abated emissions is credited to the conducting Annex B State in the form of so-called *Certified Emissions Reductions* (CERs). These CERs can be used by the Annex B State to fulfill its national emissions target. The CDM is the only Flexible Mechanism of the Kyoto Protocol that creates additional emission allowances for Annex B States. An objective of this mechanism is to transfer sustainable technologies to developing countries.[13]

In November 2008 more than 1200 CDM projects were registered and over 4200 were in the CDM registration pipeline. More than half of the registered projects are in India and China.[14] The linkage of the CDM to the European approach to reduce greenhouse gas emissions is described in Section 2.2.5.

Joint Implementation

The third Flexible Mechanism stipulated in Article 6 of the Kyoto Protocol is Joint Implementation. This mechanism allows Annex B States to finance CO_2-reducing projects in other Annex B States. If such a project results in higher emission reductions compared to business-as-usual reductions in the host state, the corresponding amount of AAUs of the host state are converted into *Emission Reduction Units* (ERUs) and transferred to the financing Annex B State. Then the financing state can use the ERUs to balance its greenhouse gas emissions. In contrast to CDMs, JIs only redistribute emission allowances between Annex B States and do not create additional ones. An objective of this mechanism is to transfer environment-friendly technologies from higher developed Annex B States to less developed Annex B States.

2.1.3 Post-Kyoto

The Kyoto Protocol is valid until 2012 and the way to a post-Kyoto agreement has not been paved yet. The parties of the UNFCCC are still negotiating a future

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[13] Voigt (2008) analyzes critical issues concerning CDM projects. According to Voigt, it is a major problem to guarantee that emission reductions are real, measurable and additional. Moreover, most current projects mainly focus on the generation of additional permits and not on the transfer of sustainable technologies.

[14] See UNFCCC (2008b).

agreement. At the moment, they only agree that further efforts to reduce greenhouse gas emissions are inevitable in order to avoid serious consequences for the world ecosystem. This is also supported by the last assessment report of the IPCC in 2007.

The objective of the 13th COP in Bali, Indonesia, in 2007 was to set up a road map for a post-Kyoto agreement involving all countries. At this conference, four pillars were defined as the foundation for a future agreement: mitigation of emissions, adaptation to climate change, technology transfer and financing (especially in the context of developing countries). Although all countries agree on the necessity of further emissions reduction, their opinions differ on many issues. For instance the European Union wants to limit global warming to 2°C and announced a minimum reduction target of 20% below its 1990 level of greenhouse gas emissions. Many island states argue that a 2°C increase is still too much and will cause serious damage in these countries. Moreover, a number of countries like the United States, Canada and Russia have reservations regarding quantified emission reduction targets. Thus, at the end of the COP in Bali, no consensus on concrete reduction goals was reached.

Besides the issue of mitigation of emissions, the participating parties in Bali also tried to find solutions for the adaptation to climate change. Especially developing countries demand assistance for adaptation, since the most serious impacts of climate change are expected to affect them. Considering this, the conference approved the final modalities for an adaptation fund. This fund will be financed by a 2% levy on transactions for CDM projects (see Section 2.1.2). Furthermore, possibilities to avoid deforestation and to improve technology transfer to developing countries were discussed at Bali. Solving these problems is still a major task for the next years on the way to establishing an international agreement to avoid climate change for the time beyond 2012.[15]

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[15] For further information on the COP in Bali in 2007, see Clémencon (2008) and Carrapatoso (2008).

2.2 The European Emissions Trading Scheme

2.2.1 National Reduction Targets

As a consequence of the Kyoto Protocol, the EU was able to establish an ambitious program to reduce greenhouse gas emissions. This program started in 2005 with a three-year *warm-up* period, followed by the first Kyoto commitment period from 2008 to 2012. The objective is to achieve the emissions reduction target stipulated by the Kyoto Protocol during the period 2008 to 2012, which is an emission level about 8% below the 1990 level. The European Union decided to apply Article 4 of the Kyoto Protocol, which allows the EU member states to fulfill their reduction targets as a group. Within the EU, the national reduction targets were redistributed. Table 2.1 shows the so-called *burden sharing* for the period 2008 to 2012 between the initial participating member states of the European Union.

The reduction targets of each member state vary from -28% for Luxembourg up to +27% for Portugal. According to Lucht (2005), the discrepancy between national reduction targets is based on the individual economic development of the different states. Thereby, different objectives like, e.g., employment, price stability and economic growth were taken into account.

Analyzing the development of greenhouse gas emissions from 1990 to 2000 reveals that the actual emission targets strongly differ from the percentages in the burden-sharing agreement. For instance, the reduction target of Germany is 21% less than in 1990. However, nearly 19% was already achieved in 2000, as many inefficient industries in Eastern Germany were shut down. This means a remaining reduction duty of 2.1%. In contrast, Spain's emissions increased as of 2000 by nearly 35%, due to economic growth. Thus, Spain faces a reduction target of nearly 20% when considering its emissions in 2000.[16]

For the period beyond 2012, the EU has decided an EU-wide emission reduction by 2020 that is at least 20% less than in 1990. As before the Commission recommend burden sharing, so that member states with low GDP per citizen and

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[16] See Schafhausen (2005).

Member State	Burden Sharing	Development 1990-2000	Difference "Burden Sharing - Status 2000"
Austria	-13.0%	+3.1%	-16.1%
Belgium	-7.5%	+6.2%	-13.7%
Denmark	-21.0%	-1.2%	-19.8%
France	0.0%	-1.7%	+1.7%
Germany	-21.0%	-18.9%	-2.1%
Greece	+ 25.0%	+23.8%	+1.2%
Ireland	+ 13.0%	+ 24.0%	-11.0%
Italy	- 6.5%	+4.1%	-10.6%
Luxembourg	- 28.0%	-45.1%	+17.1%
Netherlands	- 6.0%	+3.1%	-9.1%
Portugal	+ 27.0%	+30.1%	-3.1%
Spain	+ 15.0%	+34.8%	-19.8%
Sweden	+ 4.0%	+1.7%	+2.3%
United Kingdom	-12.5%	-12.6%	+0.1%

Table 2.1: *National greenhouse gas emission targets according to the burden sharing agreement (in % below 1990 emission levels), development from 1990 to 2000, difference "burden sharing - status 2000." Source: Schafhausen (2005).*

high expected economic growth should face lower emission targets than member states with a high GDP per citizen.[17]

2.2.2 The Hybrid Approach

In order to achieve the reduction target defined in the Kyoto Protocol at minimal costs, the EU makes use of a hybrid regulatory approach. In this approach, the EU distinguishes between firms using carbon-dioxide-intensive technologies and all other emitters, like those responsible for traffic, household and trade emissions.

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[17] See European Parliament (2008a). A detailed introduction of the European Emissions Trading Scheme beyond 2012 is given in Section 2.3.3.

The following installations are considered as carbon-dioxide-intensive by the EU legislation:[18]

- Combustion installations with a rated thermal input exceeding 20 MW
- Metal ore (including sulfide ore) roasting or sintering installations, installations for the production of pig iron or steel
- Installations for the production of cement clinker or lime
- Installations for the manufacture of glass including glass fiber
- Installations for the manufacture of ceramic products
- Industrial plants for the production of pulp and paper

These carbon-dioxide-intensive industries are assigned to a sector regulated by an emissions trading scheme, which allows firms to trade emission allowances on a Europe-wide emission permit market (referred to in the following as *Tr*-sector). Since disproportionally high transaction costs are expected for small installations, e.g. installations with less than 20 MW thermal-rated input, these are excluded from emissions trading.[19] The implementation of the European Emissions Trading Scheme is described in detail in the following Section 2.2.3.

All other emitters not participating in the Emissions Trading Scheme are subject to a mix of different policies to reduce their emissions (referred to in the following as *NTr*-sector). Examples are environmental taxes, command-and-control approaches or subsidies for abatement measures. The EU legislature leaves the decision about which policies are implemented to the member states. This means every member state decides individually on the policy instruments to regulate emissions of emitters not falling in the category of carbon-dioxide-intensive industries named in Directive 2003/87/EC. An overview of possible policies applied in the member states' *NTr*-sectors is given in Section 2.2.4.

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[18] For a more detailed description of the included installations, see Annex I of the EU Directive 2003/87/EC. In the future, aviation shall also take part in emissions trading.

[19] The impact of transaction costs on emissions trading is examined in Section 3.3. A more detailed discussion of the problem of transaction costs, especially for small- and medium-sized firms, can be found in Schleich and Betz (2004).

Under the present European Emissions Trading Law (ETL), member states had to decide in each period on the cap of emissions for the Emissions Trading Scheme. This allocation had to be in accordance with the national emissions target. Hence, the difference between the national emissions target and the amount assigned to the trading scheme remains for the other emitters not participating in emissions trading. This partitioning of a member state's total emissions to its *Tr*- and *NTr*-sector is called macro-plan. It is part of the National Allocation Plan (NAP), which each member state had to prepare in every period.[20] From 2013 on, the EU ETL changes and the partitioning of total emissions will be decided centrally by the EU.[21]

2.2.3 The Emissions Trading Sector

The EU ETL allows emitters in the *Tr*-sector to trade *European allowances* (EUAs) on a Europe-wide market for CO_2 emissions. Similar to the Flexible Mechanism of International Emissions Trading in the Kyoto Protocol, the European approach should guarantee that emission abatement takes place where it is cheapest. The member states define the initial allocation of emissions to the firms within their jurisdiction in the micro-plan, which is also part of the NAP (see Figure 2.2). However, the European Commission has a veto right if the allocation contradicts EU primary law. For the micro-plan the EU ETL sets certain limits: In the first period (2005-2007), at least 95% of the emission permits had to be allocated for free and only a maximum of 5% could be auctioned. Mentionable is that nearly no member states made use of this option during the first period.[22] In the second period (2008-2012), at least 90% of the total amount of emissions had to be allocated for free and a maximum of 10% could be auctioned. However, again only a number part of permits were auctioned. In future periods, free allocation will be further reduced (see Section 2.3.3).

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[20] In cases where the allocation for the EU Emissions Trading Scheme (ETS) seemed to be overly generous, the EU was allowed to interfere. This was the case in the second trading period. See European Commission (2007a) and European Commission (2007b).

[21] For a detailed introduction to the European Emissions Trading Scheme beyond 2012, see Section 2.3.3.

[22] See e.g. Betz et al. (2004) and Buchner et al. (2006).

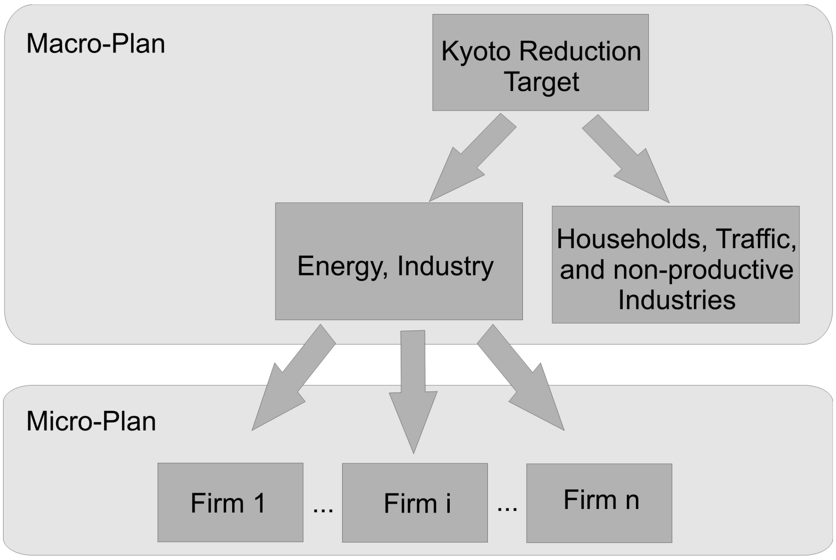

Figure 2.2: *The macro- and micro-plan as part of the National Allocation Plan.*

The EU ETL does not exactly specify how to allocate emissions for free. The most common options are to allocate emission rights based on historic emissions, *grandfathering*, or based on historic output, *benchmarking*. In both cases a basic amount of emissions e_i^0 is assigned to each emitter i in the trading sector. Under grandfathering, this basic amount corresponds to the historic emissions of the emitter in a certain time period. In cases involving benchmarking, the basic amount of emissions is calculated by multiplying the historic output of the emitter with a benchmark (e.g., average emissions per output unit). Then the total sum of basic emissions $\sum_i e_i^0$ is compared with the emissions cap of the trading sector E_{Tr} in the macro-plan, in order to define the compliance factor $\beta = E_{Tr}/\sum_i e_i^0$. The amount of emissions emitter i gets for free is therefore $\beta \cdot e_i^0$.[23] Usually, the NAPs modify the basic (grandfathering or benchmarking) approach to take factors like new entrants, closures, process-related emissions or early actions into account. Early actions describe investments of firms in abatement measures prior to the relevant period for historic emissions. Under grandfathering, such early actions result in fewer emission permits for the firms. To compensate this dis-

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[23] See Graichen and Requate (2005).

advantage of timely investments, some member states allocated extra permits for early actions.[24]

The accounting periods of the Emissions Trading Scheme are on a yearly base. Each year (until the end of February), member states hand out the corresponding emission permits determined by the NAPs to the firms. By the end of April, emitters must submit an amount of permits covering their emissions from the previous year.[25] The transfer of emission rights from one period to the next, called *banking*, is possible without any limits from the second period on. Between the first period, 2005-2007, and the second period, 2008-2012, it was not allowed to bank permits.[26] Since permits are valid for a whole period, banking is possible during a period. In contrast, *borrowing*, i.e., the transfer of permits from future periods to the current period, is not possible. Within one period, some kind of borrowing can be practiced, because the allocation of permits takes place before the permits for the emissions from the previous year must be submitted.[27]

Besides the allocation mechanism, the EU ETL allows member states to decide on further options. One option was the so-called *opt-out* rule. It enabled member states to relieve installations from participating in the Emissions Trading Scheme during the first period, if they were regulated by other appropriate environmental policies. In contrast, the *opt-in* rule enables member states to expand emissions trading to installations not named in the Emissions Trading Directive. During the first period it was allowed to include small installations from sectors already assigned to emissions trading. Starting with the beginning of the second period in 2008, installations from other sectors and greenhouse gases other than carbon dioxide can be included in the Emissions Trading Scheme. A third option for member states is to permit firms to *pool* their activities and act as one participant on the permit market. This option is restricted until 2012.[28]

In addition to firms in the emissions trading sector, every legal person can take part in emissions trading, i.e., every legal person can buy, sell or hold permits.

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[24] See Betz et al. (2004).

[25] See Article 12 and 13 of the EU Directive 2003/87/EC.

[26] See Convery et al. (2008).

[27] The economic effects of inter-temporal trade are briefly investigated in Chapter 3.

[28] See Articles 24, 27, and 28 of the EU Directive 2003/87/EC. Possible consequences of pooling under imperfect competition are analyzed in Chapter 6.

For the trade process, no limits are given by the EU ETL: bilateral contracts, exchanges, or over-the-counter-trade are possible.[29]

In case a firm is not able to submit the corresponding amount of permits to cover its emissions from the previous year by end of April, it has to pay a fine. During the first period, 2005-2007, the fine was 40 € per ton of uncovered CO_2 emissions, and from the second period onwards 100 € per ton of CO_2 has to be paid. Additionally, firms falling short of permits have to hand the missing permits in the following year.[30]

To cover their emissions, firms can also use the Flexible Mechanisms CDM and JI of the Kyoto Protocol in a limited way. The linkage of the European Emissions Trading Scheme to the Kyoto Flexible Mechanisms is described in Section 2.2.5.

2.2.4 Regulation outside the Emissions Trading Scheme

To achieve the emission targets stipulated by the Kyoto Protocol, member states must also make an effort to abate emissions outside the Emissions Trading Scheme. Since the national implementation is not regulated by the EU ETL, the applied measures differ between member states.[31] This section describes the German approach to give an idea about which environmental policies are applied for reducing greenhouse gas emissions apart from the trading scheme.[32]

According to the German NAPs, for the first and second period the emissions of the German *traffic sector* are regulated through a mix of different instruments. Examples named in the NAPs are:

- the ecological fuel tax
- the motorway charge for heavy goods vehicles

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[29] Besides spot markets for permits, Uhrig-Homburg and Wagner (2008) state that also active markets for futures and more complex derivatives are expectable.

[30] See Kruger and Pizer (2004).

[31] See Betz et al. (2004).

[32] See BMU (2004) and BMU (2006).

- an emission-based vehicle tax
- promotion of renewable energy sources for fuels
- promotion of non-sulfurous fuels
- subsidies for vehicles with low fuel consumption

Emissions of the German *household sector* are reduced through different programs financed by the KfW, a public law institution, and other measures and funding programs:

- the CO_2 reduction program (KfW)
- the CO_2 building redevelopment program (KfW)
- the housing modernization program (KfW)
- diverse qualification programs for constructors and homeowners
- promotion of innovations in the area of energy efficiency
- adjustment of the German Condominium Act

For the sectors *trade* and *non-productive industries*, the German government has not implemented any further measure to reduce greenhouse gas emissions.[33]

2.2.5 Linkage to the Kyoto Flexible Mechanisms

The EU and its member states can reduce their emission reduction commitments from the burden-sharing agreement by gaining additional rights to emit greenhouse gases from the Kyoto Flexible Mechanisms. The Flexible Mechanisms, as described above, are International Emissions Trading, the Clean Development Mechanism and Joint Implementation.

The different possibilities for member states and firms to apply the Flexible Mechanisms are visualized in Figure 2.3. The European governments can trade

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[33] See BMU (2006).

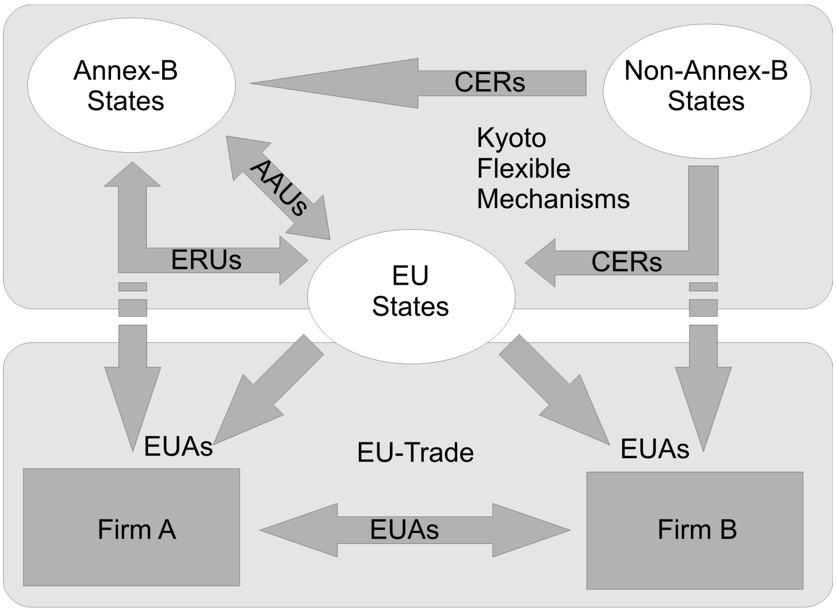

Figure 2.3: *Linkage of the EU ETS to the Kyoto Flexible Mechanisms. (Taken from Lucht, 2005. With kind permission from Springer + Business Media.)*

emission rights (AAUs) with other Annex B States, i.e., they can buy or sell emission rights on an international permit market. Another possibility is that European member states can conduct emission reduction measures in other states and get additional permits (ERUs or CERs) in this way.

Besides the possibility for member states to obtain additional permits, the *EU Linking Directive* also allows firms assigned to the Emissions Trading Scheme to obtain emission rights from the Kyoto Flexible Mechanisms.[34] With the beginning of the first trading period, 2005-2007, firms could use CERs from CDM projects to cover their emissions. Since 2008, firms are also allowed to use ERUs from JI projects. Through these mechanisms, the EU ETS is implicitly linked to the international markets for emission rights.[35]

An important issue in the context of the use of Flexible Mechanisms is the so-called *supplementary requirement* stipulated by the Marrakesh Accords and the Kyoto Protocol. It states that “the acquisition of emission reduction units shall be

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[34] See EU Directive 2004/101/EC.

[35] In the future, the EU ETS will also be linked to the national emissions trading systems in Norway, Iceland and Liechtenstein. See European Commission (2007c).

supplemental actions" and that any emissions "trading shall be supplemental to domestic actions."[36] This means governments are not allowed to buy themselves off from emission reductions and the main abatement measures must occur within each country. However, there is no quantitative definition of the supplementary requirement, therefore the EU member states have to define a maximum amount of additional credits from CDM and JI in their NAPs. In the second trading period, the number of CDM and JI credits from the Flexible Mechanisms in the ETS has been limited to around 1400 million tons.[37] In the original proposal for the Linking Directive, a review was suggested if the use of CDM and JI credits reaches 6% of total emissions in the ETS. Then the EU could set a limit of, e.g., 8%.[38] Also for future periods, the EU ETL foresees quantitative limits for the use of permits from Flexible Mechanisms.[39]

The supplementary requirement is crucial for the assumptions of the economic analysis in this work. The following models assume that the NAPs determine the scarcity of emission rights. In the institutional framework of the EU ETS, this is true since the allocation to the trading sector plus the limited amount of permits from Flexible Mechanisms gives the maximum amount of permits available on the European permit market. Without the supplementary requirement, the NAPs would not determine the scarcity of emission rights, since firms could buy as many permits on international markets for CERs and ERUs as they want. Thus, the European permit price would only be determined by the international prices for CERs and ERUs, if they are sufficiently cheap.

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[36] See Article 6(1) and Article 17 of the Kyoto Protocol.

[37] See Convery et al. (2008) and European Commission (2008a). According to estimations in the proposal for a review of the EU ETL (European Commission, 2008a), the limit for credits from Flexible Mechanisms in the second period is possibly so weak that total emissions in the EU ETS can even increase.

[38] See S. Peterson (2006).

[39] See the description of the EU climate package in Section 2.3.3.

2.3 Practical Results and Consequences from the First Trading Period

2.3.1 The NAPs 2005-2007

This section analyzes the experiences from the EU ETL during the first trading period, 2005-2007. Therefore, we will describe the NAPs and discuss possible lessons and consequences thereof.

As mentioned above, the macro-plans, as part of the NAPs, determine the amounts of emissions for the *Tr*-sectors. Comparing these allocations with the national emission caps from the burden-sharing agreement yield the remaining amounts of emissions for the *NTr*-sectors, as shown in Figure 2.4.[40] Figure 2.4 also compares the NAPs of the first period with the business as usual (BaU) emissions in 2005.[41] It reveals that the emissions caps from the burden-sharing agreement do not exceed business as usual emissions. The distribution of emissions between the *Tr*- and *NTr*-sectors shows that most member states set only weak emission reduction obligations for their *Tr*-sectors. Some states, like Italy, even assigned more emission permits to their *Tr*-sectors than expected business as usual emissions. As a consequence these macro-plans yield very strong emission reduction obligations for most *NTr*-sectors to achieve their Kyoto targets.[42]

The resulting total cap of emissions for the trading scheme was 2.1 billion tons of CO_2 per year.[43] Existing literature on the macro-plans of the first period agree that this cap was too generous (see Betz et al., 2004, Böhringer et al., 2005,

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[40] In the first period, the commitments due to the burden-sharing agreement need not be fulfilled by the member states. However, the NAPs must be consistent with a path toward achieving each member state's emission targets for 2008-2012. See Annex III of the EU Directive 2003/87/EC. Nevertheless, for the analysis in this subsection, we compare the first period NAPs with the emission caps under the burden-sharing agreement. Figure 2.4 only represents CO_2, which is by far the most important greenhouse gas.

[41] Business as usual emissions in this context means the expected emissions without any regulation. The data are taken from an estimation in Böhringer et al. (2005).

[42] Anger et al. (2006) argues that such a differentiation between sectors is probably the result of lobbying.

[43] See Convery et al. (2008).

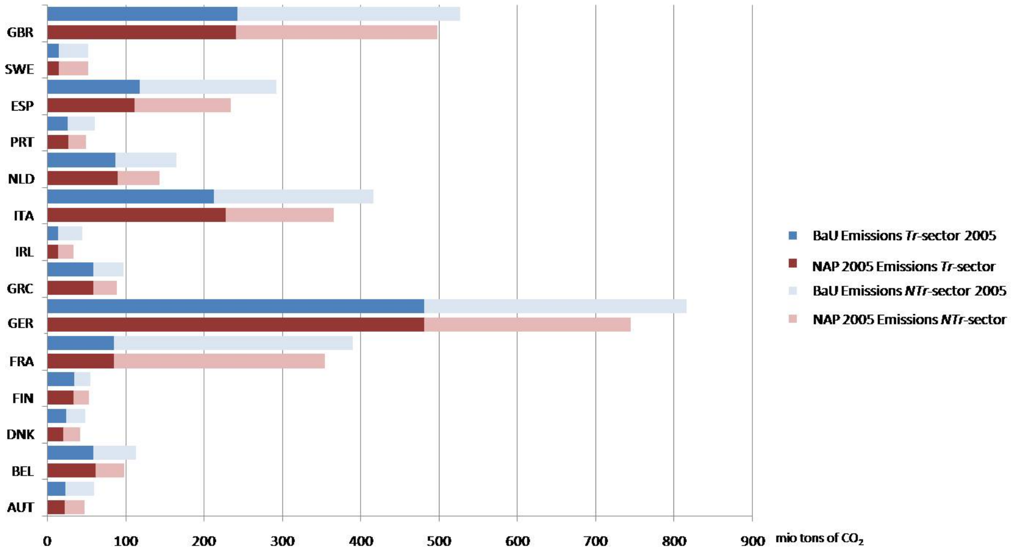

Figure 2.4: *Comparison of the NAPs 2005-2007 with the business as usual emissions in 2005 based on data from Böhringer et al. (2005).*

Klepper & Peterson, 2006, S. Peterson, 2006, and Ellerman & Joskow, 2008). Some studies even stated that the trading sector received an *overallocation* of emission rights. Thus, the estimated value of emission permits in the period 2005-2007 was zero.[44]

For emitters outside the Emissions Trading Scheme the first period allocations mean strong emission abatement efforts considering the Kyoto targets. Böhringer et al. (2005) estimate that, for example, an emission tax rate of around 50 € per ton CO_2 would be necessary for the German *NTr*-sector to achieve its reduction target. In order to compare this estimation with the actual burden for the traffic sector, we investigate the ecological fuel tax on gasoline and diesel in Germany. Referring to Germany's NAP, this is one instrument to reduce greenhouse gas emissions in the *NTr*-sector. Assuming this tax is only used to internalize the negative effects

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[44] See Böhringer et al. (2005). The estimation of a permit price of zero in the first trading period is confirmed by the European Energy Exchange (EEX) in Leipzig, which denoted the permit price per ton CO_2 below 0.10 € at the end of 2007. See also Section 2.3.2.

of CO_2, it is equivalent to a carbon dioxide tax of around 65 €/t_{CO_2} for gasoline and 58 €/t_{CO_2} for diesel.[45] [46]

These thoughts support the assumption that an allocation similar to that in the first period results in much lower costs per ton of CO_2 for firms in the *Tr*-sector than for emitters in the *NTr*-sector.[47]

The second part of the NAPs, the micro-plan, determines the allocation of emissions to the individual firms in the *Tr*-sector. As mentioned above, nearly no member state made use of the option to auction 5% of its emission rights. Only four states applied auctions in the first period, which means that only 0.13% of the total amount of permits was auctioned.[48] For the free allocation, grandfathering was mainly applied. Benchmarking was only used in few a cases, although it had been strongly promoted. Furthermore, all member states have set up a reserve of permits for new entrants and, in most member states, closed installations must forfeit post-closure emission permits.[49]

One main point of criticism in the first period was the so-called *windfall profits* caused by the free allocation. Although the permits were allocated for free, firms pass on the permit price to the consumers. Since emission permits have a market value, firms consider the opportunity costs of using the permits to cover their emissions. If they use permits for production, they lose the opportunity to

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[45] Of course the ecological fuel tax is also used to reduce other negative effects from traffic, like noise or respirable dust. However, there are additional regulatory instruments used in the traffic sector (see Section 2.2.4). We simplify assume that other negative externalities are regulated by these additional policies.

[46] The ecological fuel tax on gasoline and diesel in Germany is 15.34 cents/l. (See Umweltbundesamt, 2002.) Since one liter of gasoline creates around 2.37 kg CO_2 and one liter of diesel creates around 2.65 kg CO_2, the tax rate is equal to a carbon dioxide tax of 65 €/t_{CO_2} for gasoline and 58 €/t_{CO_2} for diesel.

[47] According to the analysis of Betz et al. (2006) and Neuhoff et al. (2006), also the proposed NAPs for the second trading period include too generous allocations for the *Tr*-sectors and would lead to disproportionately high efforts for the *NTr*-sectors. Thus, the European Commission intervened and enforced stricter emission targets for the ETS, see e.g. European Commission (2007a) and European Commission (2007b). For the actual emissions caps of the *Tr*-sectors for 2008-2012, see European Commission (2007a).

[48] According to Ellerman and Joskow (2008) in the second period, 2008-2012, 3% of total emission permits in the *Tr*-sector were auctioned.

[49] See Betz et al. (2004), Buchner et al. (2006) and Convery et al. (2008).

sell them. Hence, it is economically rational to pass on the permit price to the consumers. Especially in the power supply sector, this effect led to higher prices for consumers and to significantly higher profits for some firms.[50] [51]

2.3.2 Performance of the Permit Market

Every transfer of emission permits between firms in the ETS has to be recorded by national registries. With the first national registries entering into operation in the beginning of 2005, the spot market was launched. In 2005 already five market places for emission permits were established, e.g. the European Energy Exchange (EEX) in Leipzig. Nonetheless, over-the-counter markets were the dominant form of trading in the first period. The value of transactions in the first year, 2005, were relatively low at 262 million tons. In 2006 the trade volume increased to 809 million tons and in 2007 already 1500 million tons of CO_2 were traded.[52]

In 2005 the average price per ton CO_2 was around 22 €. Thus, it was much higher than expected because of the generous allocation to the *Tr*-sector. With this average price, the value of transactions was 5.97 € billion in 2005. In 2006 the value of transactions reached 15.2 € billion and 24.1 € billion in 2007. With these transaction volumes, the EU ETS is by far the largest environmental market in the world.[53]

Figure 2.5 shows the price development of first period emission permits on the spot market at the energy exchange in Leipzig, Germany. When the spot market in Leipzig was launched, the permit price fluctuated around the first year average price of 22 €. In April 2006 the permit price increased to nearly 30 € before the market collapsed and the price crashed to 10 €. After a short stabilization around 15 € per ton of CO_2, the price steadily decreased to 0.01 € at the end of the first trading period.

According to Convery et al. (2008), the first market period was characterized

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[50] See Ellerman and Joskow (2008).

[51] In Chapter 6 it is shown that under imperfect competition, also permit trading without free allocation can lead to higher profits.

[52] See Convery et al. (2008) and Ellerman and Joskow (2008).

[53] See Capoor and Ambrosi (2007).

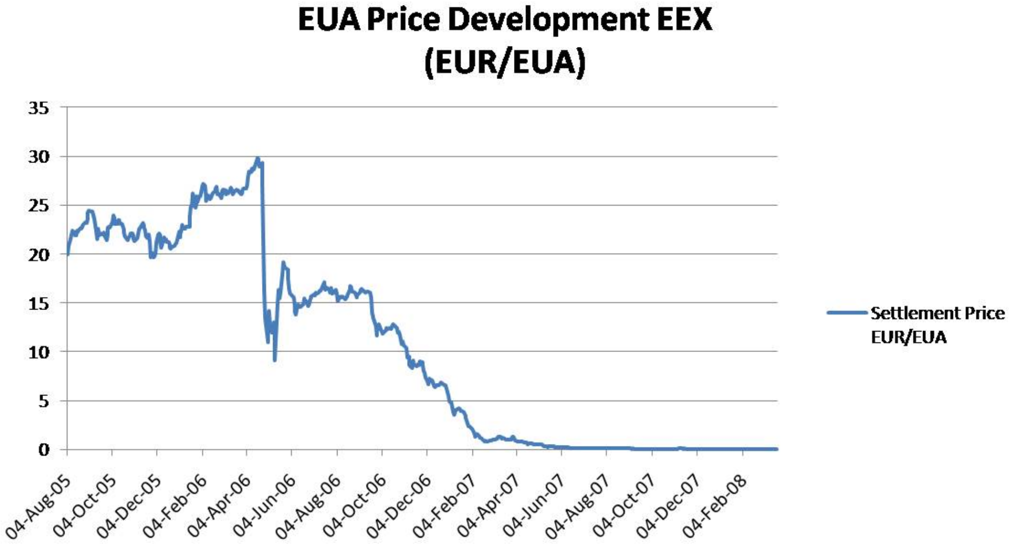

Figure 2.5: *Price development for first period EAUs on the spot market at the EEX in Leipzig from 2005 to 2008. Data taken from the EEX.*

by three stages. In the first stage, the launch period (Jan. 2005 - Apr. 2006), the power sector immediately started to buy permits to cover its emissions on a daily basis. However, at this stage most other market participants were not prepared to trade permits. Since at the same time demand for electricity increased during the winter, this created a scarcity of permits and led to unexpectedly high prices. The second stage was the information shock in April and May 2006, when the European Commission published the 2005 emissions data for the EU ETS. This data revealed a 4% surplus of emission allowances for the first trading year. Thus, the supposed scarcity of permits turned out to be a surplus and the permit price abruptly decreased to 10 €. In the last stage since November 2006, Convery et al. see the total disconnection between the first and second period prices. Since first period EUAs were not transferable to the second period, the surplus of allowances caused a converge of the permit price toward zero.[54] The permit prices for second

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[54] In a simulation with participants from companies that take part in the real EU ETS, Ehrhart et al. (2005) and Schleich et al. (2006) show that a ban of banking leads to a complete price collapse at the end of the first trading period.

period futures was, until October 2008, relatively constant at around 25 € per ton of CO_2.[55]

2.3.3 The EU Climate Package

Based on the lessons from the first period the European Commission reviewed the current ETL. In January 2008 the Commission set up a climate package which proposes some modifications for the periods beyond 2012. In December 2008 the European Parliament approved the proposal of the Commission as amended.[56] In the following, we describe the corner pillars of the climate package.

The European greenhouse gas reduction target for 2020 is 20% below 1990 emission levels. In cases where there is an international environmental agreement for the time beyond 2012, the EU agrees to tighten its reduction target to 30% below 1990 emission levels. The supposed modifications for the EU ETS foresee an extension of the trading periods to eight years, i.e., a third trading period from 2013 to 2020. To achieve the European reduction goal of 20% in 2020 and to increase reliability in the ETS, the emissions cap should be linearly reduced by 1.74% per year.[57]

To avoid windfall profits, the possibility of free allocations should be abolished in the future. With the beginning of the third trading period in 2013, 100% of the permits for the power supply sector should be auctioned. However, especially for the new member states, there is an exception for a transitional free allocation, which must not exceed 70% and must decrease to 0% in 2020.[58] For all other emitters in the ETS, 20% of the emission permits should be auctioned in 2013. This share increases to 70% in 2020, and in 2027 no free allocation should be possible anymore. For sectors at risk for carbon leakage — that is the reloca-

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[55] See e.g. the European Energy Exchange in Leipzig.

[56] See European Parliament (2008a).

[57] See European Commission (2008a).

[58] See European Parliament (2008a). According to Pletsch (2008) the German power supply industry disapproved of a 100% auctioning of permits in 2013 and lobbied for a gradually increase of the share of auctioned permits.

tion of production to third countries with less strict climate policies — there are exceptions that allow for a free allocation until 2020.[59]

Through weak limits for the use of credits from JI or CDM projects in the second period, there might be an oversupply in the EU ETS. Therefore, the climate package suggests the transferability of such credits to the third trading period. According to the proposal of the European Commission, a limit for the use of credits from Flexible Mechanisms in the *Tr*-sector should also be maintained in the future. In case the overall reduction target increases from 20% to 30% due to a post-Kyoto agreement, the amount of credits from outside the EU should be adjusted to the more restrictive reduction targets.

In the first and second period, the allocation between the *Tr*- and *NTr*-sectors, the macro-plan, was decided individually by the member states. The EU climate package foresees a modification of the EU ETS so that this allocation will be decided centrally by the EU. The future caps for the EU member states' *NTr*-sectors can be found in Table 2.2. Denmark, Ireland and Luxembourg have the strongest emissions reduction target of 20% below 2005 emission levels of their *NTr*-sector. The Bulgarian *NTr*-sector has the weakest emissions cap of 20% above 2005 emission levels of its *NTr*-sector. Analogous to the burden-sharing agreement, the economic situation and the expected development of the states were taken into account defining the national emission caps.[60]

For member states, the use of credits from JI and CDM projects to cover the emissions of their *NTr*-sectors should also be possible in the future. However, the new EU ETL stipulates that until a post-Kyoto agreement is established, the use of credits from outside the EU should be limited to 3% of the member state's *NTr*-sector's emissions in 2005. Certain member states with stricter targets will be able to use additional credits from outside the EU amounting up to 1% of their 2005 emission. After a post-Kyoto agreement, the caps for the use of credits from JI and CDM projects should be increased to half of the additional emissions reduction effort due to the international agreement.

For the analyses in the following chapters, it is important that also after the

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[59] See European Parliament (2008a). The European Commission proposed a 100% allocation in 2020. See European Commission (2008b).

[60] See European Parliament (2008b).

Member State	Reduction Target	Member State	Reduction Target
Belgium	-15%	Luxembourg	-20%
Bulgaria	20%	Hungary	10%
Czech Republic	9%	Malta	5%
Denmark	-20%	Netherlands	-16%
Germany	-14%	Austria	-16%
Estonia	11%	Poland	14%
Ireland	-20%	Portugal	1%
Greece	-4%	Romania	19%
Spain	-10%	Slovenia	4%
France	-14%	Slovakia	13%
Italy	-13%	Finland	-16%
Cyprus	-5%	Sweden	-17%
Latvia	17%	United Kingdom	-16%
Lithuania	15%		

Table 2.2: *Emission caps for the member states' NTr-sectors up to 2020, relative to 2005 emission levels. Source: European Parliament (2008b)*

described modifications of the EU ETL, the total amount of permits within the EU ETS is still limited. This means that the EU determines the scarcity of emission rights and, therefore the permit price, through the allocation of emissions. In cases where there is a completely open system, i.e., no limits for the use of credits from JI and CDM projects exist, the EU would have no possibility to control scarcity and the permit price would be solely determined by the prices on the international markets for ERUs and CERs, if they are sufficiently cheap.

2.4 Other Environmental Trading Schemes

Besides the European Emissions Trading Scheme, there are two mentionable cap-and-trade programs in the US: the SO_2 trading program (Acid Rain), which started in 1995, and the regional NO_x trading program, which started in the late 1990s. Both programs are briefly described in the following.

2.4.1 The Acid Rain Program

The US Acid Rain program was set up to cap SO_2 emissions of fossil-fuel-burning power plants. The program covers approximately 3000 installations in 48 states and is divided into two phases: phase I lasted from 1995 to 1999; phase II started in 2000 and will continue indefinitely.

In contrast to the current EU ETS, the caps in the SO_2 trading program are determined centrally by the Congressional legislation. Thereby, the required total emissions reduction of 50% is more ambitious than in the EU ETS.[61] Simliar to the European approach, nearly all emissions were allocated for free; only a 2.8% segment was auctioned. The free allocation to the individual firms in the trading scheme was based on the historic fuel input in the mid-1980s multiplied by an emissions performance standard. Also similar to the EU ETS, permits are bankable. Since the cap is centrally determined and the allocation rules are regulated by federal law, the states in the US SO_2 trading program are more or less invisible. This is a main difference to the current EU ETS, in which allocation decisions are left to the member states.[62]

According to Carlson et al. (2000), the potential cost savings of emissions trading compared to a command-and-control approach with a uniform emission rate standard are around \$700-\$800 million per year. Ellerman et al. (2000) estimates that the US trading program leads to 50% lower costs than a command-and-control approach.

2.4.2 The US NO_x Program

The US NO_x program was the world's first multilateral cap-and-trade program. It is a partnership between federal and state governments and evolved over time.

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[61] See Ellerman and Buchner (2007), and Ellerman and Joskow (2008).

[62] See Ellerman (2003) and Kruger and Pizer (2004).

In 1999, nine states and the District of Columbia launched the trading scheme, and in 2005 over 20 states participated. In addition to the power suppliers, also petroleum refineries, pulp and paper plants, and steel plants are included.[63]

Due to its decentralized structure, the US NO_x trade program is more similar to the current EU ETS than the Acid Rain program. Although a central authority, the US Environmental Protection Agency assigns the emission budgets to the states, and the states are free to allocate emissions to installations within their jurisdiction without further review. This leads to significant differences between the allocation mechanisms in some states.[64]

Since important industries in the US NO_x program and the Acid Rain program, consist of only a few firms, e.g. the power supply industry, the results of the following analyses on emissions trading under imperfect competition can also be of importance for the US trading programs.

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[63] See Aulisi et al. (2005) and Kruger and Pizer (2004).

[64] See Ellerman and Joskow (2008).

Chapter 3

The Economics of Emissions Trading

This chapter provides a brief introduction to the economics of emissions trading. The main focus of this survey is on the impact of competition intensity on related markets. Section 3.1 describes the idea behind an emissions trading scheme and gives an overview of the basic concepts, which show that under perfect conditions, emission abatement via tradeable permits is cost efficient. In Section 3.2 the impact of market power on an emissions trading scheme is analyzed. We distinguish between market power on the permit market and market power on commodity markets. In the last subsection, we suppose that firms possess market power on both markets. Section 3.3 focuses on transaction costs, imperfect monitoring and uncertainty as other possible reasons for market distortions. Section 3.4 depicts some special concerns of emissions trading in the context of international trade.

3.1 Efficient Emission Abatement via Tradeable Permits

Finding ways to regulate negative externalities and to achieve a welfare optimal use of the resources is a major task of economic theory. It is a well-known result that, in cases involving competitive firms, a polluting resource is socially optimally used if all emitters have equal marginal abatement costs and marginal abatement costs equal marginal social damage.

The first approach to regulate negative externalities, like greenhouse gas emissions, through market-based instruments is developed by Pigou (1877-1959). According to the so-called *Pigouvian rule*, an optimal tax for pollution must be equal to marginal social damage. Since competitive firms equalize their marginal abatement costs to the price of pollution, such a tax satisfies the conditions for a socially optimal use of a polluting resource in a decentralized way.

Coase (1960) promotes in his seminal work that if property rights are made explicit and transferable, the market can assure the optimal allocation of the resource. Crocker (1966) and Dales (1968) applied the idea of Coase to environmental problems. By making property rights explicit, pollution is capped and becomes a limited resource. According to Coase, the market should then guarantee the optimal use of this resource. Montgomery (1972) formally proves that for a uniformly mixing pollutant, like CO_2, an emissions trading scheme leads to a socially optimal allocation of the limited resource.[1] Similar to an environmental tax, all firms equalize their marginal abatement costs to the permit price. Thus, all polluters have the same marginal costs and also total marginal costs equal the permit price. If the total amount of emissions in the trading system is set in a way that the resulting permit price is equal to the Pigouvian tax, both approaches lead to the same outcome.

Another important result of Montgomery's model is that the permit market equilibrium is independent of the initial allocation of permits. Hence, the regulator does not need any information about the individual firms, which is a significant advantage compared to a tax scheme. Setting the right tax rate to achieve a given emission reduction target requires complete information about all emitters for the regulator.

However, the assumptions in Montgomery's model are very restrictive. Firms are assumed to be perfectly competitive and Montgomery also abstracts from any

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[1] In cases where there is a non-uniformly mixing pollutant, Montgomery (1972) distinguishes between permits to pollute and permits to emit, whereas he shows that permits to pollute are easier to handle for the regulator.

kind of market distortion, like, for example, transaction costs. In the following sections of this chapter, it is shown that diminishing these assumptions leads to distortions of the permit market and inefficient outcomes.

This first approach of Montgomery to formally analyze emissions trading is also restricted to a static framework. Cronshaw and Kruse (1996) extend the model to a temporal setting. They show in a time-discrete framework that if banking of permits is allowed, equilibrium in the permit market leads to the lowest costs for achieving a given reduction target. Rubin (1996) analyzes permit trading in continuous time through the use of optimal-control theory and confirms the result of Cronshaw and Kruse; the equilibrium solution equals the least-cost solution of a social planner. In contrast Kling and Rubin (1997) show that if the time of pollution is of importance for social damage, a permit trading scheme with free banking and borrowing does not necessarily lead to a socially optimal solution.

3.2 Tradeable Permits and Market Power

In this section, the impact of market power on an emissions trading scheme is investigated. Thereby, we first analyze the impact of market power on the permit market, which is the focus of Section 3.2.1. Section 3.2.2 gives a survey on the literature on imperfect commodity markets and environmental policies. The presented models in Section 3.2.3 assume both market power in the permit and commodity market.

3.2.1 Market Power on the Permit Market

With his seminal paper, Hahn (1984) was the first who analyzed the impact of market power on the permit market. He assumes that one firm is the price setter on the permit market and all other firms are price takers. The price-setting firm anticipates the behavior of the price takers and has an incentive to set a lower (higher) permit price compared to the optimal price if it is a net permit buyer (seller). This leads to an inefficient outcome and higher total emission abatement costs. The model also shows that the behavior of the dominant firm depends on the initial allocation. Only if the initial allocation equals the desired emissions level of the dominant firm, the firm would not take part in emissions trading, and thus an efficient outcome is achieved. The problem is that the regulator needs complete information on all firms to determine the optimal initial allocation for the dominant firm. This means that the advantage of an emissions trading scheme compared to a tax approach disappears. Westskog (1996) confirms the results of Hahn's model for n price-setting polluters.

In Maeda (2003) the number of price-taking agents is infinitely large. Based on this assumption, he shows that only if a firm has an excess of permits compared to BaU emissions that exceeds the net shortage in the permit market, the firm can enforce a permit price above the competitive level. Hagem and Westskog (2006) suggest an allocation rule where permits are allocated twice during the trading period. Depending on the deviation between the observed permit price on the market and the optimal permit price, the second allocation is adjusted. Such an allocation mechanism could ensure a cost-efficient solution and the favored distribution of costs between firms.

Hagem and Westskog (1998) analyze the model of Hahn in a temporal setting. They show in a two-period model with banking and borrowing that a dominant firm with an excess of permits sells too little compared to the cost-efficient solution. Only if the regulator allocates the efficient emission levels to the dominant firm would the firm not take part in permit trading and a cost-minimizing solution is achieved. In all other cases, the resulting permit price is too high. As an improvement, Hagem and Westskog suggest durable permits, which are all allocated in the first period. However, such a durable permit system cannot eliminate the negative effects of market power, but at least it reduces adverse effects in many cases. Hagem and Westskog (2005) show that prohibiting borrowing of emission permits probably increases the ability of the dominant firm to exploit its market power. Liski and Montero (2006) show in a dynamic setting with banking that negative effects from a large firm with market power on the spot market are reduced if an active forward-market exists or if permit holdings are imperfectly observable.

3.2.2 Market Power on Commodity Markets

The impact of imperfect commodity markets was mainly analyzed in the context of environmental taxation in the beginning. Later, the research on this topic was extended to permit trading. Hence, we first give a survey on environmental taxation of monopolies and oligopolies, especially as the results are of major importance for the analysis of the optimal allocation of emission permits under imperfect competition in Chapter 4.

Buchanan (1969) was the first who questioned whether the Pigouvian tax rule is adequate in cases where there is a monopoly, since there are two distortions: one due to monopolistic underproduction and the other due to the negative externality. He arrived at the conclusion that a Pigouvian tax, i.e., a tax equal to marginal social damage, is not sufficient and even shows that such a tax can decrease social welfare. This is the case because the Pigouvian rule does not account for both diseconomies in the market. Misiolek (1980) and Barnett (1980) analyzed the issue of monopoly taxation in a more formal way and derived a rule for an optimal taxation of the externality. Misiolek (1980) shows in a model with constant marginal costs and no abatement technology, i.e., emissions are constant with the output level, that the corrective tax leads to a welfare optimal outcome. Barnett (1980) shows in a more general model that an environmental tax as a single instrument can in most cases only achieve an optimal second-best trade-off between distortions. In all cases, the resulting optimal tax for a monopoly is less than the marginal social damage and can even be negative, i.e., a subsidy.

The first analysis of emission taxes for a Cournot oligopoly was conducted by Levin (1985). He focuses on the comparative statics of an increasing emission tax and does not consider a second-best tax rule in his model. His main result is that an increasing emission tax cannot guarantee a reduction in emissions for asymmetric Cournot oligopolies. Conrad and Wang (1993) show that total firms' profits can increase due to an increasing emission tax. Carrao and Soubeyran (1996) also analyze the comparative statics of an increasing emission tax in a more general approach. They confirm the result that firms can benefit from an increasing emission tax. A higher tax, of course, increases firms' costs. However, total industry output always decreases with an increasing tax and therefore the output price increases. Thus, there are two counteracting effects on firms' profits. The overall effect is ambiguous.

Ebert (1992) discusses a welfare optimal second-best emission tax rule for symmetric Cournot and symmetric conjectural variations oligopolies. Eberts' results are in line with the knowledge about the optimal emission tax for monopolies. He shows that for a symmetric oligopoly, the second-best emission tax is always lower than marginal environmental damage and therefore lower than the tax given by the Pigouvian rule. Simpson (1995) was the first to develop a second-best emission tax rule for asymmetric oligopolies. However, his analysis is restricted to duopoly markets and firms with constant marginal production costs. The main contribution of Simpson is that an optimal second-best emission tax is not necessarily lower than marginal social damage. If firms are asymmetric, an optimal taxation can also be higher than marginal social damage. This can be explained by an increase in social welfare due to a shift of production from the less to the more efficient firm.

In Carlsson (2000) the model of Simpson (1995) is extended by the possibility of investments in abatement technologies before production. For most cases, the welfare optimal emission tax is still below marginal social damage, only if firms use very different technologies the optimal tax exceeds marginal damage. Yin (2003) extends the models of second-best taxation of symmetric oligopolies for the case of additional externalities between producers. If the negative externality from pollution between the producers is sufficiently strong, the second-best tax exceeds marginal damage. Runkel (2004) investigates the optimal emission tax in an imperfect durable goods industry in which pollution occurs after using the product. He assumes a two-period model and shows that in the second period, the optimal emission tax is always below marginal damage. In the first period, it is ambiguous whether the optimal emission tax is below or above marginal damage.

Shaffer (1995) states that if emissions are constant to the output, a firm-specific ad valorem tax can lead to social welfare optimal production levels for a Cournot oligopoly. Kim and Chang (1993) developed an optimal tax/subsidy scheme for an oligopoly market with pollution that leads to the welfare-efficient outcome.

Beside Cournot partial market models, there are also a number of authors assuming a Bertrand framework. For instance, Requate (1993b) determines the welfare optimal emission tax for a Bertrand duopoly with homogenous goods and asymmetric constant marginal production costs. Lange and Requate (1999) investigate price-setting firms in a duopoly with differentiated goods. They show that a uniform emission tax for a uniform-mixing pollutant can either be higher or lower than marginal social damage. However, for most cases the tax should be set below marginal social damage.

Vetter (2005), for example, investigates the welfare optimal emission tax for monopolistically competitive firms. He shows that also in a monopolistic competition framework, the welfare optimal emission tax is lower than marginal damage. Compared to the social optimum, there are too few firms in the market. For a survey on monopolistic competition models investigating the welfare optimal regulation of emissions, see also Requate (2006).

All models presented in this section address the issue of environmental taxation. However, the results are transferable to emissions trading schemes. Under both kinds of regulation, firms adjust their marginal emission abatement costs either to the emission tax or to the emission permit price. For the decision of a firm, it makes in most cases no difference what kind of regulatory framework it faces. Hence, most results can also be used when analyzing imperfect competition in emissions trading schemes like the EU ETS.

Malueg (1990) was one of the first who explicitly analyzed the impact of imperfect commodity markets on emissions trading schemes. He assumes a Cournotian output market and a competitive permit market. The main result of his analysis is that the introduction of emissions trading may reduce social welfare. This could happen if firms' production technologies are sufficiently different, then a shift of production from low-cost firms to high-cost firms may be the consequence of an emissions trading scheme. In a model with constant and equal production costs and positive abatement costs, Sartzetakis (1997) contradicts the results of Malueg and shows that the introduction of emissions trading always increases social welfare. In a follow-up paper, Sartzetakis (2004) assumes unequal production and abatement technologies and comes to the same conclusion as Malueg. Introducing emissions trading may result in lower social welfare, if the less efficient firms hold too many permits after trading compared to the welfare optimal solution. Von der Fehr (1993) even shows that a monopolization may be the consequence if permit trade is allowed. If industry's total profit is maximized by monopoly, there are profitable exchanges of permits, which leaves everyone better off and only one firm active in the product market.

3.2.3 Interdependency of Imperfect Markets

The present section investigates the interdependencies if both the commodity and the permit markets are imperfectly competitive. An approach commonly used in the literature on permits trading systems with oligopoly markets is a game structure in which firms first decide on and commit to their permit holdings and then compete afterwards on the product market. Von der Fehr (1993), for example, analyzes a game with two identical firms that first commit on their permit holdings and then on their output levels à la Cournot. On the permit market, both firms are aware of the permit supply function. It can be shown that if output quantities are strategic substitutes, firms overinvest in emission permits. Through this overinvestment in the first stage, firms' marginal costs are reduced and they increase their output levels. Requate (1993a) assumes a similar game structure. First firms trade with permits, then they set their output quantities à la Cournot. On the permit market, the price is determined through a Nash-bargaining solution between the two firms. Requate compares the outcome of permit trading with an optimal emission tax and shows that neither of the policies is always superior. Requate (1993b) comes to the same result for Bertrand competition on the product market. Again, the welfare comparison between a permit trading scheme and an emissions tax is ambiguous.

Misiolek and Elder (1989) analyze a model with a dominant firm and a price-taking fringe. The dominant firm has market power on the output and permit market. They show that the dominant firm can manipulate the permit price to raise the costs of the fringe. A further interesting result is that depending on the initial allocation, a cost manipulation strategy by the dominant firm may reduce negative effects from the imperfect permit market. Eshel (2005) derives an optimal allocation rule for the case of a dominant firm and a price-taking fringe, as in Misiolek and Elder (1989). The case of a Cournot duopoly on the product market, in which one firm has market power on the permit market, is investigated in von der Fehr (1993) and Sartzetakis (1997). They show that possessing market power on the permit market is always beneficial for the dominant firm. According to Sartzetakis (1997), the effect on industry's output and social welfare is ambiguous. If the two incumbent firms encounter a potential entrant, emission permits may be used by the dominant firms as a barrier to entry.

Innes et al. (1991) investigate a structure in which one polluting firm is a monopolist in its output market and all other polluting firms are price takers in their output markets. They compare a uniform emission tax with a permit trading scheme. The resulting optimal uniform emission tax is always below marginal social damage. For the permit trading scheme, it is assumed that the monopolist is the only firm that has market power on the permit market. They show that depending on the initial allocation, the permit trading scheme is welfare superior to the tax system. This can be explained since the two distortions, one due to monopolistic underproduction and the other due to market power on the permit market, can mitigate each other. For most cases, there exists a welfare-maximizing initial allocation, where the monopolist is a permit seller.

3.3 Other Distorting Impacts on Efficient Emission Abatement

As mentioned above, imperfect competition is only one possible driver for inefficient emission abatement. In the following subsections, some other reasons for inefficient outcomes are presented. This overview, of course, only describes some examples in literature and there are various other reasons that could be the drivers behind inefficient emission abatement.

3.3.1 Transaction Costs

Coase already emphasizes that a market for tradeable property rights only leads to an optimal outcome if there are no transaction costs. In cases where transaction costs are too high, no trade at all is to be expected. Stavins (1995) identifies in his seminal paper three potential sources of transaction costs in permit markets: search and information, bargaining decision, and monitoring and enforcement. He assumes that each firm faces transaction costs that increase with the amount of permits traded. In his model, marginal emission abatement costs of permit sellers are below the permit price. Marginal abatement costs of permit buyers exceed the permit price. Hence, the condition for cost efficiency, the equalization of marginal abatement costs, is not achieved. The overall amount of traded permits decreases under transaction costs. The equilibrium outcome may depend on the initial allocation. Thus, the regulator needs complete information on all firms to determine the allocation and the major advantage of a permit trading scheme compared to an emission tax is lost. Only if the initial allocation exactly meets the cost-efficient allocation of emission, i.e., no trade occurs, the welfare optimal solution is achieved. However, Stavins (1995) shows that if marginal transaction costs decrease with the transaction volume, the distortions from transaction costs are reduced if the initial allocation is further away from the optimal outcome. This can be explained by scale economics of trading of which firms can take advantage.

If the number of firms in the permit market is high enough, Stavins assumes, that transaction costs should be of less importance, since it should be easier for firms to find trading partners.

3.3.2 Monitoring Costs and Enforcement

One very restrictive assumption in Montgomery's basic emissions trading model in Section 3.1 is that all firms are compliant, i.e., they report their true emissions and hand in the appropriate amount of permits. This implicitly assumes that the regulator is able to monitor firms' emissions and can sanction non-compliance. If this is not the case, there is no incentive for a firm to stand to the rules.

Malik (1990) analyzes what happens if the regulator is not able to monitor all firms' emissions. He shows that if there is imperfect monitoring, firms may have an incentive for non-compliance and a permit trading scheme does not result in an abatement cost-minimizing solution. The resulting permit price depends on the firms' attitude toward risk and the enforcement policy of the regulator. However, in most cases the permit price under non-compliance is less than the optimal price.

Stranlund (2004) analyzed the optimal enforcement policy in cases where there is non-compliance. He shows that an emissions trading program with a constant marginal penalty for non-compliance can lead to a given emissions target at the lowest costs.

Van Egteren and Weber (1996) combine the model of Malik (1990) with the idea of Hahn (1984). It is assumed that one firm in the permit market has a dominant position and can set the permit price. They show that the initial allocation is not only fundamental in determining the permit price, like in Hahn's model, but also in determining the level of compliance. Hence, they suggest that the initial allocation should be used as a policy instrument for increasing the performance of permit markets. Chavez and Stranlund (2003) show that if an enforcement policy is implemented that guarantees compliance, an initial allocation leaving some market power to the dominant firm is desirable to reduce overall costs. Malik (2002) shows that even some non-compliance may be desirable, since it can reduce negative effects through market power. Similarly, market power on the permit market may reduce negative effects from non-compliance.

Chavez and Stranlund (2004) analyze the interdependencies between imperfect monitoring and transaction costs in the permit market. In absence of transaction costs, there is no reason to apply different enforcement policies to firms. In case of constant marginal transaction costs, Chavez and Stranlund show that net permit buyers have a higher incentive to cheat and should be monitored more closely. Net permit-selling firms have a lower incentive for non-compliance and can be monitored less closely. Within each group, all firms should be monitored uniformly. However, if marginal transaction costs are not constant, the monitoring level of each firm must be determined individually, which makes it much more difficult for the regulator to define the right enforcement policy.

3.3.3 Uncertainty

In his seminal paper, Weitzman (1974) was the first who analyzed the impact of uncertainty on a permit trading scheme. Thereby, he focuses on the comparison between a quantity policy, like an emissions trading scheme, and a price policy, like an environmental tax. He assumes that the social costs from emission abatement as well as social benefits are uncertain and that the regulator can only maximize expected social welfare. Weitzman states that the environmental instrument that avoids the bigger error should be chosen. He shows that it depends on the slopes of the marginal benefit and marginal cost function, which policy is superior. If marginal benefits are more sensitive than marginal costs, a quantity instrument is superior; if marginal costs are more sensitive than marginal benefits, a price policy leads to higher expected welfare.

Based on the work of Weitzman, a lot of other authors analyzed the impact of uncertainty on the optimal choice of policy instruments. For instance, Stavins (1996) extends the model of Weitzman and assumes that uncertainty in benefits and costs are in some way correlated. He shows that if there is a positive correlation between uncertain benefits and uncertain costs, then a quantity instrument becomes more favorable. A negative correlation tends to favor the price instrument.

Robert and Spence (1976) analyze the use of mix or hybrid instruments. They suggest an emissions trading scheme with an upper and lower price cap to reduce the negative impact of uncertainty. Another paper analyzing the optimal choice of the policy instrument is by Quirion (2005), in which he compares price and quantity instruments with relative emission caps, i.e., emission limits proportional to the polluting firm's output. He shows that, in most cases, either price policy or quantity policy is welfare superior to an relative emission cap, depending on the sensitivity of benefits and costs, as in Weitzman (1974).

Besides uncertain cost and benefit functions, many models on uncertainty in permits trading systems assume uncertain amounts of ex-post emissions because future emissions of an installation are more likely a prediction or expectation than certain knowledge. One can think of fluctuations in electricity demand, purity of raw materials or mechanical breakdowns that create stochastic forecasts. Carlson and Sholtz (1994) compare different types of issue and expiration dates for permits. They reason that a permit trading system, like the European one, is not efficient if emissions are uncertain; for example, in cases where there are high non-compliance penalties, excessive permit holdings (compared to expected emissions) emerge as "insurance" against falling short.

Mrozek and Keeler (2004) compare non-tradeable and tradeable permits with uncertain emission levels. They find out that emissions are always closer to the optimum when permits are tradeable. Hennessy and Roosen (1999) analyze the effects of merging firms when emissions are uncertain. They argue that under perfect competition, expected profits of merged firms are at least as high as the sum of expected profits of individual firms. Moreover, emissions are closer to the cost-efficient solution if firms purchase permits together.

In contrast to the models described above, Maeda and Tezuka (2004) analyze uncertain future emissions in a system with intertemporal trade. They find a negative impact of uncertainty on the present permit price. Seifert et al. (2008) develop a stochastic equilibrium model to analyze the emission permit price-process under uncertain future emissions.

Montero (1998) extends the model on transaction costs of Stavins (1995) for uncertainty in a way that some trade is interdicted by the regulator, e.g. in order to avoid hot spots of emissions. He shows that this results in an overall reduced welfare. However, if the initial allocation is near the optimal allocation, the reduction in welfare is minimal. This means that the equilibrium outcome depends on the initial allocation and the information advantage of an emissions trading scheme is lost.

3.4 Emissions Trading in the Context of International Trade

The issue of international markets is of major concern when analyzing environmental policies. Since most environmental problems are of an international dimension, policy instruments are likely to affect international trade. Hence, a huge literature on this issue evolved. Since the analysis of the EU ETS in the following chapters is focused on imperfect markets, we restrict this survey to environmental policies in international markets under imperfect competition.

With their seminal paper on export subsidies and international market share rivalry, Brander and Spencer (1985) started a new direction in literature. They show that if firms compete in an imperfect international commodity market, it is individually rational for each country to subsidize exports of its firms. However, overall welfare would rise if governments reduce their subsidies.

Conrad (1993) was the first who extended the model of Brander and Spencer (1985) to analyze the impact of environmental taxes in an international context. He assumes Cournot competition and that output is exported to a third country's market. In his model, he shows that if the governments of the exporting countries are allowed to set environmental taxes and emission abatement subsidies individually, the equilibrium taxes are less than if governments set only emission taxes. Governments abuse the subsidy as a trade instrument in the imperfect competitive international market. Barrett (1994) also restricts consumption to a third country and analyzes national environmental standards as a single instrument. He shows that if there is only one firm in each country behaving à la Cournot, environmental standards that are individually determined by the exporting countries are always weaker than environmentally optimal standards. The resulting marginal abatement costs are less than the marginal social damage. If there are more firms in each country, the effect of strategic behavior on environmental standards is ambiguous. Under Bertrand competition with one firm in each country, the result changes and strategic environmental standards are stronger than environmentally optimal standards. In contrast Kennedy (1994) assumes a closed two-country economy with Cournot competition. Analogous to the one-country models in Section 3.2.2, the optimal emission tax that maximizes total welfare is always lower than the marginal environmental damage. However, if countries determine their taxes individually, these taxes are welfare inefficient. By choosing their taxes, countries consider two effects: the so-called *rent capture effect*, which lowers equilibrium taxes to gain an advantage over the competing country and capture foreign rent, and the *pollution shifting effect*. Thereby, countries try to shift pollution to the competing country. The resulting equilibrium taxes are always lower than the globally efficient tax.

The basic concepts of Conrad (1993), Barrett (1994) and Kennedy (1994) have been extended in various ways, like imperfect information (Nannerup, 1998), investments in R&D (Simpson & Bradford, 1996) or vertical related markets (Hamilton & Requate, 2004).

Rauscher (1994) shows that countries can use their environmental policies as substitutes for missing trade policies. If countries are allowed to differentiate taxes between economic sectors, industries producing internationally traded goods are taxed differently than industries only producing nationally traded goods. Sartzetakis and Constantatos (1995) analyze a two-country model with given emission targets. One country applies a command-and-control approach, whereas the other country use an emissions trading scheme to reduce emissions. Comparing both approaches reveals that the total market share of firms in the emissions trading scheme increases relatively to the firms regulated by the command-and-control system.

In Duval and Hamilton (2002), optimal cooperative and non-cooperative emission taxes are compared in a two-country model with Cournot firms producing an internationally traded good. The optimal cooperative emission taxes depend on marginal environmental damage from pollution and on an imperfect competition effect. Analogous to Section 3.2.2, the environmental tax is also used to reduce market distortions from imperfect competition. If firms are asymmetric in their production technologies, the resulting national emission taxes are differentiated across countries. Furthermore, they show that the non-cooperative taxes depend on three effects besides domestic marginal damage: the terms-of-trade effect, the imperfect competition effect and the pollution shifting effect. The terms-of-trade effect means that a country tries to influence commodity prices through the environmental tax depending on whether it is an importing or exporting country. According to Requate (2006), the terms-of-trade effect and the imperfect competition effect can also be interpreted as rent capture and domestic consumption effect. Comparing the cooperative and non-cooperative tax levels reveals that non-cooperative behavior leads to an inefficient outcome.

Cremer and Gahvari (2004) study the effects of economic integration and tax harmonization in a closed two-country model. Thereby, they investigate commodity and emission taxes in a perfect competitive environment. In their model, an economic integration yields increasing aggregate emissions and lower welfare. The impact only of harmonizing commodity taxes on aggregate emissions and welfare is ambiguous. If only emission taxes are harmonized and the resulting commodity taxes increase due to the harmonization, firms adapt less polluting technologies, but aggregate emissions decline and welfare increases.

Pratlong (2005) analyzes the emission reduction targets in a two-country model with firms competing in an international product market à la Cournot and domestic markets of emission permits. He compares a situation where countries decide simultaneously and non-cooperatively on their reduction targets and where one country is a Stackelberg leader. In cases where there is a Stackelberg leader, emission targets of this country are always less stringent.

This survey on environmental policies under international trade and imperfect competition only gives a brief insight into the extensive literature in this field. However, most work is done on the impact of non-cooperative behavior of countries when determining emission standards or emission taxes. Only very few papers consider the special context of the EU ETS, as shown in Chapter 5.

Chapter 4

Emissions Allocation under Imperfect Competition

As described in Chapter 2, the European approach to reducing greenhouse gas emissions distinguishes between firms using a carbon-dioxide-intensive technology and all other emitters, like those responsible for traffic and household emissions as well as that produced from non-productive industry sectors. Carbon-dioxide-intensive firms are assigned to a sector regulated by an emissions trading scheme (*Tr*-sector). All other emitters are subject to a mix of other policies (*NTr*-sector). A more detailed introduction to the European approach is given in Section 2.2. This chapter investigates the crucial question of how an optimal macro-plan, the partitioning of the total amount of emissions between the *Tr*- and the *NTr*-sector, should look.

Existing literature on the decided macro-plans agrees that the trading sector receives too many emission rights and, as a consequence thereof, marginal emission abatement costs for firms in the trading sector are much lower than marginal abatement costs for emitters in the non-trading sector of many EU member states. The allocation in the first trading period, 2005-2007, is described in detail in Section 2.3.1 and Section 2.3.2.

Current studies like those of Betz et al. (2004), as well as Böhringer et al. (2005), Klepper and Peterson (2006), and S. Peterson (2006) claim that such allocations that create unequal marginal abatement costs between sectors result in unnecessarily high costs for the restriction of carbon dioxide. Böhringer et al. assume that the macro-plans of the first trading period lead to costs eight times higher than necessary to achieve the aimed reduction goals. Therefore, they suggest a shift of emission rights from the *Tr*- to the *NTr*-sector for future periods.

In contrast to this suggestion, the analysis in the following sections shows that an allocation with lower marginal abatement costs for emitters in the *Tr*-sector does not inevitably lead to higher costs for reducing emissions. Furthermore, cost minimization can even require reduced marginal abatement costs for the members of the *Tr*-sector. Comparable results are derived by Ruocco and Wiegard (1997), Böhringer (2002a), and Richter and Schneider (2003). They show that environmental tax differentiation between industries and households can be beneficial if indirect effects on other taxes and the labor market are taken into account (the so-called second and third dividends). For instance, Rauscher (1994), Hoel (1996) and Withagen et al. (2007) show that if environmental taxes are used as an alternative for trade policies, taxes can differ between sectors of the economy producing internationally traded goods and those only producing nationally traded goods.

Now the question arises: What is the optimal partition and, accordingly, the optimal burden-sharing between the trading and the non-trading sector? At this juncture, we address the relevant issue whether the level of competition on related markets has an impact on the optimal allocation. This is of particular interest since the energy sector, as a part of the trading sector, is dominated by an oligopoly of a few firms that unambiguously possess power on the energy market.[1] On this account, the following chapter analyzes the impact of firms' behavior on the cost-efficient allocation of emission permits.

A well-known result from the literature on externalities is that, only in cases where there is perfect competition cost efficiency requires that all emitters' marginal abatement costs are equal to the marginal environmental damage of emissions. However, in thecase the externality is produced by an imperfectly competitive industry this result cannot be maintained and marginal abatement costs differ from the marginal environmental damage. For a more detailed literature overview, see also Section 3.2.2.

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[1] See e.g. Convery et al. (2008).

The literature on externalities usually investigates the problem of oligopoly regulation in the context of partial markets and does not consider the hybrid nature of the European approach. Since the European Emissions Trading Scheme concerns major parts of the economy, it is questionable if a partial market approach is sufficient here. Hence, in the following, the problem of how to allocate emissions in the European Emissions Trading Scheme efficiently is analyzed by using a general equilibrium model. To investigate the impact of oligopoly , the general equilibrium approach includes imperfectly competitive markets.

Another model investigating the impact of imperfect competition on environmental regulation with a general equilibrium approach can be found in Böhringer, Welsch, and Löschel (2008). In a computational general equilibrium (CGE) model with imperfect competition and free entry, they analyze the structural changes in Germany due to a uniform environmental tax for all emitters. They show that changes under imperfect competition are larger than under perfect competition. Furthermore, they point out that total abatement costs for achieving a certain reduction goal are higher under imperfect competition. In contrast, we account for the hybrid nature of the actual EU ETS and do not assume a uniform tax for all emitters. Our focus is on the optimal allocation of emission rights and the impact of imperfect competition on this allocation.

A main result of our analysis is that if commodity markets are imperfectly competitive, a welfare-efficient allocation requires unequal marginal abatement costs between sectors. This result contradicts the implicit assumption in current studies about the efficient allocation of emission rights in the European Emissions Trading Scheme, saying that only equal marginal costs for all emitters minimize the total costs for achieving the overall emissions target. A numerical example shows that even if only one industry of comparable size to the German power supply industry is imperfectly competitive, the resulting difference between marginal costs is of a non-negligible size.

This chapter is organized as follows: Section 4.1 gives a short introduction to general equilibrium models with imperfect competition. In Section 4.2 the general assumptions of the model are introduced. The welfare-maximizing allocation of emissions is then derived in Section 4.3. A numerical example in Section 4.4, analyzing the German power supply industry, shows that the difference between sectors' marginal costs in the EU ETS is probably of a significant magnitude. Section 4.5 analyzes possible consequences of multiplicity of equilibria and Section 4.6 extends the model to account for substitution effects between different consumption goods. Section 4.7 provides the conclusion.

4.1 Methodology

The current chapter analyzes the impact of imperfect competition on the European Emissions Trading Scheme with a general equilibrium model. For a better understanding of the model, this section gives a short overview of general equilibrium concepts with imperfect competition.

First approaches of imperfect competition in oligopolies go back to Cournot (1838). He introduced an equilibrium concept in which every firm knows the consumers' demand function and chooses an output level that maximizes its profit, assuming the output of its competitors as fixed and given. This concept is also known as Cournot-Nash equilibrium.[2] Criticizing the idea of quantity-setting firms as unrealistic, Bertrand (1883) introduced the concept of price-setting firms, also known as Bertrand-Nash equilibrium. In this approach, firms choose their prices, taking other prices as given. The output quantities are then generated by the prices. These first concepts of imperfect competition are partial market approaches in which each firm is aware of the consumers' demand function. They do not address the issue of how the demand function is derived. However, in these approaches, any impact on other markets and prices is neglected. In a general equilibrium context, as formulated in Walras (1874), a change in a firm's decision variable would affect all other markets and prices. The questions arising in a general equilibrium context are: Which kind of demand function do imperfectly competitive firms base their production decisions on? Do they just conjecture some subjective demand function or do they really understand all impacts that their decisions have on the economy?

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[2] The Cournot equilibrium corresponds to the more general concept of Nash equilibrium. A detailed formal description of the concept of Nash equilibrium can be found in Berninghaus et al. (2002).

The first attempt to introduce imperfect competition in a general equilibrium context was made by Negishi (1961). He restricts his analysis on monopolistic firms and assumes that each monopolist has *subjective* inverse demand functions for its own goods. This means that each monopolist conjectures an arbitrary inverse demand function with the restrictions that it is linear and decreasing and that the observed price in the economy is equal to the conjectured price of the monopolist. Negishi defines the equilibrium as the state of the economy in which each consumer and each competitive firm maximizes its utility and profit respectively, taking all prices as given. Every monopolistic firm maximizes its profit based on its conjectured inverse demand function. A main criticism of this approach is that for every feasible allocation in this economy, a subjective demand function exists for which this allocation is an equilibrium, as defined by Negishi.[3]

Another approach introduced by Gabszewicz and Vial (1972) is the Cournot-Walras equilibrium, in which each imperfect competitor is aware of the *objective* inverse demand function. Assuming a two stage procedure: In the first stage, imperfectly competitive firms choose their production levels, and in the second stage, we have a Walrasian equilibrium, where the consumers maximize their utility, taking prices and the decisions of the first stage as given. The imperfectly competitive firms in the first stage construct the demand function by anticipating the equilibrium behavior of consumers in the second stage. With this knowledge, they decide on their production levels à la Cournot, i.e., they take the competitors' quantities as fixed and given.

According to Bonanno (1990), there are some problems with this approach. First of all, standard assumptions about consumers' preferences are not sufficient to guarantee the existence of a Walrasian equilibrium in the second stage for each feasible production decision. Even if a unique Walrasian equilibrium exists for all feasible production plans, it could be that the resulting inverse demand function has a shape such that no Cournot equilibrium exists in the first stage. The assumptions that guarantee the existence of a unique Cournot-Walras equilibrium are much more restrictive than the standard assumptions for a Walrasian equilibrium. A further problem is that for the construction of the inverse demand function, a price normalization is required. In contrast to the Walrasian equilibrium with per-

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[3] See Gary-Bobo (1989).

fect competition, Gabszewicz and Vial show that the Cournot-Walras equilibrium strongly depends on the choice of this price normalization. Grodal (1996) presents an example in which nearly every feasible production plan can be established as an equilibrium by choosing the right normalization rule. However, according to Willenbockel (2003), the price normalization problem has a negligible impact on most applied general equilibrium models and is therefore of a more theoretical nature. Although this is still an unsolved issue in the theory of general equilibrium, it is not important for the model in this chapter. We assume a small open economy in which at least one price is given by the world market. With a fixed exchange rate equal to one, all other prices in the economy are normalized.

In this context, the *feedback effect* or Ford effect must also be mentioned. This effect addresses the problem that firms' profits are a part of the consumers' income and therefore also part of the anticipated demand function. In the model of Gabszewicz and Vial, firms take the feedback effect into account, which of course relies on very strong assumption about firms' information. Although, if the owners of the firms realize that they are also consumers of their own products, it is no longer reasonable to assume that profit maximization is the right objective. It would be more reasonable if firms were to maximize the owners' utility. However, Hoffmann (2002) states that in applied general equilibrium models, the practical implications of such a change in firms' objective functions are very small. Hart (1985a) suggests that if firms are relatively small compared to the rest of the economy, it is more realistic not to consider the feedback effect at all. On this note, a number of authors introduced general equilibrium concepts without feedback effect. For instance, Kaas (2001) analyzes a Cournot-Walras equilibrium without feedback effects from changing profits and shows that if firms are symmetric and neglect the impact of their behavior on consumers' income, the outcome of this equilibrium coincides with the perfectly competitive equilibrium. In our model, we also refer to the suggestion of Hart and assume that firms are not aware of the feedback effect and act with the objective of pure profit maximization.

All hitherto described approaches are based on the Cournot concept of quantity-setting strategic agents. Of course, there are also a number of models following the Bertrand approach of price-setting imperfect competitors. Important contributions are by Marschak and Selten (1974), Nikaido (1975) and Silvestre (1977).

The above-described idea of an *objective* approach is often criticized as unrealistic because a strategic agent needs to have complete information about the whole economy to construct the *objective* demand function. For this purpose, some authors try to find a compromise between the *subjective* approach of Negishi and the *objective* approach. One contribution is the approach by Silvestre (1977), who conjectures that firms do not know the *objective* demand functions but are at least aware of the slope the demand functions have in equilibrium. In his model, each imperfectly competitive firm conjectures a linear demand function whose value and slope in equilibrium is consistent with the objective demand function. With this estimated demand function, an imperfectly competitive firm maximizes its profit as price setter. The assumptions necessary for the existence of such an equilibrium are much weaker than those for the objective approaches described above. It is noteworthy that, as shown in Bonanno and Zeeman (1985), the equilibrium described by Silvestre can be very different from the equilibrium in which firms know the objective demand function.

Another approach between *subjective* and *objective* demand function is the Cournotian Monopolistic Competition equilibrium by d'Aspremont et al. (1991), (1995) and (1997). In this approach, it is assumed that firms are, in a way, foreseeing that they know their consumers' preferences but are myopic and not able to internalize the impact of their behavior on prices in other markets of the economy. This approach is similar in some way, to the tradition of Chamberlin (1933), where firms have only "local" market power and no "global" market power.[4] Firms competing in an imperfect market correctly anticipate the *objective* consumers' demand function but take the prices in all other markets as fixed and given. Based on this demand function, firms set their production quantities à la Cournot.

The approach used in the following model is based on the idea of d'Aspremont et al. (1991), (1995) and (1997). We modify their concept of Cournotian Monopolistic Competition equilibrium in a way that does not restrict the analysis to Cournotian competition between imperfect competitors. We extend the approach by the idea of conjectural variations. This allows for investigating different kinds

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[4] For a more recent version of Chamberlin's idea, see Hart (1985b).

of competition, like price taking, Cournot or cartel behavior, in one model.[5] For the feedback effect, we assume that firms are not aware of it; we suppose, analogously to Kaas (2001), that firms fail to internalize this effect and take consumers' income as fixed and given.

4.2 General Framework

The following theoretical model investigates an economy that produces two commodities, X and Y. We assume a small open economy in which capital, raw materials and the commodity Y are internationally traded, i.e., these prices are given by the world market.[6] The exchange rate between prices on the world and the national markets is assumed to be equal to one. Thus, the prices in the economy are normalized by the exchange rate and the world prices. Commodity X is traded on a national market. The emissions target $\bar{E}$ for this economy is also exogenously given, e.g. from an international environmental agreement like the Kyoto Protocol. In the economy we distinguish between four different types of agents: one representative household, competitive firms, oligopolistic firms with market power, and a government.

The representative household not only represents the households, but also the traffic sector, the trade sector and small industries. Thus, it represents the entire *NTr*-sector. The household interacts with the rest of the economy in a way that it consumes the commodities produced by the other agents and supplies them with labor. Emissions resulting from the household and the *NTr*-sector respectively are regulated by only one regulatory instrument, an emission tax.[7] The *Tr*-sector

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[5] For a survey on conjectural variations see Kamien and Schwartz (1983) or Dixit (1986).

[6] In cases involving a small open economy, the investigated economy is assumed to be so small compared to the world economy that it does not influence world prices.

[7] Remember that in the real European approach, the *NTr*-sector is regulated by a mix of different policies like taxes, subsidies, or command-and-control approaches. Without loss of generality, we restrict the regulation of the *NTr*-sector in the model to one policy instrument: an emission tax. This is possible because the *NTr*-sector's burden only depends on its marginal emission abatement costs and not on the used policy. For instance, a command-and-control approach can lead to identical marginal costs as a tax.

consists of a set $M = \{1,...,m\}$ of firms, whose emissions are regulated by the Emissions Trading Scheme. Firms' produce only final goods.

The model is structured as a two-stage game in which in the first stage, a benevolent planner decides on the emission limit E_{Tr} allocated to the *Tr*-sector and the amount of emissions for the *NTr*-sector. In the second stage all agents of the economy decide on their actions given the allocation of the benevolent planner. The exact descriptions of each type of agent are provided in more detail in the following subsections.

4.2.1 The Representative Household

The household representing the whole *NTr*-sector consumes an amount $x \in \mathbb{R}_{\geq 0}$ of commodity X and an amount $y \in \mathbb{R}_{\geq 0}$ of commodity Y. Additionally, the household consumes a certain amount of emission causing raw materials in the form of energy ($h \in \mathbb{R}_{\geq 0}$), e.g. for heating or mobility. Since each raw material unit creates a non-avoidable amount of emissions, the consumption of raw material is measured in the corresponding amount of emission units. To regulate the negative externality, the household's emissions are subject to an environmental tax t. Besides consumption, the household supplies firms with labor. The labor supply l is measured in negative units, which can be interpreted as a loss in leisure time ($l \in \mathbb{R}_{\leq 0}$).

The utility of the representative household depends on its level of consumption and labor supply. The utility function $V(x,y,h,l) := U(H(x,y,h),l)$ is weakly separable between the consumption goods and the supply of labor. For U we assume that $U_H, U_l > 0$, $U_{HH}, U_{ll} \leq 0$ and $U_{Hl} \geq 0$.[8] For H it is assumed that $H_x, H_y, H_h > 0$, and $H_{xx}, H_{yy}, H_{hh} \leq 0$. To assure a unique solution and that the second-order condition for a utility maximization is always satisfied, it is assumed that $V(x,y,h,l)$ is strictly quasi-concave. Thus, we have the usual properties of monotonic and strictly convex preferences.[9] Furthermore, the assumptions about

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[8] $f_x(x,y,...)$, $f_y(x,y,...)$ represents the (partial) derivatives of the function $f(x,y,...)$. Analogously, second derivatives are abbreviated.

[9] See Mas-Colell et al. (1995) or Chiang and Wainwright (2005).

the derivatives of the utility function imply that consumption and leisure time are complementary goods.

The household's decision on consumption and labor supply is subjected to its budget I, which consists of the firms' profits $\sum_{k\in M}\Pi_k$ after a profit tax θ and an exogenous part I_e:

$$I = (1-\theta)\sum_{k\in M}\Pi_k + I_e. \tag{4.1}$$

The exogenous part I_e can, for example, be interpreted as the return from savings in the form of capital. The budget constraint of the household is therefore

$$p\cdot x + q\cdot y + (s+t)\cdot h + w\cdot l = I,$$

where p and q are the prices of the commodities X and Y, s is the price for raw material (measured in emission units) and w represents the household's wage for each labor unit. We assume that the household takes all prices and its income as given and maximizes its utility as a price taker. Hence, we have the following household's maximization problem:

$$\max_{x,y,h,l} U(H(x,y,h),l)$$

$$\text{s.t. } p\cdot x + q\cdot y + (s+t)\cdot h + w\cdot l = I$$

Utility-maximizing behavior yields the following system of first-order conditions:

$$H_x - \frac{U_l}{U_H}\cdot\frac{p}{w} = 0 \tag{4.2}$$

$$H_y - \frac{U_l}{U_H}\cdot\frac{q}{w} = 0 \tag{4.3}$$

$$H_h - \frac{U_l}{U_H}\cdot\frac{s+t}{w} = 0 \tag{4.4}$$

$$p\cdot x + q\cdot y + (s+t)\cdot h + w\cdot l - I = 0 \tag{4.5}$$

With the first-order conditions, we can state the following definition of consumer behavior.

Definition 4.1. *$\tilde{x}(p,q,w,s,t,I)$, $\tilde{y}(p,q,w,s,t,I)$, $\tilde{h}(p,q,w,s,t,I)$, and $\tilde{l}(p,q,w,s,t,I)$ are the utility-maximizing consumption levels solely depending on prices and income, which are defined by the system of equations (4.2)-(4.5).*

4.2.2 Firms in the Trading Sector

The trading sector consists of two types of firms: firms that compete in a perfectly competitive product market and firms that compete in an imperfectly competitive product market. Let $M = \{1,...,m\}$ be the overall set of firms in the Emissions Trading Scheme.

Each firm $i \in N \subseteq M$ produces an amount $x_i \in \mathbb{R}_{\geq 0}$ of the homogeneous commodity X and possesses market power on its output market. The firms of set N could represent, for example, a geographically restricted commodity market in which the industry's total output determines the price (e.g., the electricity market).

Every firm $j \in \bar{N} := M \backslash N$ produces an amount $y_j \in \mathbb{R}_{\geq 0}$ of commodity Y, but in contrast to a firm in subset N, it does not possess any market power on its output market.

All firms in M produce their output by using labor, capital and energy as input factors. Thereby, the use of energy produces an amount $e_k \in \mathbb{R}_{\geq 0}$ of emissions for firm $k \in M$.[10] As mentioned above, we consider a small open economy that is a price taker on the global markets for raw material and capital. Therefore, the price for raw material s and the price for capital r are exogenously given. The wage w for labor input is endogenously determined by the labor market. The costs of a firm $k \in M$ are given by a differentiable function $C^k(z_k, e_k, w, s, r) : \mathbb{R}^5_{\geq 0} \rightarrow \mathbb{R}_{\geq 0}$ with the following properties:[11]

(1) $C^k_{z_k}(\cdot) > 0, C^k_{z_k z_k}(\cdot) > 0,$

(2) $C^k_{e_k}(\cdot) < 0, C^k_{e_k e_k}(\cdot) > 0,$

(3) $C^k_{z_k e_k}(\cdot) < 0$ and

(4) $C^k_{z_k z_k}(\cdot) C^k_{e_k e_k}(\cdot) - C^k_{z_k e_k}(\cdot)^2 > 0.$

As quite common in economics, firms' marginal production costs are positive and increase in output (see (1)). The possibility of abating emissions is already

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[10] As already mentioned, the used raw materials are measured in units of emissions.

[11] The variable z_k denotes x_k for $k \in N$ and y_k for $k \in \bar{N}$.

included in the cost function, since it depends also on the firm's emissions level. Since a higher pollution level means lower abatement efforts, production costs decrease if a firm's emissions increase.[12] We assume that the cheapest abatement measures are always realized first and hence that the cost function is convex in emissions (see (2)). Further, marginal production costs decrease if firms are allowed to emit more (see (3)). To assure that the second-order condition for an interior solution of a firm's profit maximization is satisfied, the Hessian of the cost function regarding a firm's decision variables,

$$\mathrm{H}(C(z_k, e_k, \cdot)) = \begin{bmatrix} C^k_{z_k z_k} & C^k_{z_k e_k} \\ C^k_{z_k e_k} & C^k_{e_k e_k} \end{bmatrix},$$

is positive definite (see (4)).

The usage of energy creates emissions that must be balanced with an appropriate amount of emission permits. Each firm $k \in M$ gets an initial amount of emission permits $e^0_k \in \mathbb{R}_{\geq 0}$. We assume that all emission allowances of the trading sector E_{Tr} are allocated at the beginning ($E_{Tr} = \sum_{k=1}^{m} e^0_k$). As has been usual in the European Emissions Trading Scheme, it is assumed that grandfathering is applied as the mechanism for the initial allocation in the Tr-sector. With $C^k_{e_k}(\cdot) < 0$, it is implicitly assumed that the reduction goal is strict enough to assure a positive permit price. Therefore, firms use all permits ($\sum_{k=1}^{m} e_k = \sum_{k=1}^{m} e^0_k$). Emitters can sell spare permits or buy more if they run short. Permits are traded on an allowances market at a price $\sigma \in \mathbb{R}_{\geq 0}$. Firms behave on this market as price takers.[13]

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[12] Of course, if an unnecessarily high input of raw materials is used, production costs increase in e_k. Therefore, it would be more accurate to assume that for all z_k, w, s, and r, there exists an emissions level $\bar{e}_k$ such that $C^k_{e_k}(\cdot) = 0$, and $C^k_{e_k}(\cdot) < 0$ if $e_k < \bar{e}_k$, and $C^k_{e_k}(\cdot) \geq 0$ if $e_k > \bar{e}_k$. See e.g. Requate (2006). The restriction in this model on $C^k_{e_k}(\cdot) < 0$ is not essential for the results.

[13] This assumption can be motivated even for the largest CO_2-emitting sector, the EU electricity sector, according to the results of Svendsen and Vesterdal (2002). They estimate the possibility of market power in permits trading and remark that for the permit market, the market shares of the largest CO_2 emitters are not big enough to execute market power. Moreover, the permit market will become more competitive in the future with increasing liquidity.

4.2.3 Behavior of Competitive Firms

In this subsection, the behavior of perfectly competitive firms in set $\bar{N}$ is investigated. Every firm $j \in \bar{N}$ chooses its output and its emissions level in a way that it maximizes its total profit

$$\Pi_j = q \cdot y_j - C^j(y_j, e_j, w, s, r) - \sigma \cdot (e_j - e_j^0)$$

taking all prices as fixed and given. First-order conditions for profit maximization are

$$q - C^j_{y_j}(\cdot) = 0, \quad \text{and} \tag{4.6}$$

$$-C^j_{e_j}(\cdot) - \sigma = 0 \tag{4.7}$$

for all $j \in \bar{N}$.[14] From condition (4.7), one can easily see that all competitive firms in the *Tr*-sector have equal marginal abatement costs $-C^j_{e_j}(\cdot)$ and that their behavior is independent of the micro-plan.

4.2.4 Behavior of Firms with Market Power

Firms with market power consider the impact of their actions on the consumption behavior of the household. Thereby, we assume that firms are aware of the utility function of the household but that they are in a way myopic and are not able to predict the impact of their actions on other prices. Hence, they take all other prices and the household's income as fixed and given. This approach is in line with the general equilibrium concept of Cournotian Monopolistic Competition equilibrium.[15]

The inverse demand function anticipated by the firms with market power is derived from the system of equations (4.2)-(4.5). Solving $\tilde{x}(p, q, w, s, t, I)$ for p yields the inverse demand function. For the further analysis, we assume that all

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[14] Since the Hessian of $C^j(\cdot)$ is positive definite, the second-order condition for a maximum is always satisfied.

[15] See d'Aspremont et al. (1991), (1995) and (1997). For a brief survey on the different approaches of general equilibrium models with imperfect competition, see Section 4.1.

firms in N conjecture this inverse demand function $\Psi(x,q,w,s,t,I)$, which is well defined and decreasing in x. Since commodity X is only traded on a national commodity market, market clearance implies $x = \sum_{i\in N} x_i$.

Lemma 4.15 in the Appendix shows that the assumption for a decreasing inverse demand function is satisfied for common conditions on the utility function. For instance, we have a decreasing demand function if the utility function is quasi-linear in labor ($U_{HH} = U_{ll} = U_{Hl} = 0$).[16] Quasi-linearity of the utility function is a quite usual assumption in economic analyses. Also in the case of linear homogeneity of H, which includes the whole set of nested utility functions with constant elasticity of substitution (CES), we receive a decreasing demand function. This kind of utility functions are usually applied in computable general equilibrium models (CGE models).[17]

Given the inverse demand function, each firm $i \in N$ maximizes its own profit

$$\Pi_i = \Psi(x_i + x_{-i}, q, w, s, t, I)x_i - C^i(x_i, e_i, w, s, r) - \sigma \cdot (e_i - e_i^0)$$

with $x_{-i} = \sum_{j\in N\setminus\{i\}} x_j$ by choosing its own output and emissions level.[18] As mentioned before, the firms in set N are myopic in a way that they cannot forecast the impact of their decisions on other prices and the income of the household. Therefore, we assume that they take all prices in the economy differently from their own output market and the household's income as fixed and given.

In order to consider different kinds of firms' behavior, we model the competition on the commodity market of the firms of set N by means of *conjectural variations*.[19] Every firm $i \in N$ has beliefs about the behavior of the other firms in set N. The rivals' *expected* output change due to an increase in firm i's output is represented by a constant v^i.

$$\frac{d(\sum_{j\in N\setminus\{i\}} x_j)}{dx_i} := v^i \tag{4.8}$$

The *conjectural variations* framework offers the possibility to investigate different expected kinds of competition on the product market in one model. In cases where

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[16] See also Mas-Colell et al. (1995).

[17] For a survey on CGE models, see e.g. Böhringer et al. (2003).

[18] In the following, we denote the competitors of firm i by $-i$.

[19] For a survey on conjectural variations, see for example Kamien and Schwartz (1983) and Dixit (1986).

of $v^i = -1$ for all $i \in N$, firms behave like price takers in the product market, for $v^i = 0$ for all $i \in N$, firms behave à la Cournot. For symmetric firms $v^i = n-1$ for all $i \in N$ corresponds to a market share collusion. We consider expected competition between price takers and collusion, therefore, $v^i \geq -1$ for all $i \in N$.

Considering the expected rivals' response to an output change according to (4.8) implies (as a system of first-order conditions for a profit maximization) for all $i \in N$

$$\Psi(x_i + x_{-i}, q, w, s, t, I) + (1 + v^i) x_i \Psi_x(x_i + x_{-i}, q, w, s, t, I) - C^i_{x_i}(\cdot) = 0, \tag{4.9}$$

$$-C^i_{e_i}(\cdot) - \sigma = 0. \tag{4.10}$$

The equations (4.9) and (4.10) show that, in equilibrium, all firms have equal marginal abatement costs $-C^i_{e_i}(\cdot)$, and that the profit-maximizing output and the cost-minimizing emission levels are also independent of the initial allocation of permits within the *Tr*-sector $(e^0_1, ..., e^0_m)$, also called the micro-plan.

4.2.5 The Government

The government offers certain services to the citizens and therefore has exogenously given expenditures g. Public expenditures are financed by the environmental tax t in the non-trading sector and an additional tax θ on firms' profits $\sum_{k \in M} \Pi_k$. A balanced national budget yields

$$g = t \cdot h + \theta \cdot \sum_{k \in M} \Pi_k. \tag{4.11}$$

It is assumed that the government always sets the environmental tax in a way that the national emissions target $\bar{E}$ is achieved for a given allocation E_{Tr}, i.e.,

$$\bar{E} = E_{Tr} + h. \tag{4.12}$$

The profit tax is determined in a way that public expenditures are covered. In this model, we do not consider the impact of distorting taxes. A model analyzing interaction between energy taxation and distorting labor taxes can, for example, be found in Richter and Schneider (2003).

4.2.6 Equilibrium of the Economy

For a general equilibrium, all related markets must be cleared: the permit market, the market for the commodities X and the labor market.

$$E_{Tr} - \sum_{k=1}^{m} e_k = 0 \tag{4.13}$$

$$x - \sum_{i \in N} x_i = 0 \tag{4.14}$$

$$l + \sum_{k \in M} \frac{\partial C^k(\cdot)}{\partial w} = 0 \tag{4.15}$$

With the hitherto made assumptions about the behavior of the economic subjects, the equilibrium of the economy can be defined.

Definition 4.2. *: Given an allocation E_{Tr} for the Tr-sector, a configuration of values $(x^*, y^*, h^*, l^*, \{x_i^*, e_i^*\}_{i \in N}, \{y_j^*, e_j^*\}_{j \in \bar{N}})$, and prices and taxes $(p^*, w^*, t^*, \theta^*, \sigma^*)$ is an equilibrium of the economy if it satisfies the conditions given by (4.2)-(4.7) and (4.9)-(4.15).*

Existence of Equilibrium

To assure the existence of an equilibrium as defined above, further assumptions, for example on the utility function of the household, are necessary. The assumptions assuring the existence of a Walras equilibrium are not sufficient to guarantee the existence of an equilibrium as described in Definition 4.2.[20] For instance, the usual assumptions cannot guarantee that the imperfect competitive firms' reaction functions intersect. In cases involving Cournot conjectures ($v^i = 0, \forall i \in N$), sufficient conditions for the reaction functions to intersect are that firms have bounded capacities and quasi-concave profit functions.[21] The first-order conditions (4.9)

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[20] For the assumptions assuring the existence of a Walras equilibrium, see for example Mas-Colell et al. (1995).

[21] For the existence of a Nash-, see for example Berninghaus et al. (2002). The assumption of quasi-concave profit functions are usual in general equilibrium models with imperfect competition. See Gabszewicz and Vial (1972) and Bonanno (1990).

and (4.10) only describe a firm's profit maximum considering the expected rivals' response to an output change if the second-order necessary condition is satisfied, i.e., the Hessian

$$\begin{bmatrix} 2(1+v^i)\Psi_x(\cdot)+(1+v^i)^2x_i^*\Psi_{xx}(\cdot)-C^i_{x_ix_i} & -C^i_{x_ie_i} \\ -C^i_{x_ie_i} & -C^i_{e_ie_i} \end{bmatrix}$$

is negative semidefinite in equilibrium for all $i \in N$. Hence, to assure the existence of an equilibrium, further assumptions, for example on the third derivations of the household's utility function, are necessary. However, even if an equilibrium exists, it is not guaranteed that all parameters are within a reasonable range. For instance, the resulting profit tax θ should be between 0 and 1.

In the following analysis, we assume for the sake of simplicity that the conditions for the existence of at least one equilibrium for all feasible allocations, E_{Tr}, are satisfied.

Multiplicity of Equilibria

Due to the hitherto very general formulation of the model and the possibility of asymmetric firms, multiple equilibria cannot be excluded. Chapter 4.5 analyzes an example of multiplicity of equilibria due to firms' asymmetry and possible consequences thereof. One impact of multiplicity , of course, that a benevolent planner can only determine the welfare-optimal allocation of emissions if he is aware of all equilibria to which a certain allocation may lead. For the following analysis, we rely on the assumption that, in cases involving multiplicity, the benevolent planner can choose the equilibrium state leading to the highest welfare.[22] For instance, a possible way for the benevolent planner to avoid non-desired equilibria could be a price cap, as described in Section 4.5.2.

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[22] The approach that a benevolent planner can choose the equilibrium leading to the highest welfare is also used in Richter and Schneider (2003)

4.3 Welfare-Efficient Allocation of Emissions

In the following subsections, we define the optimization problem of a benevolent planner and derive the conditions for a welfare-maximizing allocation of emissions between the *Tr*- and the *NTr*-sector. Therefore, we first need to define the allowed allocation plans for this model. Based on this definition, the optimization problem is set up and a necessary condition for an efficient allocation is determined. Since the hitherto very general setting makes it very difficult to make more precise statements on the efficient allocation, additional simplifying assumptions are introduced that allow for a more detailed analysis.

4.3.1 Allowed Allocation Plans

For the derivation of the conditions for an efficient allocation plan, we have to determine the set of possible allocations. First, the allocation to the *Tr*-sector E_{Tr} is naturally restricted by the overall emissions target $\bar{E}$. If the amount of emissions assigned to the *Tr*-sector is equal to the overall emissions target, the emission tax t must ensure that no emissions are created in the *NTr*-sector.

Since we do not allow for emission subsidies in the *NTr*-sector, the resulting tax t in the *NTr*-sector must be greater or equal zero. Hence, the lower limit for the allocation to the *Tr*-sector is given by the situation where only the *Tr*-sector is regulated and carries the whole burden of abatement. Technically speaking, the smallest possible allocation of emission rights to the *Tr*-sector, $\underline{E}_{Tr}$, is the amount of emissions that leads to an emission tax rate t of zero in the *NTr*-sector.

In the following, we assume that the allocation of permits to the trading sector E_{Tr} is between $\underline{E}_{Tr}$ and the overall emission target $\bar{E}$.

4.3.2 The Efficient Allocation

It is assumed that a benevolent planner determines the initial allocation of permits for the trading sector E_{Tr} and hence indirectly the amount of emissions for the non-trading sector h in a welfare optimal way, subject to the set of possible allocation plans. Thereby, the planner acts as a Stackelberg leader anticipating the equilibrium behavior of all other agents. In cases involving multiplicity of equilibria a benevolent planner can determine the equilibrium that will be realized in the second stage and chooses the equilibrium that leads to the highest welfare. Therefore, we introduce the welfare function

$$W(E_{Tr}) := U(H(x^*(E_{Tr}), y^*(E_{Tr}), h^*(E_{Tr})), l^*(E_{Tr})).$$

In cases involving multiplicity of equilibria for a certain allocation E_{Tr}, the variables x^*, y^*, h^* and l^* correspond to the equilibrium that leads to the highest utility $U(\cdot)$ for the household. Clearly, if multiple equilibria exist, the function $W(E_{Tr})$ is not continuous over the whole range of E_{Tr}.

For a benevolent planner, we have the following optimization problem:

$$\max_{E_{Tr}} \; W(E_{Tr}) \tag{4.16}$$

$$\text{s.t. } \underline{E}_{Tr} \leq E_{Tr} \leq \bar{E}$$

Solving this optimization problem results in the following proposition.

Proposition 4.3. (Efficient allocation): *If the solution* E^*_{Tr} *to (4.16) satisfies*

- $\underline{E}_{Tr} < E^*_{Tr} < \bar{E}$ *and*
- $W(E_{Tr})$ *is continuously differentiable at* E^*_{Tr},

the welfare-maximizing allocation of emissions between the trading and the non-trading sector leads to a difference in the tax rate for the non-trading sector and the permit price for the trading sector of

$$t^* - \sigma^* = -\Psi_x(x^*, w^*, s^*, t^*, I^*) \sum_{i \in N} (1 + v^i) x^*_i \frac{dx^*_i}{dE_{Tr}}.$$

Proof. As first-order condition of the optimization problem, we have

$$U_H H_x \frac{dx^*}{dE_{Tr}} + U_H H_y \frac{dy^*}{dE_{Tr}} + U_H H_h \frac{dh^*}{dE_{Tr}} + U_l \frac{dl^*}{dE_{Tr}} = 0.$$

With $E_{Tr}+h^*=\bar{E}$, we have $\frac{dh^*}{dE_{Tr}}=-1$. Using the first-order conditions of the households' optimization problem, (4.2) - (4.4), results in

$$p^*\frac{dx^*}{dE_{Tr}}+q\frac{dy^*}{dE_{Tr}}-(s+t^*)+w^*\frac{dl^*}{dE_{Tr}}=0.$$

With the definition of the firms' profit functions and (4.1), (4.11) and (4.14), the household's budget constraint (4.5) can be simplified to

$$s\cdot h^*+q\cdot y^*-q\sum_{j\in\bar{N}}y_j^*=I_e-\sum_{k\in M}C^k(\cdot)-w^*\cdot l^*-g.$$

Applying Shepard's Lemma to a firm's cost function yields $C^k(\cdot)=s\cdot e_k^*+w^*\cdot\frac{\partial C^k(\cdot)}{\partial w}+r\cdot\frac{\partial C^k(\cdot)}{\partial r}$.[23] Combining this with (4.13) and (4.15) yields for the budget constraint

$$s\cdot(h^*+E_{Tr})+q\cdot y^*-q\sum_{j\in\bar{N}}y_j^*+r\cdot\sum_{k\in M}C^k(\cdot)_r=I_e-g. \tag{4.17}$$

Inserting $E_{Tr}+h^*=\bar{E}$ in (4.17) and differentiating with respect to E_{Tr} yields

$$r\frac{d\sum_{k\in M}C^k(\cdot)_r}{dE_{Tr}}=q(\frac{d\sum_{j\in\bar{N}}y_j^*}{dE_{Tr}}-\frac{dy^*}{dE_{Tr}}). \tag{4.18}$$

For the cost functions, we have $C^k=s\cdot e_k^*+r\cdot C_r^k+w^*\cdot C_w^k$ and hence,

$$C_{z_k}^k\frac{dz_k^*}{dE_{Tr}}+C_{e_k}^k\frac{de_k^*}{dE_{Tr}}=s\cdot\frac{de_k^*}{dE_{Tr}}+r\cdot\frac{dC_r^k}{dE_{Tr}}+w^*\cdot\frac{dC_w^k}{dE_{Tr}}$$

for $k\in M$. Summing up over all $k\in M$ and considering (4.7), (4.10), (4.15) and (4.18), we have

$$w^*\frac{dl^*}{dE_{Tr}}=s+\sigma^*-\sum_{k\in M}C_{z_k}^k\frac{dz_k^*}{dE_{Tr}}+q\frac{d\sum_{j\in\bar{N}}y_j^*}{dE_{Tr}}-q\frac{dy^*}{dE_{Tr}}.$$

---

[23] This Lemma is named after Ronald Shephard and says that the derivative of the cost function with respect to the price of an input factor equals the cost-minimizing input level. To apply Shephard's Lemma, the cost function of the firm has to be differentiable, which is, for example, ensured if the production function is smooth, increasing and strictly quasi-concave; see Chiang and Wainwright (2005). In Shephard (1953), a proof using the distance function can be found. Standard textbooks usually use an alternative proof based on the envelope theorem; see e.g. Chiang and Wainwright (2005), and Simon and Blume (1994).

With this result, we can simplify the first-order condition of the regulator's optimization problem to

$$\sum_{i \in N} (p^* - C^i_{x_i}) \frac{dx_i^*}{dE_{Tr}} + \sum_{j \in \bar{N}} (q^* - C^j_{y_j}) \frac{dy_j^*}{dE_{Tr}} + \sigma^* - t^* = 0.$$

With $p^* = \Psi(x^*, w^*, s, t^*, I^*)$ and due to the first-order conditions of firms' profit maximization (4.6) and (4.9), we get Proposition 4.3.

$\square$

Proposition 4.3 shows that, in a welfare-optimal solution, the permit price in the trading sector differs from the environmental tax in the non-trading sector if firms expect imperfect competition ($v^i > -1$).[24]

Interestingly, it is ambiguous, which sector faces the higher marginal abatement costs. The derivative of the inverse demand function $\Psi_x(\cdot)$ in Proposition 4.3 is always negative. If we have $v^i > -1$, the sign of the sum solely depends on the sign of $\frac{dx_i^*}{dE_{Tr}}$. Intuitively, one would expect that $\frac{dx_i^*}{dE_{Tr}}$ is positive, which results in an optimal permit price σ^*, which is less than the tax t^*. A more generous allocation to the *Tr*-sector reduces necessary abatement efforts of the firms and therefore costs. Reduced costs normally correspond to a higher output. However, the analysis in the following subsection shows that the sign of $\frac{dx_i^*}{dE_{Tr}}$ can also be negative.

This result indicates that with the European ETS, the regulator has introduced a system in which an imperfect industry has a direct impact on the optimal regulation of the perfect competitive firms of set $\bar{N}$ and on the emitters in the *NTr*-sector.

If the optimal allocation leads to $\sigma^* < t^*$, firms in the *Tr*-sector face a lower permit price compared to the tax rate in the *NTr*-sector. This means that firms of

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[24] This result is in accordance with with the literature on the second-best taxation of externalities in partial markets. The difference between sectors' marginal costs in this model is comparable with the difference between an optimal tax and the marginal environmental damage in some partial market models. In contrast to these models, we analyze a general equilibrium model with imperfect competition and do not restrict the regulatory scheme to one oligopoly product market. For a survey on the literature on taxation of externalities in oligopolies, see Section 3.2.2 or Requate (2006).

set $\bar{N}$ benefit from the imperfect competition between firms of set N. Then we have the strange situation that the European regulator has created a system in which firms in the *Tr*-sector are interested in other industries in the Emissions Trading Scheme being imperfectly competitive. Furthermore, if marginal abatement costs of emitters in the *NTr*-sector exceed the optimal permit price for emitters in the *Tr*-sector, one can say that the correction of the market-distorting behavior of firms of set N are *financed* by the emitters in the *NTr*-sector, but all other firms in the *Tr*-sector benefit from this market correction.

In case a cost-minimizing solution requires $\sigma^* > t^*$, we have a vise versa situation, in which perfectly competitive firms suffer from other industries in the *Tr*-sector being imperfectly competitive. In this case, they face a higher permit price and therefore their profits decrease. On the other hand, emitters in the *NTr*-sector benefit from this constellation.

If all firms in N have conjectural variations equal to -1 every emitter in each sector must face equal marginal abatement costs ($t^* = \sigma^*$). Therefore, only if all firms behave like price takers on their commodity markets must all marginal abatement costs be equal.

4.3.3 Partial Markets Considerations

As shown above, only the signs of $\frac{dx_i^*}{dE_{Tr}}$ in Proposition 4.3 are ambiguous. Hence, one has to analyze the behavior of firms in set N in response to an increasing amount of emissions to determine which sector faces a higher burden under the optimal allocation. In the hitherto general setting, this determination is not straightforward. Thus, for simplification, we neglect substitution effects in the consumption behavior of the household. Therefore, we assume that the commodities X, Y and energy are neither substitutes nor complements ($H_{xy} = H_{xh} = H_{yh} = 0$). Furthermore, we assume that the nested utility from consumption is linear in the amount of commodity Y. Hence, the nested utility function H is quasi-linear in y ($H_{yy} = 0$). With these simplifying assumptions, the conjectured demand function Ψ equals the *objective* inverse demand function $P(x)$:

$$\Psi(x,q,w,s,t,I) = \frac{q}{H_y} \cdot H_x =: P(x).$$

Moreover, we suppose that firms in set N have a constant labor demand in the relevant parameter range (i.e., due to Shepard's lemma $C^i_{w_i}(\cdot)$ being constant for all $i \in N$).[25] Equations (4.9) and (4.10) can be rewritten to

$$P(x) + (1 + v^i)x_i P_x(x) - C^i_{x_i}(\cdot) = 0, \tag{4.19}$$

$$-C^i_{e_i}(\cdot) - \sigma = 0. \tag{4.20}$$

The solution of this system of equations defines the equilibrium output and emission levels x^c_i and e^c_i, which solely depend on the permit price σ. To determine which sector benefits from imperfect commodity markets, we additionally restrict the analysis to a duopoly market, but allow for asymmetric firms.

With these additional assumptions we "shift" the model from the general equilibrium perspective to a partial market analysis. Of course, a partial market analysis neglects inter-market or income effects, but even without these effects, the sector with higher marginal costs cannot be determined in general. The analysis is based on the partial market model in Simpson (1995), which investigates the optimal taxation of externalities in duopolistic markets. The model was extended in Requate (2006) for non-constant marginal production costs. In addition to non-constant marginal production costs, we further extend Simpson's model for conjectural variations and adapt it to the framework of the European ETS. Thus, we can show that if firms are not too asymmetric, the emitters in the non-trading sector must face higher marginal costs, and if firms are very asymmetric, marginal abatement costs in the trading sector are higher.[26]

Since the following analysis is restricted to a duopoly commodity market, we define $N = \{1,2\}$. Solving equation (4.20) yields the cost-minimizing emissions level $\hat{e}_i(x_i,\sigma)$ for firm i, which only depends on the firm's output and the permit price. Applying the theorem of implicit functions to (4.20), we have

$$\frac{\partial \hat{e}_i}{\partial x_i} = -\frac{C^i_{x_i e_i}}{C^i_{e_i e_i}} > 0 \quad \text{and} \quad \frac{\partial \hat{e}_i}{\partial \sigma} = -\frac{1}{C^i_{e_i e_i}} < 0 \tag{4.21}$$

---

[25] Due to the assumptions of constant labor demand and fixed capital and raw material prices, the derivatives of the cost function $C^i_{x_i}(\cdot)$ and $C^i_{e_i}(\cdot)$ depend in the following only on x_i and e_i.

[26] See also Löschel (2007).

for $i \in \{1,2\}$. These results show that the cost-minimizing emissions level increases if production is expanded and decreases if permits get more expensive, which is quite intuitive. Substituting $\hat{e}_i(x_i,\sigma)$ in lhs of (4.19) yields the firm's marginal profit solely depending on the firms' output levels and the permit price:

$$P(\cdot)+(1+v^i)x_iP_x(\cdot)-C^i_{x_i}(x_i,\hat{e}_i(x_i,\sigma)):=\mu^i(x_1,x_2,\sigma)$$

Firm i's "implicit reaction function", anticipating cost-minimizing emission behavior, is then given by $\mu^i(x_1,x_2,\sigma)=0$. From these conditions, we can derive the equilibrium output level $x^c_i(\sigma)$ for all $i \in \{1,2\}$. Including the result in $\hat{e}_i(x_i,\sigma)$, we have the equilibrium emissions level $e^c_i(\sigma)$.

Following Dixit (1986), we define

$$\begin{aligned} a_i:=\mu^i_{x_i} &= (2+v^i)P_x(\cdot)+(1+v^i)x_iP_{xx}(\cdot)-C^i_{x_ix_i}-C^i_{x_ie_i}\frac{\partial\hat{e}_i}{\partial x_i} \\ &= (2+v^i)P_x(\cdot)+(1+v^i)x_iP_{xx}(\cdot)-C^i_{x_ix_i}+\frac{C^{i2}_{x_ie_i}}{C^i_{e_ie_i}} \end{aligned}$$

and

$$b_i:=\mu^i_{x_{-i}}=P_x(\cdot)+(1+v^i)x_iP_{xx}(\cdot).$$

For (4.19) and (4.20) to define a profit maximum, we must have $a_i+v^ib_i<0$ for $i \in \{1,2\}$.[27] Since we assume stability of the equilibrium, the conditions $a_i<0$ and $\Delta:=a_1a_2-b_1b_2>0$ may hold in the equilibrium.[28] Due to the assumptions about the cost function, the Hessian of $C_i(x_i,e_i)$ is positive definite and since $v_i \geq -1$, we can show that $a_i-b_i<0$ always holds.[29]

With this additional notation, the reaction of the firms to an increasing permit price can be analyzed.

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[27] This condition corresponds to the Hessian of the profit functions being negative definite.

[28] These stability conditions are based on the myopic adjustment process in Dixit (1986), whereby we implicitly assume that firms always choose the cost-minimizing amount of emissions if they adjust their output levels (i.e., Condition (4.20) is always satisfied). If we assume a dynamic system in which also the emissions level is subject to a myopic adjustment process, the necessary and sufficient stability conditions in Dixit (which are based on the Gershgorin circle theorem, see e.g. Limebeer, 1982) also imply the conditions $a_i<0$ and $\Delta:=a_1a_2-b_1b_2>0$.

[29] Seade (1980) shows for a different adjustment process that the condition $|a_i|>|b_i|$ assures stability of the equilibrium. Tirole (1988) points out that if $|a_i|>|b_i|$ always holds, this guarantees uniqueness of the equilibrium.

Lemma 4.4. *The effect of an increasing permit price on the output level of a firm* ($\frac{\partial x_i^c}{\partial \sigma}$) *is ambiguous. The deviative* $\frac{\partial x_i^c}{\partial \sigma}$ *is positive iff*

$$\frac{\frac{\partial \hat{e}_i}{\partial x_i}}{\frac{\partial \hat{e}_{-i}}{\partial x_{-i}}} < \frac{b_i}{a_{-i}}.$$

Proof. We totally differentiate the implicit reaction functions

$$P(\cdot) + (1+v^i)x_i P_x(\cdot) - C^i_{x_i}(x_i, \hat{e}_i(x_i, \sigma)) = 0$$

for all $i \in N$ with respect to the permit price σ. We then have

$$\begin{bmatrix} a_1 & b_1 \\ b_2 & a_2 \end{bmatrix} \begin{bmatrix} \frac{dx_1^c}{d\sigma} \\ \frac{dx_2^c}{d\sigma} \end{bmatrix} = \begin{bmatrix} \frac{\partial \hat{e}_1}{\partial x_1} \\ \frac{\partial \hat{e}_2}{\partial x_2} \end{bmatrix}.$$

Solving the system of equations yields

$$\begin{bmatrix} \frac{dx_1^c}{d\sigma} \\ \frac{dx_2^c}{d\sigma} \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} a_2 & -b_1 \\ -b_2 & a_1 \end{bmatrix} \begin{bmatrix} \frac{\partial \hat{e}_1}{\partial x_1} \\ \frac{\partial \hat{e}_2}{\partial x_2} \end{bmatrix}.$$

This yields firm i's change in output

$$\frac{dx_i^c}{d\sigma} = \frac{a_{-i}\frac{\partial \hat{e}_i}{\partial x_i} - b_i \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}}{\Delta}. \tag{4.22}$$

Since the denominator is by assumption always positive, i.e., $\Delta > 0$, the sign of $\frac{dx_i^c}{d\sigma}$ is solely determined by the numerator. As $a_{-i} < 0$, $\frac{\partial \hat{e}_i}{\partial x_i} > 0$ and with the possibility that $b_i < 0$ the sign of (4.22) is ambiguous.[30] Therefore, we have

$$\frac{dx_i^c}{d\sigma} > 0 \Leftrightarrow \frac{\frac{\partial \hat{e}_i}{\partial x_i}}{\frac{\partial \hat{e}_{-i}}{\partial x_{-i}}} < \frac{b_i}{a_{-i}}$$

□

In contrast to the case of exogenously given commodity prices, an increasing output can be the consequence of a higher permit price if prices are endogenous.

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[30] After applying the stricter assumptions of Simpson (1995), equation (4.22) coincides with his results.

As shown in the proof of Lemma 4.4, a necessary condition for (4.22) being positive is $b_i < 0$, i.e., the slope of the firm's reaction function must be negative. In terms of Bulow et al. (1985), this means that a necessary condition for an increasing output is that a firms considers its output as *strategic substitute*. In cases where output is a *strategic complement* ($b_i > 0$), the effect of an increasing permits price is unambiguous and the change in output is always negative.

Lemma 4.5. *If one firm's output increases due to a higher permit price, the competitor's output must decrease to an even greater extent.*

Proof. Due to $a_i - b_i < 0$ and (4.22), we have

$$\frac{dx_1^c}{d\sigma} + \frac{dx_2^c}{d\sigma} = \frac{(a_1 - b_1)\frac{\partial \hat{e}_2}{\partial x_2} + (a_2 - b_2)\frac{\partial \hat{e}_1}{\partial x_1}}{\Delta} < 0. \tag{4.23}$$

$\square$

According to Lemma 4.5, only one firm's output can increase with an increasing permit price. But even if one firm's output increases, this positive effect is always outweighed by a decreasing output level of its competitor. Hence, the total industry's output always decreases.

With the results of Lemma 4.4 and Lemma 4.5, we can derive the conditions for an optimal permit price exceeding the environmental tax in the *NTr*-sector.

Proposition 4.6. (Condition for a higher permit price.) *For* $\frac{d\sigma^*}{dE_{Tr}} < 0$ *and with* $L_i := \frac{P - C^i_{x_i}}{P}$ *a welfare-maximizing allocation induces* $\sigma^* > t^*$ *iff* $\exists i \in N$ *with*

$$\frac{dx_i^c}{d\sigma} > 0 \text{ and } \frac{L_i}{L_{-i}} > \frac{\left|\frac{dx_{-i}^c}{d\sigma}\right|}{\frac{dx_i^c}{d\sigma}}.$$

Proof. With the additional assumptions for the duopoly imperfect product market, the optimal difference between tax and permit price from Proposition 4.3 can be simplified to

$$t^* - \sigma^* = -P_x(\cdot)\frac{d\sigma^*}{dE_{Tr}} \cdot \sum_{i \in \{1,2\}} (1 + v^i)x_i^* \frac{dx_i^c(\sigma^*)}{d\sigma}$$

with $x_i^* = x_i^c(\sigma^*)$. By assuming $\frac{d\sigma^*}{dE_{Tr}} < 0$, the term outside the sum is always negative. Therefore, the sign of the difference $t^* - \sigma^*$ is only negative if

$$\sum_{i\in\{1,2\}} (1+v^i)x_i^* \frac{dx_i^c(\sigma^*)}{d\sigma} > 0.$$

Multiplying the sum with $-\frac{P_x}{P}$ and applying the first-order condition (4.19) we have

$$\sum_{i\in\{1,2\}} \frac{P - C^i_{x_i}}{P} \frac{dx_i^c(\sigma^*)}{d\sigma} > 0.$$

Due to Lemma 4.5, we know that if $\frac{dx_i^c(\sigma^*)}{d\sigma} > 0$ we have $\frac{dx_{-i}^c(\sigma^*)}{d\sigma} < 0$. With $L_i := \frac{P-C^i_{x_i}}{P}$ we have

$$\frac{L_i}{L_{-i}} > -\frac{\frac{dx_{-i}^c}{d\sigma}}{\frac{dx_i^c}{d\sigma}}.$$

□

Proposition 4.6 shows that, for most parameter constellations, the permit price σ^* is lower than the environmental tax t^*, which means that the *Tr*-sector carries a lower burden than the *NTr*-sector. Only in cases where a firm's output increases due to a more restrictive regulation of emissions ($\frac{dx_i^c}{d\sigma} > 0$) and the Lerner index L_i of this firm is sufficiently higher than the index of its competitor is the efficient tax rate is lower than the permit price.[31] From Lemma 4.5 it is obvious that from $\frac{dx_i^c}{d\sigma} > 0$ follows $\left|\frac{dx_{-i}^c}{d\sigma}\right| > \frac{dx_i^c}{d\sigma}$.

The result of Proposition 4.6 is based on the assumption of a decreasing permit price function ($\frac{d\sigma^*}{dE_{Tr}} < 0$). Intuitively, this can be motivated by the intuition that a more generous allocation to the *Tr*-sector corresponds to less abatement efforts for the firms. But for sufficiently asymmetric firms, it is possible that the permit price increases due to a more generous allocation (see Section 4.5.1). In this case, the conditions derived in Proposition 4.6 lead to a permit price lower than the environmental tax in the *NTr*-sector.

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[31] The Lerner index is a measure for the market power of a firm. It measures the ratio of the difference between price and marginal costs and the market price. See Bester (2004).

This very special case is for the real EU ETS of minor importance, since it is only possible in the unlikely case that the firm that uses the more carbon-dioxide-intensive technology has a competitive advantage through a higher permit price. A necessary condition for this is strongly asymmetric marginal production costs. A more detailed analysis of this special case can be found in Section 4.5, which analysis the consequences of multiple equilibria.

The main finding of this section is that even if for most cases the higher burden must be carried by the *NTr*-sector, a general conclusion can not be drawn. This analysis shows that even if we neglect any income or substitution effects, it still depends on firms' asymmetry which sector faces the higher marginal abatement costs. Hence, the decision of which sector has the lower burden can only be made using a case-by-case analysis.

Another question is whether the magnitude of the difference is of any relevance for the European ETS or if we are only talking about a theoretical result. Therefore, a numerical example is conducted in Section 4.4.

4.4 Numerical Example

The results in Section 4.3 show that an unambiguous identification of the direction in which the effect points is not possible without further knowledge about the emitting firms. Collecting this information correlates, of course, with additional costs for the regulator. Therefore, the question arises as to whether the consideration of oligopoly markets is of real relevance for the European Emission Trading Scheme. Hence, we apply a simple numerical example in order to answer this question.

This numerical example is based on stricter assumptions than the general model in Section 4.2. Hence, of course it is not possible to exactly determine the optimal difference in marginal abatement costs between both sectors. In this example, we just analyze the magnitude that the difference may have and if the theoretical result in this chapter should be considered in further analysis of the EU ETS, or if it is of minor importance.

In this section, we assume an imperfectly competitive industry with n firms. In doing so, we maintain the partial market assumptions of Section 4.3.3. Therefore, we assume $H_{xy} = H_{xh} = H_{yh} = H_{yy} = 0$ and constant labor demand of the imperfect industry. Furthermore, in a first analysis, we assume that all firms have Cournot conjectures about their competitors' behavior.[32] In the second part of this numerical example, a profit-maximizing cartel is analyzed.

Due to computational reasons, we have to introduce some additional assumptions concerning the demand and firms' cost functions. For the firms' cost functions, we suppose that they are linear in output,

$$C^i_{x_i x_i}(\cdot)C^i_{e_i e_i}(\cdot) - C^i_{x_i e_i}(\cdot)^2 = 0 \tag{4.24}$$

and that the cost minimal amount of emissions for the next output unit is approximately equal to the average amount of emissions per output unit

$$\frac{\partial \hat{e}_i(x_i^*, \sigma^*)}{\partial x_i} \approx \frac{e_i^*}{x_i^*}. \tag{4.25}$$

This cost function is critical in two ways: First, it assumes that firms' marginal production costs are constant. Second, the average emissions per output unit are constant, i.e., firms have no possibility to abate emissions.[33] In the short-term, this assumption neglects the possibility of fuel switches (e.g., from coal to gas) if production is expanded. However, one can argue that in the medium-term, firms maintain their mix of different technologies and, therefore, marginal production costs and average emissions are constant. Of course, the assumptions about the

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[32] Borenstein and Bushnell (1999) e.g. support the use of a Cournot model to analyze electricity markets, since prices mainly depend on available capacities.

[33] For instance the cost function

$$C^i(x_i, e_i) = \underbrace{s \cdot e_i}_{\text{raw material costs}} + \underbrace{r \cdot \alpha_i(\lambda_i \cdot x_i - e_i)^2}_{\text{emission abatement costs}} + \underbrace{F_i}_{\text{fixed costs}}$$

satisfies these properties for large α_i. The parameter λ_i is the amount of emissions per output unit without abatement. Hence, $\lambda_i x_i - e_i$ is the amount of abated emissions. The parameter α_i reflects the firm's possibilities to abate emissions. The term F_i represents the firm's fixed costs, including the wage for the constant labor demand. For this cost function, we have due to (4.20) $\frac{\partial \hat{e}_i(x_i,\sigma)}{\partial x_i} = \frac{e_i}{x_i} + \frac{s+\sigma}{2r\alpha_i x_i}$. If emission abatement is very expensive, i.e., α_i is very large, the fraction $\frac{s+\sigma}{2r\alpha_i x_i}$ tends toward zero.

cost function do not exactly reflect the real cost structure of the investigated industry, but for the sake of computability, it is applied to this model as an approximation. Furthermore, constant price elasticity of demand is assumed, $\varepsilon < 0$, which leads to an inverse demand function

$$P(x) = \beta x^{\frac{1}{\varepsilon}} \tag{4.26}$$

with $x = \sum_{i \in N} x_i$.

Proposition 4.7. (Interior solution): *If x_i is the equilibrium output of a firm i satisfying (4.19), (4.20), (4.24) and (4.26) for all $i \in N$ it must hold that*

$$\varepsilon < -\max_{i \in N} \left\{ (1 + v^i) \frac{x_i}{x} \right\}.$$

Proof. Including the additional assumptions made for the numerical example, firm i's profit function becomes

$$\Pi_i(x_i, x_{-i}, e_i) = \beta x^{\frac{1}{\varepsilon}} \cdot x_i - C^i(\cdot) - \sigma(e_i - e_i^0).$$

The first-order conditions are

$$\beta x^{\frac{1}{\varepsilon}} + \frac{1}{\varepsilon} \beta x^{\frac{1}{\varepsilon}-1} (1 + v^i) \cdot x_i - C^i_{x_i} = 0, \text{ and} \tag{4.27}$$

$$-C^i_{e_i} - \sigma = 0. \tag{4.28}$$

The determinant of the Hessian of the profit function considering the expected rival's response is

$$-C^i_{e_i e_i} \cdot \left(\frac{2\left(1 + v^i\right)}{\varepsilon} \beta x^{\frac{1}{\varepsilon}-1} + \frac{1}{\varepsilon} \left(\frac{1}{\varepsilon} - 1 \right) \beta x^{\frac{1}{\varepsilon}-2} \left(1 + v^i\right)^2 \cdot x_i \right)$$
$$+ \underbrace{C^i_{x_i x_i}(\cdot) C^i_{e_i e_i}(\cdot) - C^i_{x_i e_i}(\cdot)^2}_{=0}.$$

Since we only investigate expected competition between price-taking and collusion, we have $-1 < v^i \leq \frac{x - x_i}{x_i}$.[34] A necessary condition to guarantee that (4.27)

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[34] Since we assume constant production costs, i.e. $C^i_{x_i x_i}(\cdot) C^i_{e_i e_i}(\cdot) - C^i_{x_i e_i}(\cdot)^2 = 0$, we have to exclude the case of price-taking firms, i.e. $v^i = -1$. In cases involving collusive behavior, we have $v^i = \frac{x - x_i}{x_i}$. For conjectural variations in cases involving collusion, see Dixit (1986).

and (4.28) determine a profit maximum is that the determinant of the Hessian is greater or equal to zero in equilibrium. Hence, the following condition must be satisfied

$$\varepsilon \leq -\frac{(1+v^i)s_i}{2-(1+v^i)s_i}, \tag{4.29}$$

whereas s_i is firm i's market share (x_i/x). Combining (4.27) and (4.28) the first-order conditions simplify to

$$\beta x^{\frac{1}{\varepsilon}}(1+\frac{1+v^i}{\varepsilon}s_i) - C^i_{x_i}(x_i, \hat{e}_i(x_i, \sigma)) = 0.$$

For the existence of an interior solution, a necessary condition is that the term $1+\frac{1+v^i}{\varepsilon}s_i$ is positive, which coincides with the condition

$$\varepsilon < -(1+v^i)s_i. \tag{4.30}$$

It is easy to show that condition (4.30) is at least as restrictive as condition (4.29). Therefore, for an interior solution for all firms $i \in N$, the following condition must be satisfied:

$$\varepsilon < -\max_{i \in N}\left\{(1+v^i)s_i\right\}.$$

$\square$

With the additional assumptions about firms' cost functions and the inverse demand function, only a few values are needed to estimate the optimal difference between sectors' marginal abatement costs. We need to know the number of firms in the oligopoly, the firms' output levels in equilibrium, the firms' emissions, the price elasticity of demand and the slope of the permit price function.

4.4.1 The German Electricity Market

In the following, we investigate an imperfect market in the *Tr*-sector, which is comparable to the German power supply industry. Table 4.1 shows the five dominating firms in the German electricity market, which control a total market share

Company	Electricity production (x_i) [bil.kWh]	CO_2 emissions (e_i) [mil.t]	e_i/x_i
RWE	149	116	0.78
E.On	131	65	0.50
Vattenfall	76	73	0.96
EnBW	68	10	0.15
STEAG	40	36	0.90
Sum	464	300	0.65

Table 4.1: *Electricity production and CO_2 emissions of the largest German power suppliers. Source: WWF (2006).*

of over 80%.[35] Due to Borenstein and Bushnell (1999), supply elasticity from other small firms could be incorporated as part of the demand elasticity. In the medium-term, entry and exit effects can also be included by assuming a more elastic demand function.

As mentioned in Chapter 2, the actual allocation for the first trading period leads to much higher marginal costs for the *NTr*-sector than for the *Tr*-sector. If we assume that the optimal difference in marginal costs is of comparable size, the firms' equilibrium output levels can be taken from the first column in Table 4.1 as an approximation. Since the determination of the price elasticity of electricity demand is very difficult and varies with the investigated time period, a range of elasticities is used in this example. The examined price elasticities are between the theoretical upper bound and -2. In the case of the German electricity market and Cournot behavior, an interior solution requires, due to Proposition 4.7, an elasticity less than the negative market share of RWE. This means that $\varepsilon < -0.32$.[36]

To estimate the properties of the permit price function, we use the cost func-

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[35] See e.g. WWF (2006), Hirschhausen et al. (2007).

[36] The assumption of small absolute elasticities in the short-term and relatively high absolute elasticities in the long-term are common in the analysis of electricity markets. Lise et al. (2006) assumes a price elasticity of demand for the German electricity market of -0.4. Pfaffenberger (1993) uses in the short-term an elasticity of -0.13 and in the long-term an elasticity of -1.93. Borenstein and Bushnell (1999) analyze the Californian market for electricity for a range of elasticities between -0.1 and -1.

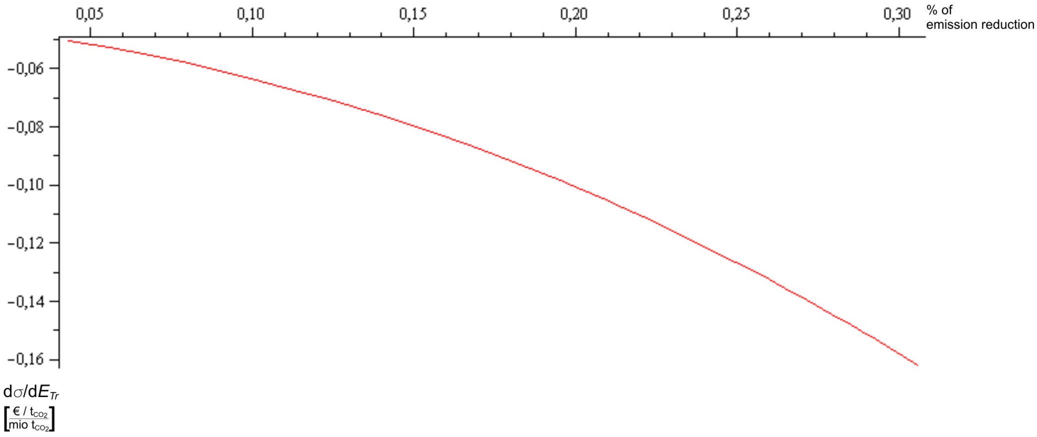

Figure 4.1: *Slope of permit price function*

tions published in Böhringer et al. (2005) for 14 EU states' trading sectors. These functions are critical, as they are calculated with the implicit assumption of perfectly competitive markets, which we are criticizing. Due to a lack of more exact data, we use these functions as an approximation to calculate the slope of the permit price function. The derivation of the slope of the permit price function in a more general version can be found in Section 5.1.1 and in the numerical example in Section 5.1.4. Figure 4.1 shows the resulting values of the derivation of the permit price function, depending on the relative reduction of emissions compared to the projected emissions in 2005 without any abatement. To face the possibly inaccurate cost functions, we investigate again a range of values for the derivation. Therefore, the following slopes of the permit price function are used for our analysis: $-0.05\frac{€/\text{t}_{CO_2}}{\text{mil t}_{CO_2}}$, $-0.10\frac{€/\text{t}_{CO_2}}{\text{mil t}_{CO_2}}$, and $-0.15\frac{€/\text{t}_{CO_2}}{\text{mil t}_{CO_2}}$.

4.4.2 Cournot Behavior

First, we analyze the case where all five firms behave as quantity setters ($v^i = 0, \forall i \in N$). The computed cost-minimizing difference in marginal abatement costs between sectors for this case are shown for particular parameter values in Table 4.2 and are visualized in Figure 4.2.

It can be shown that for small absolute demand elasticities – which is a reasonable assumption for a short-term analysis – the difference $t^* - \sigma^*$ is maximal

$\frac{d\sigma}{dE_{Tr}} \left[\frac{€/t_{CO_2}}{\text{mil } t_{CO_2}}\right]$ ε	-0.05	-0.10	-0.15
-0.33	13.51	27.02	40.53
-0.50	7.78	15.57	23.35
-1	5.05	10.10	15.14
-2	4.13	8.27	12.40

Table 4.2: *Difference in marginal costs under Cournot behavior in* $€/t_{CO_2}$

and decreases with increasing absolute values of the demand elasticity. Moreover, the steeper the permit price function, the higher the optimal difference between the sectors' marginal costs is. In cases where there is a very inelastic demand function ($\varepsilon = -0.33$) and a very reactive permit price function ($\frac{d\sigma}{dE_{Tr}} = -0.15$), the difference adds up to more than 40 € per ton of carbon dioxide. Also, for the case of a very elastic demand function ($\varepsilon = -2$) and a relatively flat permit price function ($\frac{d\sigma}{dE_{Tr}} = -0.05$), the difference is still over 4 €.

Estimations of the optimal marginal abatement costs for first period neglecting imperfect markets were between 5 and 14 €. Actual market prices for permits in the first and second trading period have been between 0 and 30 €.[37] Comparing this scale of marginal costs within our numerical example, necessary differences between marginal abatement costs of 4 to 40 €, it can be concluded that the impact of imperfect commodity markets on the allocation of emissions in the EU ETS should be taken into account.

Another result of the numerical example is that nearly all firms reduce their output if the permit price increases. Although, there are two exceptions. The company EnBW, which generates the lowest level of emissions for an additional output unit ($\frac{\partial \hat{e}_i}{\partial x_i} = 0.15$), is the only company increasing its output due to a higher permit price for all investigated demand elasticities. This coincides with the more general case of Section 4.3.3, in which a company applying a less carbon-dioxide-

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[37] For example Böhringer et al. (2005) estimated the optimal marginal abatement costs for the EU ETS at 13.9 € (see also Section 5.1.4). For the permit price development during the first period, see Section 2.3.2.

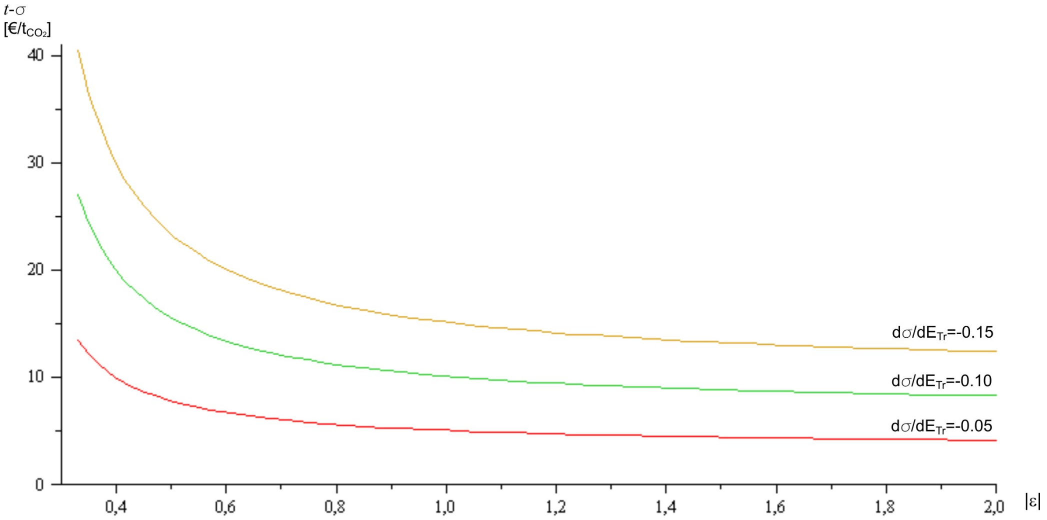

Figure 4.2: *Difference in marginal costs under Cournot behavior in* $€/t_{CO_2}$.

intensive technology ($\frac{\partial \hat{e}_i}{\partial x_i} < \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}$) has more easily an advantage over its competitors if the permit price rises ($\frac{dx_i^c}{d\sigma} > 0$).

Only for very inelastic demand functions ($\varepsilon > -0.41$), the company STEAG also increases its output as a consequence of a higher permit price (as shown in Figure 4.3). That a company extends its output due to a higher permit price without creating the lowest level of emissions can be motivated by interpreting the result of Lemma 4.4 for the duopoly case. We know that the output of a firm i only increases if

$$\frac{\frac{\partial \hat{e}_i}{\partial x_i}}{\frac{\partial \hat{e}_{-i}}{\partial x_{-i}}} < \frac{b_i}{a_{-i}}.$$

For the duopoly case, using the additional assumptions (4.24) and (4.25) of the numerical example, we know that $\frac{b_i}{a_{-i}} > \frac{b_{-i}}{a_i}$ is equivalent to $s_i < s_{-i}$. Hence, if firms' production technologies have an equal demand for emissions, only the firm with the lower market share could increase its output due to an increasing permit price. Although, if the market share s_i of firm i is sufficiently small, the fraction $\frac{b_i}{a_{-i}}$ increases with a less elastic demand function.[38] This justifies why STEAG, being the company with the lowest market share in the example, increases its

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[38] For the deviation of $\frac{b_i}{a_{-i}}$ we have $\frac{d(b_i/a_{-i})}{d\varepsilon} = \frac{(s_{-i}-2s_i)}{\varepsilon^2(2+s_{-i}(\frac{1}{\varepsilon}-1))^2}$. Therefore, if $s_i < 0.5s_{-i}$ the fraction increases as a consequence of a less elastic demand function.

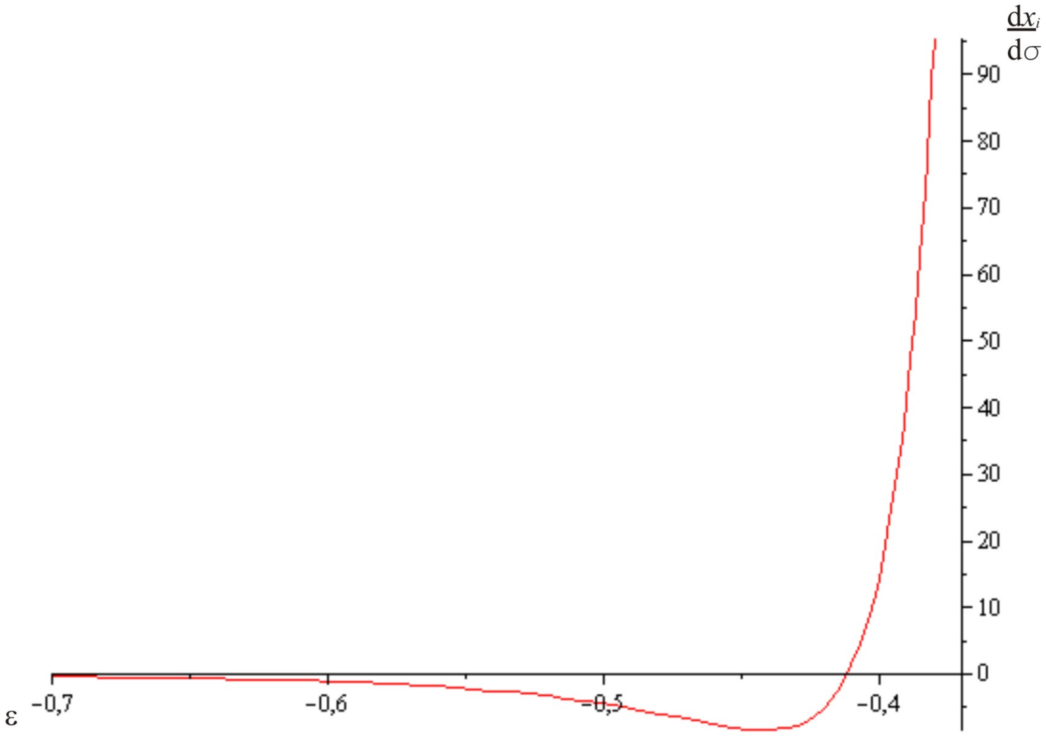

Figure 4.3: *Output changes of STEAG due to an increasing permit price depending on the demand elasticity* ε *(for* $\beta = 1 \times 10^6$*).*

$\frac{d\sigma}{dE_{Tr}} \left[\frac{€/t_{CO_2}}{\text{mil } t_{CO_2}}\right]$ ε	-0.05	-0.10	-0.15
-1.05	315.00	630.00	945.00
-1.5	45.00	90.00	135.00
-2	30.00	60.00	90.00

Table 4.3: *Difference in marginal costs with cartel behavior in* $€/t_{CO_2}$

output as a consequence of a higher permit price if the demand function becomes very inelastic.

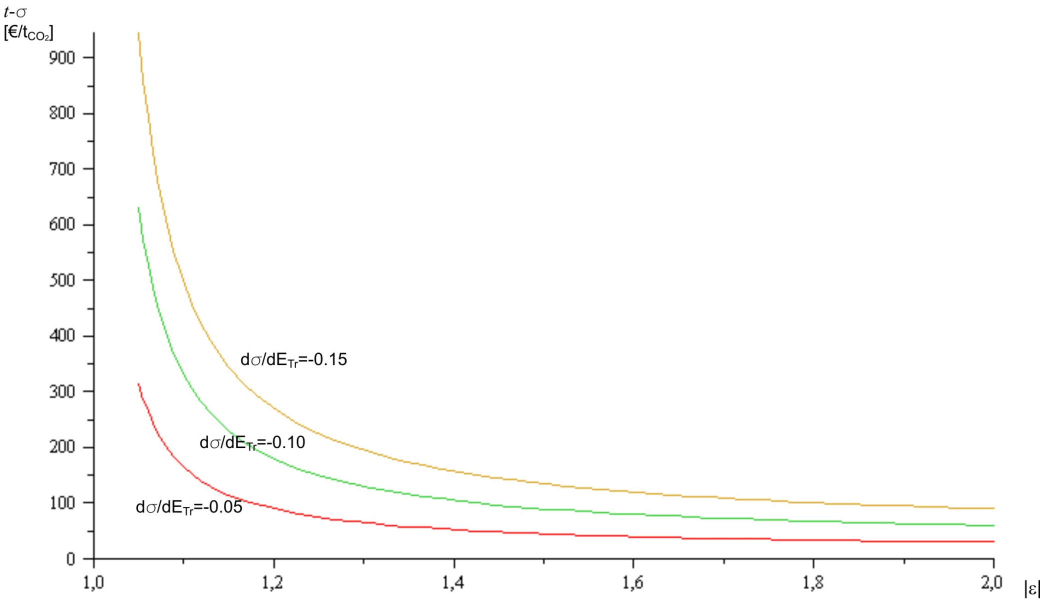

Figure 4.4: *Difference in marginal costs with cartel behavior in* €/t_{CO_2}

4.4.3 Cartel Behavior

We analyze now the extreme case that all five companies act as a profit-maximizing cartel. For this purpose, we assume that all five firms act as one firm and produce 464 bil. kWh of electricity using a mix of technologies that is constant in marginal production costs and in average emissions per output unit. For an interior solution of the profit-maximization problem, the demand function must be elastic due to price changes ($\varepsilon < -1$).

The computed optimal differences between the marginal costs of both sectors are given in Table 4.3 and in Figure 4.4. The value varies from 30 € for a very elastic demand and a flat permit price function to 945 € for a nearly inelastic demand and a steep permit price function.

These values seem to be pretty high and are probably not realistic, as the analyzed scenario of cartel behavior does not fit the conditions on the German electricity market. However, this scenario is a kind of worst-case scenario and shows that the impact of imperfect industries in the *Tr*-sector on an optimal allocation cannot be neglected per se and should be included in further research.

4.5 The EU Emissions Regulation and Multiplicity of Equilibria

Since in this work the EU emissions regulation is analyzed in a very general setting, multiplicity of equilibria cannot be excluded. Hence, we assume that in cases involving multiple equilibria, the regulator is able to choose the most favored equilibrium.[39] One possible approach for the regulator to choose an equilibrium and avoid undesired equilibria in an emissions trading scheme could be an additional price regulation, which is analyzed in the following.

As an example for multiplicity of equilibria, we analyze again the partial market scenario of Section 4.3.3, which neglects any substitution effects between consumption goods and income effects. Hence, we maintain the assumptions of $H_{xy} = H_{xh} = H_{yh} = H_{yy} = 0$ and constant labor demand of imperfect firms. The main results of this analysis are that multiple equilibria cannot be excluded and that an additional price regulation can outperform a pure quantity regulation like emissions trading. The explanation is that only a supplemental price regulation can guarantee a certain equilibrium, whereas a pure emissions trading scheme cannot assure a certain market outcome. To investigate this, firms' emission behavior has to be examined in detail.

4.5.1 Firms' Emission Behavior

The conditions in Proposition 4.6 for a higher permit price σ compared to the environmental tax t in the *NTr*-sector are based on the assumption that the permit price decreases with an increasing allocation of emissions to the *Tr*-sector. This seems to be quite intuitive, since a more generous allocation coincides with less effort of the firms in the *Tr*-sector to reduce emissions. But it can be shown that this intuitive interpretation is not always true. If firms are asymmetric, certain emitters can benefit more from less strict regulations than others. A consequence could be that the market structure changes, like we have already seen in Section 4.3.3: One firm can extend its production if the permit price rises. This effect also

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[39] See also Section 4.2.

has an impact on firms' emission behavior and a result thereof could be that the permit price rises if the allocation of permits to the trading sector is enlarged.

In this section, we assume that the *Tr*-sector contains only two firms and both possess market power ($M = N = \{1,2\}$). The output level $x_i^c(\sigma)$ and the emissions level $e_i^c(\sigma)$ of firm i are still the equilibrium levels derived in Section 4.3.3, i.e., the solution of (4.19) and (4.20). From (4.13), we know that in equilibrium firms use all allocated emission permits:

$$E_{Tr} = \sum_{i=1}^{2} e_i^c(\sigma^*).$$

Using the theorem of implicit functions we have

$$\frac{d\sigma^*}{dE_{Tr}} = \frac{1}{\sum_{i=1}^{2} \frac{de_k^c(\sigma^*)}{d\sigma}}. \tag{4.31}$$

To determine the sign of $\frac{d\sigma^*}{dE_{Tr}}$, we examine firms' emission behavior in response to an increasing permit price, $\sum_{i=1}^{2} \frac{de_k^c(\sigma^*)}{d\sigma}$.

Lemma 4.8. *The emissions level of firm i only increases due to an increasing permit price (*$\frac{de_i^c}{d\sigma} > 0$*) iff its output increase is sufficiently strong (*$\frac{dx_i^c}{d\sigma} > -\frac{1}{C^i_{x_ie_i}}$*).*

Proof. Solving (4.20) yields the cost-minimizing emissions level $\hat{e}_i$ depending on firm i's output and the permit price. Using $e_i^c(\sigma) = \hat{e}_i(x_i^c(\sigma), \sigma)$, the slope of the equilibrium emissions level with respect to the permit price is

$$\frac{de_i^c}{d\sigma} = \frac{\partial \hat{e}_i}{\partial x_i}\frac{dx_i^c}{d\sigma} + \frac{\partial \hat{e}_i}{\partial \sigma}. \tag{4.32}$$

Due to (4.21), the last term rhs of (4.32) is always negative. The sign of the first term rhs solely depends on the sign of $\frac{dx_i^c}{d\sigma}$ since $\frac{\partial \hat{e}_i}{\partial x_i}$ is positive. In the case of the equilibrium output decreasing with the permit price, the equilibrium emissions level also decreases, i.e.s $\frac{de_i^c}{d\sigma} < 0$. If the equilibrium output increases with the permit price, the effect on the firm's emissions is ambiguous. Only if the output increase is sufficiently will the emissions level also increase:

$$\frac{de_i^c}{d\sigma} > 0 \Leftrightarrow \frac{dx_i^c}{d\sigma} > -\frac{\frac{\partial \hat{e}_i}{\partial \sigma}}{\frac{\partial \hat{e}_i}{\partial x_i}} \Leftrightarrow \frac{dx_i^c}{d\sigma} > -\frac{1}{C^i_{x_i e_i}}.$$

□

There are two effects of an increasing permit price on the optimal emissions level: a direct and an indirect effect. The direct effect is based on the increased costs for emitting carbon dioxide ($\frac{\partial \hat{e}_i}{\partial \sigma}$) and is always negative. The indirect effect arises from the change in output ($\frac{\partial \hat{e}_i}{\partial x_i}$) and is only positive if a firm increases its production. If this increase is sufficiently strong, the indirect effect exceeds the direct effect and even total emissions can increase in response to a higher permit price.[40]

Lemma 4.9. *Necessary conditions for an industry's total emissions to rise in response to a higher permit price are*

- *there exists a firm i (*$i \in \{1,2\}$*) whose emissions level increases due to a higher permit price (*$\frac{de_i^c}{d\sigma} > 0$*) and*
- *for which* $\frac{\partial \hat{e}_i}{\partial x_i} > \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}$.

Proof. Summing up the effects of an increasing permit price on a firms' emission yields

$$\frac{de_1^c}{d\sigma} + \frac{de_2^c}{d\sigma} = \frac{\partial \hat{e}_1}{\partial x_1}\frac{dx_1^c}{d\sigma} + \frac{\partial \hat{e}_2}{\partial x_2}\frac{dx_2^c}{d\sigma} + \frac{\partial \hat{e}_1}{\partial \sigma} + \frac{\partial \hat{e}_2}{\partial \sigma}. \tag{4.33}$$

The last two terms of (4.33) are negative; only the first two terms are ambiguous. If both firms decrease their output total emissions must also decrease. The interesting case is if one firm's output increases. We assume w.l.o.g. that $\frac{dx_1^c}{d\sigma} > 0$, then due to (4.23), it must hold that $\frac{dx_2^c}{d\sigma} < 0$ and $\frac{dx_1^c}{d\sigma} < \left|\frac{dx_2^c}{d\sigma}\right|$.

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[40] This result is already known in literature. Requate (2006) shows that it cannot be guaranteed that the amount of emissions decreases with an higher emission tax rate.

Furthermore, if we have $0 < \frac{\partial \hat{e}_1}{\partial x_1} < \frac{\partial \hat{e}_2}{\partial x_2}$, we can state that (4.33) must always be negative. Only if $\frac{\partial \hat{e}_1}{\partial x_1} > \frac{\partial \hat{e}_2}{\partial x_2}$, is the sign of (4.33) ambiguous.

$\square$

Lemma 4.9 shows that total emissions can only increase due to a higher permit price if the firm, emitting more for an additional output unit (i.e., $\frac{\partial \hat{e}_i}{\partial x_i} > \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}$), extends its production with an increasing permit price (i.e., $\frac{dx_i^c}{d\sigma} > 0$). In cases where there is increasing total emissions, we have, due to (4.31), the counterintuitive situation that the permit price is positively correlated with the amount of emissions assigned to the *Tr*-sector ($\frac{d\sigma^*}{dE_{Tr}} > 0$).[41]

In this case, the assumption $\frac{d\sigma^*}{dE_{Tr}} < 0$ in Proposition 4.6 does not hold. As described in Section 4.3.3, this means that the conditions in this proposition lead to a lower permit price compared to the environmental tax in the *NTr*-sector ($\sigma^* < t^*$).

However, the following lemmata show that this is very unlikely and that aggregate emissions can only increase if the demand function is sufficiently convex or concave.[42] For most cases, it can be shown that industry's emissions decrease after the permit price increases. Hence, the assumption of a decreasing permit price nearly always holds and so does the result of Proposition 4.6.

Lemma 4.10. *$\frac{\partial \hat{e}_i}{\partial x_i} < \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}$ is a necessary condition for $\frac{dx_i^c}{d\sigma} > 0$ and $\frac{de_i^c}{d\sigma} > 0$ if*

- $C^i_{x_i}(x_i^*, e_i^*) = C^{-i}_{x_{-i}}(x_{-i}^*, e_{-i}^*)$, *or*
- $C^i_{x_i}(x_i^*, e_i^*) > C^{-i}_{x_{-i}}(x_{-i}^*, e_{-i}^*)$ *and* $P_{xx} \leq \frac{P_x \cdot (a_{-i} - b_{-i})}{C^i_{x_i} - C^{-i}_{x_{-i}}}$, *or*
- $C^i_{x_i}(x_i^*, e_i^*) < C^{-i}_{x_{-i}}(x_{-i}^*, e_{-i}^*)$ *and* $P_{xx} \geq \frac{P_x \cdot (a_{-i} - b_{-i})}{C^i_{x_i} - C^{-i}_{x_{-i}}}$.

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[41] The effect of an increasing permit price on firms' profits is also ambiguous. We show that both firms can benefit from a higher permit price, in contrast to Simpson (1995) and Requate (2006). For a detailed analysis, see Chapter 6.

[42] This result extends the result in Levin (1985), who showed only for the case without any emission abatement that increasing aggregate emissions imply a demand function with an extreme curvature.

Proof. Due to (4.22), the sufficient conditions for $\frac{dx_i^c}{d\sigma} > 0$ are $b_i < 0$ and

$$\frac{a_{-i}}{b_i} < \frac{\frac{\partial \hat{e}_{-i}}{\partial x_{-i}}}{\frac{\partial \hat{e}_i}{\partial x_i}}.$$

Therefore, if $\frac{a_{-i}}{b_i} \geq 1$ the condition $\frac{\partial \hat{e}_i}{\partial x_i} < \frac{\partial \hat{e}_{-i}}{\partial x_{-i}}$ is a necessary condition for $\frac{dx_i^c}{d\sigma} > 0$ to hold. Reformulating $\frac{a_{-i}}{b_i} \geq 1$ yields $a_{-i} - b_i \leq 0$, which is equal to

$$[(1+v^i)x_i - (1+v^{-i})x_{-i}]P_{xx}(\cdot) \geq (1+v^{-i})P_x(\cdot) - C^{-i}_{x_{-i}x_{-i}} + \frac{C^{-i2}_{x_{-i}e_{-i}}}{C^{-i}_{e_{-i}e_{-i}}}.$$

Inserting (4.19) yields

$$(C^i_{x_i} - C^{-i}_{x_{-i}})P_{xx}(\cdot) \leq (a_{-i} - b_{-i})P_x(\cdot). \tag{4.34}$$

Since $a_{-i} - b_{-i}$ and $P_x(\cdot)$ are always negative, condition (4.34) is always satisfied for $C^i_{x_i} = C^{-i}_{x_{-i}}$.

If $C^i_{x_i} > C^{-i}_{x_{-i}}$, we have $P_{xx}(\cdot) \leq \frac{(a_{-i}-b_{-i})P_x(\cdot)}{C^i_{x_i}-C^{-i}_{x_{-i}}}$. For the case of $C^i_{x_i} < C^{-i}_{x_{-i}}$, we have $P_{xx}(\cdot) \geq \frac{(a_{-i}-b_{-i})P_x(\cdot)}{C^i_{x_i}-C^{-i}_{x_{-i}}}$.

□

Lemma 4.11. *For $C^i_{x_i}(x_i^*, e_i^*) > C^{-i}_{x_{-i}}(x^*_{-i}, e^*_{-i})$ the condition $P_{xx} \leq \frac{P_x\cdot(a_{-i}-b_{-i})}{C^i_{x_i}-C^{-i}_{x_{-i}}}$ is always satisfied if firm $-i$ regards its output as strategic substitute and $v^{-i} \geq 0$.*

Proof. If $P_{xx}(\cdot) \leq 0$, the condition $P_{xx} \leq \frac{P_x\cdot(a_{-i}-b_{-i})}{C^i_{x_i}-C^{-i}_{x_{-i}}}$ is always satisfied, since P_x and $a_{-i} - b_{-i}$ are negative and $C^i_{x_i} - C^{-i}_{x_{-i}}$ is positive.

Let us now consider the case $P_{xx}(\cdot) > 0$. For $C^i_{x_i} > C^{-i}_{x_{-i}}$ the condition $P_{xx}(\cdot) \leq \frac{(a_{-i}-b_{-i})P_x(\cdot)}{C^i_{x_i}-C^{-i}_{x_{-i}}}$ is always satisfied if $a_{-i} - b_i \leq 0$. See the Proof of Lemma 4.10. If outputs are strategic substitutes ($b_1, b_2 < 0$), it is easy to show that $0 \leq (1+v^i)x_iP_{xx} < -P_x$ must hold for all $i \in \{1,2\}$. Therefore, we have $b_i \geq P_x$ and $a_{-i} < (1+v^{-i})P_x(\cdot) - C^{-i}_{x_{-i}x_{-i}} + \frac{C^{-i2}_{x_{-i}e_{-i}}}{C^{-i}_{e_{-i}e_{-i}}}$. Hence, we have for the difference $a_{-i} - b_i$:

$$a_{-i} - b_i < v^{-i}P_x(\cdot) - C^{-i}_{x_{-i}x_{-i}} + \frac{C^{-i2}_{x_{-i}e_{-i}}}{C^{-i}_{e_{-i}e_{-i}}}.$$

Since the Hessian of the cost function is positive definite, the difference is always negative if $v^{-i} \geq 0$.

$\square$

Lemma 4.10 shows that, for most cases, a necessary condition for a firm to increase output due to a higher permit price ($\frac{dx_i^c}{d\sigma} > 0$) is that the firm creates fewer emissions for an additional output unit than its competitor ($\frac{\partial \hat{e}_i}{\partial x_i} < \frac{\partial \hat{e}_{-j}}{\partial x_{-j}}$). In other words, the firm uses a production technology that depends less on usage of fossil fuels compared to the other firm. This can be interpreted to mean that the firm suffers less from higher costs for emitting carbon dioxide and thus has an advantage vis-a-vis its competitor.

In case, a firm produces with higher marginal costs ($C^i_{x_i}(\cdot) > C^{-i}_{x_{-i}}(\cdot)$) and creates more emissions for an additional output unit compared to its competitor ($\frac{\partial \hat{e}_i}{\partial x_i} > \frac{\partial \hat{e}_{-j}}{\partial x_{-j}}$), the firm's output and emissions can only increase due to a higher permit price if the inverse demand function is sufficiently convex. But Lemma 4.11 shows that for quite common assumptions, for example outputs being strategic substitutes and conjectural variations greater or equal to zero (e.g. Cournot competition), the inverse demand function can never exceed this threshold.

For a firm producing with lower marginal costs ($C^i_{x_i}(\cdot) < C^{-i}_{x_{-i}}(\cdot)$) and emitting more for an additional output unit than its competitor ($\frac{\partial \hat{e}_i}{\partial x_i} > \frac{\partial \hat{e}_{-j}}{\partial x_{-j}}$), its output and emissions can only increase with the permit price if the inverse demand function is sufficiently concave. In this case, the firm has lower marginal production costs if emissions are constant, although it prefers to create more emissions for an additional output unit compared to its competitor. This situation only occurs if the higher marginal production costs of the competitor mainly depend on other parameters than the input of fossil fuels. It can be assumed that such a constellation is of minor relevance for most industries participating in the European ETS.

Hence, for most cases with increasing output of firm i in response to an increasing permit price ($\frac{dx_i^c}{d\sigma} > 0$), it is reasonable to assume that $\frac{\partial \hat{e}_i}{\partial x_i} < \frac{\partial \hat{e}_{-j}}{\partial x_{-j}}$. Therefore, based on Lemma 4.9 and $\frac{d\sigma^*}{dE_{Tr}} = \frac{1}{\sum_{i=1}^{2} \frac{de_k^c(\sigma^*)}{d\sigma}}$, the assumption of a decreasing permit price ($\frac{d\sigma^*}{dE_{Tr}} < 0$) can be justified, although the analysis shows that the permit price may increase with the allocation to the *Tr*-sector. In this case, the conditions in Proposition 4.6 lead to a higher permit price compared to the tax rate t in the *NTr*-sector. Furthermore, the following section shows that if the permit price increases for certain parameter ranges, a multiplicity of equilibria on the permit market is likely to arise.

4.5.2 Supplementary Price Regulations

The previous section shows that the intuitive assumption in Proposition 4.6 of a negative correlation between permit price and the initial allocation to the *Tr*-sector does not hold in general. Although it is unlikely, the case of an increasing permit price function must be taken into account when analyzing an emissions trading scheme. The curve in Figure 4.5 shows an example for a correlation between permit price and initial allocation, which is in some parts positive. The overall tendency should, of course, be negative.

From the market-clearing condition (4.13), we know that in equilibrium $E_{Tr} = e_1^c(\sigma) + e_2^c(\sigma)$ holds. Hence, a requirement for a correlation between σ and E_{Tr}, as shown in Figure 4.5, is that a unique solution $x_1^c(\sigma)$, $x_2^c(\sigma)$, $e_1^c(\sigma)$, and $e_2^c(\sigma)$ for the system of first-order conditions

$$P(\cdot) + (1+v^i)x_i P_x(\cdot) - C^i_{x_i}(x_i, \hat{e}_i(x_i,\sigma)) = 0, \ \ \forall i \in \{1,2\}, \tag{4.35}$$

exists for given σ. If firms' reaction functions intersect, a sufficient condition for a unique solution is that outputs are strategic substitutes for both firms ($b_i < 0$). In this case, the derivatives of both reaction functions are less than 1 in absolute values.[43] Since the assumption of strategic substitutes is common in quantity competition, the industry equilibrium is also very likely to be unique.[44]

For the following Proposition, we introduce the definitions of $\Gamma(\sigma) := \sum_{i=1}^{2} e_k^c(\sigma)$ and $\bar{\sigma}$ as the smallest permit price for which we have $\bar{E} = \Gamma(\bar{\sigma})$. The permit price $\bar{\sigma}$ is the price for which all emissions have been allocated to the *Tr*-sector.

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[43] Following Tirole (1988), this condition is sufficient for reaction curves to intersect only once. The derivative of the reaction function is $-\frac{b_i}{a_i}$. For $b_i < 0$ the condition $\left|\frac{b_i}{a_i}\right| < 1$ is equivalent to $a_i - b_i < 0$, which is true by definition of a_i and b_i.

[44] See Bulow et al. (1985).

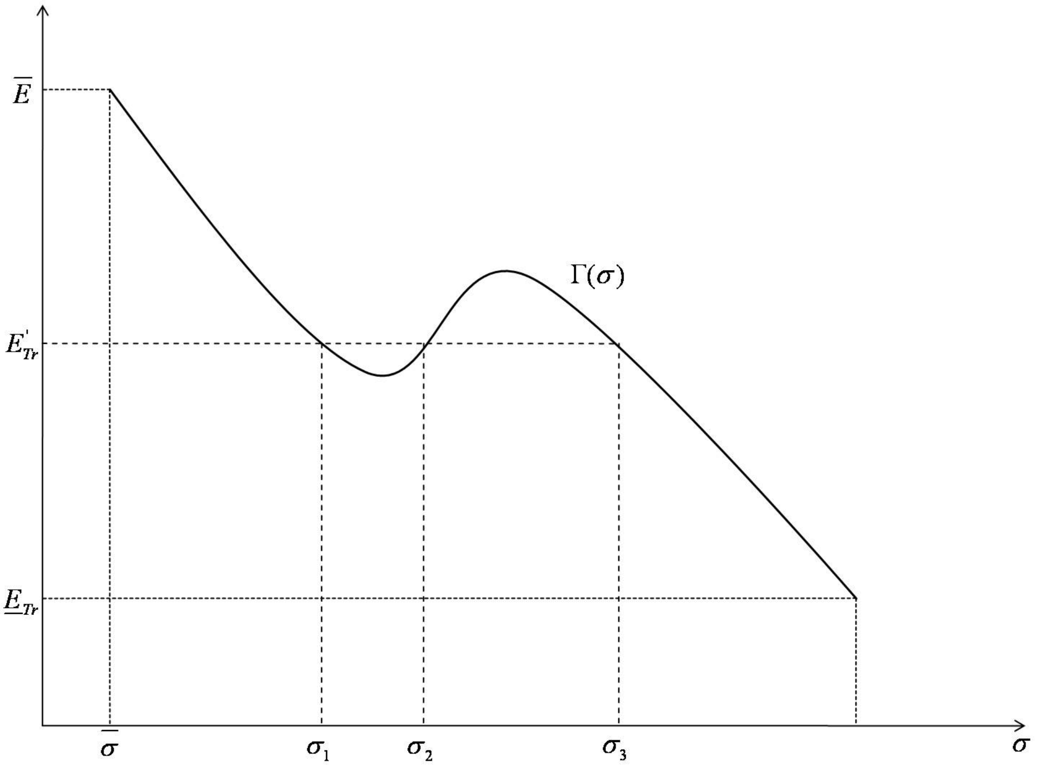

Figure 4.5: *Multiplicity of Equilibria*

Proposition 4.12. (Multiplicity of Equilibrium): *If there is a price* $\tilde{\sigma} > \bar{\sigma}$ *with* $\Gamma(\tilde{\sigma}) < \bar{E}$ *and* $\Gamma'(\tilde{\sigma}) > 0$*, and a unique solution of (4.35) for* $\sigma \in [\bar{\sigma}, \tilde{\sigma}]$ *exists, a pure quantity regulation can constitute multiple equilibria.*

Proof. Since we assume twice continuously differentiable inverse demand and cost functions, $\Gamma(\sigma)$ is in the relevant parameter range a continuous function if for all σ a unique solution of (4.35) exists. Per definition, we have $\bar{E} = \Gamma(\bar{\sigma})$. Therefore, if a $\tilde{\sigma} > \bar{\sigma}$ with $\Gamma(\tilde{\sigma}) < \bar{E}$ and $\Gamma'(\tilde{\sigma}) > 0$ exists, there exists a $\sigma' \in (\bar{\sigma}, \tilde{\sigma})$ with $\Gamma(\sigma') = \Gamma(\tilde{\sigma})$ and $\Gamma'(\sigma') < 0$.

A pure quantity regulation only defines the total amount of emissions E_{Tr} in the trading scheme and possesses no regulatory power on the permit price. If a price $\tilde{\sigma}$ exists, a pure quantity regulation that sets the total quantity E_{Tr} equal to $\Gamma(\tilde{\sigma})$ has at least two equilibrium prices $\tilde{\sigma}$ and σ'.

$\square$

Proposition 4.12 shows that even if we restrict the analysis to partial markets and firms' reaction functions intersect only once, multiple equilibria can occur. It is possible that a total amount of emissions set by the regulator can lead to different equilibrium permit prices. Figure 4.5 shows such a case. If the regulator chooses the amount of emissions E'_{Tr}, three different equilibrium prices (σ_1, σ_2, and σ_3) exist that probably lead to different levels of welfare.

To ensure a certain outcome of the permit market, a price regulation is necessary. If, for example, σ_1 in Figure 4.5 is the located permit price by the regulator, an upper price limit that is in the interval (σ_1, σ_2) can guarantee σ_1 as a certain outcome of the permit market. Usually, upper price limits in tradeable permit systems are used to protect markets from extreme price fluctuation, e.g., through carpetbaggers or uncertainty.[45] The result of Proposition 4.12 adds a new interpretation to price regulations. If multiple equilibria exist, price regulation can exclude non-desired equilibria and can be used to steer the market to a certain equilibrium outcome.

Of course, the results of this section are more of a theoretical character, since Lemma (4.8) to (4.11) point out that this special case of multiplicity of equilibria in response to an increasing permit price function is of minor importance for the European ETS. The results of this analysis are more relevant if the regulated industries in a tradeable permit system are very asymmetric concerning the marginal abatement costs. If we go back to the general equilibrium model of Section 4.3.2 without partial market assumptions, many other scenarios with multiplicity of equilibria are imaginable. In these cases, an additional price regulation could also be helpful to avoid non-desired equilibrium states.

4.6 Substitution Effects

The previous sections suggest that imperfectly competitive industries have a significant impact on the optimal allocation of emissions. The question is how the optimal allocation of emissions is influenced by other interplays between sectors

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[45] For uncertainty and the impact of additional price regulation, see for example Robert and Spence (1976).

not considered thus far. Examples for possible interdependencies can be found in Ruocco and Wiegard (1997), Böhringer (2002a), and Richter and Schneider (2003), who show that environmental tax differentiation between industries and households can be beneficial if indirect effects on other taxes and on the labor market are taken into account (the so-called second and third dividends). Rauscher (1994), Hoel (1996) and Withagen et al. (2007) show that if environmental taxes are used as a substitute for missing trade policies, taxes can differ between sectors of the economy producing internationally traded goods and those producing only nationally traded goods.

In this section, another relevant kind of interdependency between sectors in the European ETS is analyzed. We assume that the output of an industry in the *Tr*-sector is purchased by consumers in the *NTr*-sector and these consumers have the possibility to substitute the product of the *Tr*-sector through another CO_2-creating good. The most prominent example for this scenario is the market for electricity. Electricity is produced by oligopoly industries in the *Tr*-sector and is mainly consumed by households in the *NTr*-sector. Households can substitute electricity with different alternatives. Examples are heating, hot water or cooking, for which electricity can be replaced by the usage of gas or oil.

4.6.1 Empirical Evidence

This subsection should justify the importance of the substitutability of electricity and fossil fuels for the European ETS. A study conducted by Frey et al. (2007) reveals that in 2004 around 1.4 mil. German homes were heated through the use of electricity. As shown in Figure 4.6, around 52% of the electricity consumed by the households was used for room heat, warm water or process heat, like cooking.

Investigating the whole economy, 14% of the electricity in Germany was used for room heating and warm water. From the overall CO_2 emissions, 19% was created by electricity used for low-temperature heat, for example room heat, warm water or process heat.

From 1995 until 2004, the electricity demand for room heat even increased by 5.7%, whereas the overall demand for room heat only increased by 2.8%. This means an overproportional growth in electricity heating.

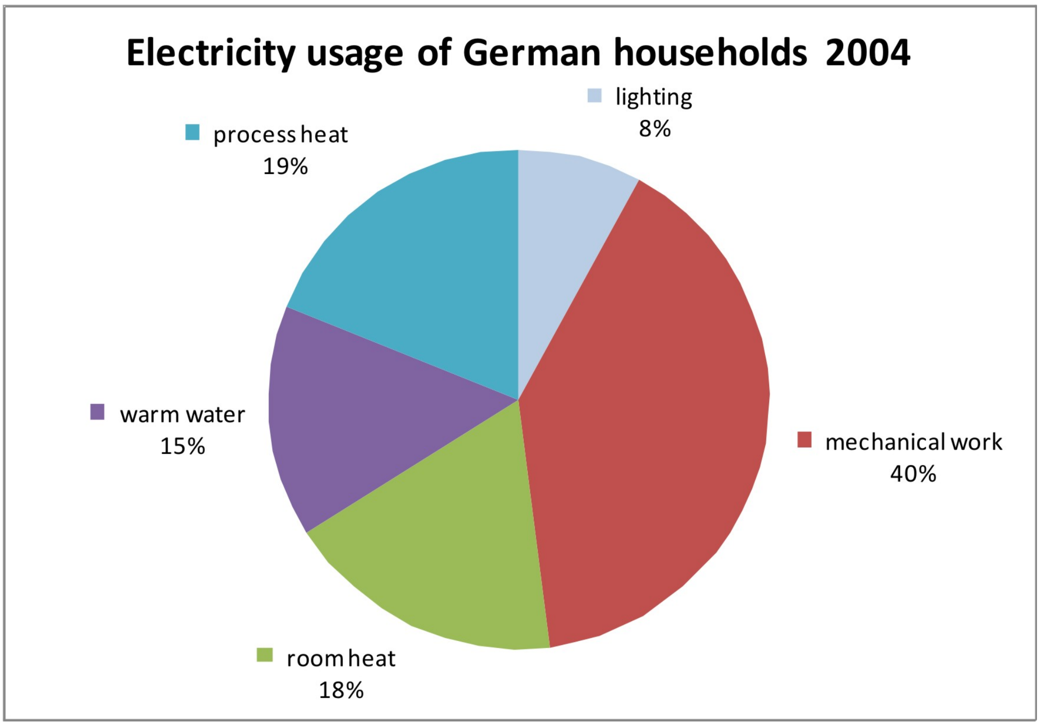

Figure 4.6: *Electricity usage of German households in 2004 (taken from Frey et al. 2007)*

In Germany room heat based on electricity is usually very inefficient in terms of its CO_2 balance, since electricity is mainly produced with fossil fuels. Electricity resistance heating, for example fan heaters, radiators or night storage heaters, accounts for 99% of all electricity used for room heating. This kind of heating systems creates 3.6 times more CO_2 emissions compared to conventional gas heating systems. Only 1% of the electricity is used for heat pumps, which are significantly more efficient than electricity resistance heating.

For other European countries, the percentage of electricity used for heating are even higher. For instance in Sweden, 50% of the total usage of electricity is for room heating and warm water.

Since conversion from electricity-based heating systems to gas-based systems is possible, it is reasonable to assume that households substitute electricity for gas or oil in response to price changes. Considering the numbers in this section, it is self-evident that such a substitution could have a considerable impact on the EU ETS.

4.6.2 Implications of Substitution Effects

For the theoretical analysis of the described substitution effect, we still use the partial market approach from Section 4.3.3. However, we extend the assumptions in a way that the output of firms with market power can be substituted by the household through the usage of energy. Therefore, the cross derivative H_{xh} is negative. All other assumptions of Section 4.3.3 are maintained. Hence, all other goods in the economy are neither substitutes nor complements. We still have $H_{yx} = H_{yh} = H_{yy} = 0$ and constant labor demand of imperfectly competitive firms. For the *Tr*-sector, we assume $M \supseteq N = \{1,2\}$. Since the household in this section can substitute between commodity X and the usage of energy, the inverse demand function conjectured by firms 1 and 2 is now a function that also depends on the amount of energy h used by the household. Therefore, the inverse demand function in this section is

$$P(x,h) := \frac{q}{H_y} H_x(x,h).$$

Since assumptions about the third derivatives of utility functions are not reasonable, we simplifying assume that H_{xxh} and therefore P_{xh} are of negligible size. The index s indicates that commodity X and energy are substitutes. The output level $x_i^s(\sigma,h)$ and emissions level $e_i^s(\sigma,h)$ of firm i are defined by the solution of

$$P(x,h) + (1+v^i)x_i P_x(x,h) - C^i_{x_i}(x_i, \hat{e}_i(x_i,\sigma)) = 0 \tag{4.36}$$

for all $i \in \{1,2\}$. To analyze the impact of substitutability on the welfare optimal allocation of emissions between the *Tr*- and *NTr*-sector, we have to investigate the impact of a change in the energy usage of the household on the production of commodity X.

Lemma 4.13. *If the conditions in Lemma 4.10 are satisfied and P_{xh} is negligibly small, firm i's output x_i^s cannot increase with an increasing usage of energy h by the household.*

Proof. Differentiating of (4.36) with respect to h yields

$$\begin{bmatrix} a_1 & b_1 \\ b_2 & a_2 \end{bmatrix} \begin{bmatrix} \frac{\partial x_1^s}{\partial h} \\ \frac{\partial x_2^s}{\partial h} \end{bmatrix} = \begin{bmatrix} -P_h(x,h) - (1+v^1)x_1^s P_{xh} \\ -P_h(x,h) - (1+v^2)x_2^s P_{xh} \end{bmatrix}.$$

Solving this system of equations we have

$$\frac{\partial x_i^s}{\partial h} = -\frac{a_{-i}(P_h(x,h) + (1+v^i)x_i^s P_{xh}) - b_i(P_h(x,h) + (1+v^{-i})x_{-i}^s P_{xh})}{\Delta}$$

for all $i \in \{1,2\}$. If we use the assumption that the cross derivation of the inverse demand function is of negligible size ($P_{xh}(\cdot) \approx 0$), we can simplify the result to

$$\frac{\partial x_i^s}{\partial h} \approx -\frac{P_h(x,h)}{\Delta}(a_{-i} - b_i).$$

Since per assumption $P_h(\cdot) < 0$ and $\Delta > 0$, the sign of $\frac{\partial x_i^s}{\partial h}$ solely depends on the difference $a_{-i} - b_i$. If the conditions given by Lemma 4.10 are satisfied, we have $a_{-i} - b_i \leq 0$ and therefore also $\frac{\partial x_i^s}{\partial h} \leq 0$.

□

It has already been argued in Section 4.5.1 that for most relevant cases, the conditions of Lemma 4.10 are satisfied. Since the cross derivation $P_{xh} = \frac{q}{H_y} H_{xxh}$ is negligible, we can act in the following on the assumption that a firm's output does not increase if the household's energy consumption increases. This result is intuitive. If both commodities are substitutes and the household uses more energy, the demand for commodity X decreases and therefore the firms' output. However, if the conditions of Lemma 4.10 are not satisfied, which means that the firms are sufficiently asymmetric in costs, an exception must be made. In this case, a firm's output could increase even if demand declines. But as long as P_{xh} is negligible, industry's total output always decreases with an increasing energy consumption.

$$\frac{\partial x_1^s}{\partial h} + \frac{\partial x_2^s}{\partial h} = -\frac{P_h(x,h)}{\Delta}(a_1 - b_1 + a_2 - b_2) < 0$$

Proposition 4.14. (Substitution Effect) *If the conditions of Lemma 4.10 are satisfied and P_{xh} is negligibly small, substitutability of commodity X and energy always has a non-negative impact on the optimal difference $t^* - \sigma^*$.*

Proof. With the assumptions made in this section, the optimal difference between permit price and environmental tax in Proposition 4.3 can be simplified to

$$t^* - \sigma^* = \sum_{i \in \{1,2\}} -(1+v^i)x_i^* P_x(x^*,h^*) \left(\frac{\partial x_i^s(\sigma^*,h^*)}{\partial \sigma} \frac{d\sigma^*}{dE_{Tr}} + \frac{\partial x_i^s(\sigma^*,h^*)}{\partial h} \frac{dh^*}{dE_{Tr}} \right)$$

with $x_i^* = x_i^s(\sigma^*, h^*)$. The optimal difference $t^* - \sigma^*$ can be divided into two effects for each firm. The first effect is the permit price effect, whose sign is determined by the sign of $\frac{\partial x_i^s(\sigma^*,h^*)}{\partial \sigma}\frac{d\sigma^*}{dE_{Tr}}$, since $-(1+v^i)x_i^* P_x(x^*, h^*)$ is always non-negative. From the Sections 4.3.3 and 4.5.1, we know that if firms are sufficiently symmetric, this effect is positive, which is true for the most relevant cases.

The second effect is the substitution effect, whose sign only depends on the sign of $\frac{\partial x_i^s(\sigma^*,h^*)}{\partial h}\frac{dh^*}{dE_{Tr}}$. Due to (4.12), we have $\frac{dh^*}{dE_{Tr}} = -1$. From Lemma 4.13, we know that if the conditions of Lemma 4.10 are satisfied and P_{xh} is negligibly small, $\frac{\partial x_i^s(\sigma^*,h^*)}{\partial h}$ is always non-positive. Hence, under these assumptions, the substitution effect is always non-negative.

$\square$

Proposition 4.14 shows that the possibility to substitute goods of the *Tr*-sector with goods of the *NTr*-sector probably increases the optimal difference between sectors' marginal abatement costs. This emphasizes the previous results that cost-efficient emissions reduction requires a lower burden of emission abatement for the *Tr*-sector compared the *NTr*-sector. Of course, this special kind of substitution effect between electricity and the usage of gas or oil is only one prominent example. To decide on an optimal allocation plan, a lot of other substitution and income effects have to be taken into account.

4.7 Conclusion

This chapter shows that cost efficiency in the European Emissions Trading Scheme does not inevitably require equal marginal emission abatement costs for all emitters. Depending on commodity market competition and firms' asymmetry, marginal abatement costs of emitters in the trading sector must be above or below marginal costs of the non-trading sector to minimize overall costs. This result is in contradiction to the common assumption in literature that an optimal macro-plan must satisfy equal marginal costs. Certainly, if only one small industry is imperfectly competitive and the number of price-taking firms in the *Tr*-sector is sufficiently large, the impact on an optimal allocation is negligible. However, in case a very large industry or a sufficient number of industries in the *Tr*-sector are imperfectly competitive, an unequal allocation can increase welfare significantly.

A simplified analysis of the German power supply industry shows that under Cournot competition, the burden on the *NTr*-sector should be between 4 € and 40 € higher per ton of CO_2 compared to the *Tr*-sector. For the case of cartel behavior on the German electricity market, a mark-up of up to 900 € for the *NTr*-sector could be necessary. In literature marginal abatement costs of the *Tr*-sector are estimated as up to 30 €. Therefore, it could be that the tax in the *NTr*-sector must be twice as high as the permit price in the *Tr*-sector. Unequal marginal costs can increase welfare significantly since market-distorting behavior of imperfectly competitive firms is mitigated.

Although, it is unlikely, the model in this chapter shows that, even under very simplified assumptions, multiplicity of equilibrium cannot be excluded. In these cases, an additional price regulation could help to steer the economy to the preferred equilibrium.

An extension of the analysis for substitution effects has shown that if households can replace electricity through the use of oil or gas, this would have a positive effect on the optimal difference between environmental tax and permit price. Since in Europe room heating is still very often based on electricity, this prominent substitution effect should be taken into account in future analyses of the EU ETS.

To conclude, this chapter shows that the simplifying allocation rule used in literature (only equal marginal costs for all sectors maximize welfare) could lead to unnecessarily high costs for society. It also reveals that more precise analyses are inevitable, since the assumption of perfectly competitive markets cannot be maintained for the EU ETS.

The advantage of the hybrid European approach is that it provides the possibility of unequal marginal costs through its *inter-sector flexibility*, i.e., the regulator can determine the marginal costs for emitters in each sector by choosing a certain macro-plan. A problem of this approach is, of course, that the regulator needs complete information about all emitters to choose an optimal allocation plan and, therefore, the main advantage of an emissions trading system compared to an emission tax is lost. The question is whether an instrument like tradable permits should be used to correct the negative effects of imperfect competition. Admittedly, it is preferable if the regulator achieves perfect competition without abusing environmental policies. According to Requate (2006) “the most simple rule is to tax emissions and subsidize output. Subsidies, however, are prohibited by several international agreements (EU Treatise, WTO rules etc.). Therefore more sophisticated mechanisms have to be developed for regulating a number of market imperfections.” On this account, why not use the allocation of emissions to achieve at least a second-best solution?

Surely, the analyzed effects are only some of the possible interdependencies between sectors. The analytical framework used in this chapter is still very artificial and a lot of other effects are not considered, e.g., that gains from the environmental tax can be used to reduce other distorting taxes, like an income tax. The stylized model in this chapter also neglects the future integration of the Flexible Mechanisms of the Kyoto Protocol or trading schemes in other countries into the European system. Currently, the use of allowances from Flexible Mechanisms is still restricted due to the *supplementary criterion*. However, if firms in the emissions trading sector are allowed to freely trade allowances on a world market, the marginal abatement costs are only determined by the world price for emission rights. Hence, the EU regulator loses its steering-wheel to influence the European permit price through the allocation. Therefore, one question is whether the usage of additional allowances from Flexible Mechanisms or the linkage to other trading schemes should be restricted in order to maintain the inter-sector flexibility of the European system.[46]

However, even if overall welfare is improved, one must recognize that an allocation with unequal marginal costs between sectors influences the profits of all firms. In cases where the optimal allocation leads to a reduced permit price, all competitive firms in the trading sector benefit from this allocation. This effect on their profits gives an incentive for institutional abuse of the Emissions Trading Scheme. For example, firms can make use of the *opt-in* rule of the European

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[46] According to Kruger et al. (2007) an unrestricted linkage of the EU ETS could also have negative consequences because of large capital flows if the linked trading schemes have different greenhouse gas obligations. See for example Russia and the so-called hot air problem.

Emissions Trading Law to switch from the *NTr*-sector to the *Tr*-sector. For a detailed analysis of permit price changes on firms' profits, see Chapter 6 or Ehrhart, Hoppe, and Löschel (2008).

Appendix

A. Conditions for a Decreasing Demand Function

Lemma 4.15. *: Sufficient conditions for a decreasing inverse demand function* $\Psi(x,q,w,s,t,I)$ *in x are*

- $U_{HH} = U_{ll} = U_{Hl} = 0$ *or*
- *H is linear homogeneous and* $x \neq 0$*.*

Proof. For $U_{Hl} = U_{HH} = U_{ll} = 0$ total differentiation of the first-order conditions (4.2)-(4.5) with respect to p yields

$$\begin{bmatrix} H_{xx} & H_{xy} & H_{xh} & 0 \\ H_{yx} & H_{yy} & H_{yh} & 0 \\ H_{hx} & H_{hy} & H_{hh} & 0 \\ p & q & s+t & w \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dp} \\ \frac{d\tilde{y}}{dp} \\ \frac{dh}{dp} \\ \frac{d\tilde{l}}{dp} \end{bmatrix} = \begin{bmatrix} \frac{U_l}{U_H}\frac{1}{w} \\ 0 \\ 0 \\ x \end{bmatrix}.$$

With Cramer's rule we obtain

$$\frac{d\tilde{x}}{dp} = \frac{1}{w \cdot \begin{vmatrix} H_{xx} & H_{xy} & H_{xh} \\ H_{yx} & H_{yy} & H_{yh} \\ H_{hx} & H_{hy} & H_{hh} \end{vmatrix}} \cdot \frac{U_l}{U_H}(H_{yy}H_{hh} - H_{hy}^2).$$

Since we assume that the utility function is strictly quasi-concave to guarantee a unique solution of the households optimization problem, the bordered Hessian

$$\bar{H} = \begin{bmatrix} 0 & w & q & s+t & p \\ w & 0 & 0 & 0 & 0 \\ q & 0 & U_H H_{yy} & U_H H_{yh} & U_H H_{yx} \\ s+t & 0 & U_H H_{hy} & U_H H_{hh} & U_H H_{hx} \\ p & 0 & U_H H_{xy} & U_H H_{hx} & U_H H_{xx} \end{bmatrix}$$

has alternating signs of the leading principal minors,[47] i.e.,

$$\begin{vmatrix} 0 & w & q \\ w & 0 & 0 \\ q & 0 & U_H H_{yy} \end{vmatrix} > 0, \quad \begin{vmatrix} 0 & w & q & s+t \\ w & 0 & 0 & 0 \\ q & 0 & U_H H_{yy} & U_H H_{yh} \\ s+t & 0 & U_H H_{hy} & U_H H_{hh} \end{vmatrix} < 0,$$

$$\begin{vmatrix} 0 & w & q & s+t & p \\ w & 0 & 0 & 0 & 0 \\ q & 0 & U_H H_{yy} & U_H H_{yh} & U_H H_{yx} \\ s+t & 0 & U_H H_{hy} & U_H H_{hh} & U_H H_{hx} \\ p & 0 & U_H H_{xy} & U_H H_{hx} & U_H H_{xx} \end{vmatrix} > 0.$$

Applying these conditions, it is straightforward that $H_{yy}H_{hh} - H_{hy}^2$ is positive and

$$\begin{vmatrix} H_{xx} & H_{xy} & H_{xh} \\ H_{yx} & H_{yy} & H_{yh} \\ H_{hx} & H_{hy} & H_{hh} \end{vmatrix}$$

is negative. Hence, we obtain $\frac{d\tilde{x}}{dp} < 0$.

To prove that the inverse demand function $\Psi(x, q, w, s, t, I)$ is decreasing in x in cases where H is linear homogeneous, we prove that good X is not a Giffen good. The possibility of a Giffen good can be excluded if the good is not inferior.[48] Total differentiation of the first-order conditions of the maximization problem of

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[47] See Chiang and Wainwright (2005).

[48] For the relation between Giffen goods and inferior goods, see e.g. Varian (1995).

the household due to a change in income yields:

$$\begin{bmatrix} H_{xx}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{p}{w} & H_{xy}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{p}{w} & H_{xh}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{p}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{p}{w} \\ H_{yx}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{q}{w} & H_{yy}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{q}{w} & H_{yh}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{q}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{q}{w} \\ H_{hx}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{s+t}{w} & H_{hy}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{s+t}{w} & H_{hh}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{s+t}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{s+t}{w} \\ p & q & s+t & w \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dI} \\ \frac{d\tilde{y}}{dI} \\ \frac{d\tilde{h}}{dI} \\ \frac{d\tilde{l}}{dI} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}.$$

By using $\frac{d}{dx}(\frac{U_l}{U_H}) = \frac{d}{dy}(\frac{U_l}{U_H})\frac{H_x}{H_y} = \frac{d}{dh}(\frac{U_l}{U_H})\frac{H_x}{H_h}$ and $\frac{H_x}{p} = \frac{H_y}{q} = \frac{H_x}{s+t}$ we have

$$\begin{bmatrix} H_{xx}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{p}{w} & H_{xy}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{q}{w} & H_{xh}-\frac{d}{dx}(\frac{U_l}{U_H})\frac{s+t}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{p}{w} \\ H_{yx}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{p}{w} & H_{yy}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{q}{w} & H_{yh}-\frac{d}{dy}(\frac{U_l}{U_H})\frac{s+t}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{q}{w} \\ H_{hx}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{p}{w} & H_{hy}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{q}{w} & H_{hh}-\frac{d}{dh}(\frac{U_l}{U_H})\frac{s+t}{w} & -\frac{d}{dl}(\frac{U_l}{U_H})\frac{s+t}{w} \\ p & q & s+t & w \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dI} \\ \frac{d\tilde{y}}{dI} \\ \frac{d\tilde{h}}{dI} \\ \frac{d\tilde{l}}{dI} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}.$$

With $p\frac{d\tilde{x}}{dI} + q\frac{d\tilde{y}}{dI} + (s+t)\frac{d\tilde{h}}{dI} = 1 - w\frac{d\tilde{l}}{dI}$ the system of equations can be simplified to

$$\begin{bmatrix} H_{xx} & H_{xy} & H_{xh} & \Omega H_x \\ H_{yx} & H_{yy} & H_{yh} & \Omega H_y \\ H_{hx} & H_{hy} & H_{hh} & \Omega H_h \\ p & q & s+t & w \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dI} \\ \frac{d\tilde{y}}{dI} \\ \frac{d\tilde{h}}{dI} \\ \frac{d\tilde{l}}{dI} \end{bmatrix} = \begin{bmatrix} \gamma H_x \\ \gamma H_y \\ \gamma H_h \\ 1 \end{bmatrix}, \tag{4.37}$$

with $\Omega := \frac{d}{dH}(\frac{U_l}{U_H}) - \frac{d}{dl}(\frac{U_l}{U_H})\frac{U_H}{U_l}$ and $\gamma := \frac{d}{dH}(\frac{U_l}{U_H})\frac{1}{w}$. Due to the assumptions on the utility function, we have $\Omega, \gamma \geq 0$. The case $\Omega = 0$ can only occur if $U_{HH} = U_{ll} = U_{Hl} = 0$. For this case, we have already proven that $\frac{d\tilde{x}}{dp} < 0$ holds.

Consider that H is linear homogeneous. Due to Euler's Theorem, we have $xH_x + yH_y + hH_h = H$ and $s_1 H_{s_1 s_1} + s_2 H_{s_1 s_2} + s_3 H_{s_1 s_3} = 0$ for $s_1 \neq s_2, s_1 \neq s_3, s_2 \neq s_3$ and $s_1, s_2, s_3 \in \{x, y, h\}$.[49] With these additional conditions, we can reformulate (4.37) to

$$\begin{bmatrix} xH_{xx} & xH_{xy} & xH_{xh} & \Omega x H_x \\ yH_{yx} & yH_{yy} & yH_{yh} & \Omega y H_y \\ hH_{hx} & hH_{hy} & hH_{hh} & \Omega h H_h \\ p & q & s+t & w \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dI} \\ \frac{d\tilde{y}}{dI} \\ \frac{d\tilde{h}}{dI} \\ \frac{d\tilde{l}}{dI} \end{bmatrix} = \begin{bmatrix} \gamma x H_x \\ \gamma y H_y \\ \gamma h H_h \\ 1 \end{bmatrix}.$$

Adding up the equations yields

$$p\frac{d\tilde{x}}{dI} + q\frac{d\tilde{y}}{dI} + (s+t)\frac{d\tilde{h}}{dI} + (w + \Omega H)\frac{d\tilde{l}}{dI} = 1 + \gamma H.$$

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[49] See Simon and Blume (1994).

With $p\frac{d\tilde{x}}{dI}+q\frac{d\tilde{y}}{dI}+(s+t)\frac{d\tilde{h}}{dI}+w\frac{d\tilde{l}}{dI}=1$, we have $\Omega H\frac{d\tilde{l}}{dI}=\gamma H$. The assumption $x\neq 0$ yields $H>0$.

For $\Omega>0$, the system of equations (4.37) can be further simplified to

$$\begin{bmatrix} H_{xy} & H_{yy} & H_{hy} \\ H_{hx} & H_{hy} & H_{hh} \\ H_{x} & H_{y} & H_{h} \end{bmatrix} \begin{bmatrix} \frac{d\tilde{x}}{dI} \\ \frac{d\tilde{y}}{dI} \\ \frac{d\tilde{h}}{dI} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \varepsilon \end{bmatrix},$$

with $\varepsilon := -\frac{\frac{d}{dI}(\frac{U_I}{U_H})}{w\cdot\Omega}\geq 0$. Using Cramer's rule, $xH_x+yH_y+hH_h=H$, and $s_1H_{s_1s_1}+s_2H_{s_1s_2}+s_3H_{s_1s_3}=0$ for $s_1\neq s_2, s_1\neq s_3, s_2\neq s_3$, and $s_1,s_2,s_3\in\{x,y,h\}$ yields

$$\frac{d\tilde{x}}{dI}=\frac{\varepsilon\cdot\tilde{x}}{H},$$

which is always non-negative. According to this result, we can exclude that good X is inferior. Hence, we have $\frac{d\tilde{x}}{dp}<0$.[50]

$\square$

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[50] According to Katzner (1970), the derivative $\frac{d\tilde{x}}{dp}$ can be separated into an income and a substitution effect, whereas the substitution effect is always negative. The income effect is defined as $-\tilde{x}\cdot\frac{d\tilde{x}}{dI}$, which is in our case, as proven above, non-positive. Hence, the overall effect must be negative.

Chapter 5

Strategic Behavior of Member States

Thus far, we have implicitly assumed that National Allocation Plans in the European Emissions Trading Scheme are determined by a central planner, since we only investigated an individual country scenario. However, in the first two trading periods, each member state individually decided on its own allocation plan and the European Commission only has a veto right if an allocation plan contradicts EU jurisdiction (see Section 2.2). For future periods, the system will change. According to the recently decided EU climate package, future allocation plans will solely be determined by the EU.[1] At this juncture, the question arises as to whether central planning by the European Commission is really preferable. Kruger et al. (2007) argue that a decentralized simultaneous allocation would not lead to cost efficiency in general, since member states are probably not aware of other states' abatement possibilities. Another justification for a central planner could be that decentrally determined allocation plans by national regulators provide incentives to behave strategically. Thereby, different incentives for strategic behavior are imaginable. First, member states can try to influence the emission permit market. A state whose *Tr*-sector is a net buyer of permits on the EU permit market is, of course, interested in a lower permit price; whereas a permit selling state prefers a higher permit price. Second, since all kinds of trade policies are abolished on the integrated European market, member states could try to substitute absent trade policies through a strategic allocation of emission permits.

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[1] See Section 2.3.

In a theoretical model, Alaimo et al. (2005) compare the case of centrally and decentrally decided allocations. However, they assume that a member state only decides on the state's *total* amount of emissions, which is then automatically assigned to the *Tr*-sector. This is in contrast to the actual EU ETS, in which the total amount is *fixed* and member states decide only on the distribution of emissions to the *Tr*- and *NTr*-sector. The main result of the model of Alaimo et al. is that, in the decentralized case, the European emissions reduction target is less stringent than in the centralized case.

Viguier et al. (2006) analyze a scenario in which member states cannot determine the exact amount of emissions they want to allocate to a sector, but they can choose between different allocation rules, for example different kinds of grandfathering. The payoffs resulting from the different possible configurations of allocation rules are derived from a multi-country, multi-sectoral, and dynamic-recursive CGE model. Viguier et al. state that the incentive of a member state to act strategically is rather small, since the impact of strategic behavior on welfare is limited.

In contrast to these models, we analyze a scenario in which member states strategically allocate a given amount of emissions to their *Tr*- and *NTr*-sectors, possessing market power on the emission permit market.

In the first section of this chapter, any kind of imperfect competition on commodity markets is neglected, i.e., we implicitly assume that all economic entities are price takers. Furthermore, emission abatement costs of an economic sector are not influenced by other sectors and depend only on the available amount of emissions for this sector. Thus, the only considered interaction between sectors is via the permit market. Based on these assumptions, it can be shown that depending on whether a state is a net seller or buyer of permits, it has an incentive to choose an allocation in order to increase or decrease the permit price. Unfortunately, such strategic behavior leads to an inefficient allocation of permits between the *Tr*- and the *NTr*-sectors. Consequences are investigated in a numerical example, based on cost functions taken from Böhringer et al. (2005). Interestingly, the numerical example shows that the permit price with strategic behavior is nearly the same as the price under a welfare-efficient allocation. However, in contrast to a central planner, environmental taxes vary among the different member states, which has a significant impact on the emission abatement costs of some states. Furthermore, strategic behavior affects states' permit trade volumes. A result thereof is, for instance, that the German *Tr*-sector's abatements costs under strategic behavior are twice as high.

Independently, Böhringer and Rosendahl (2008) analyze in a similar approach strategic allocation of emissions in the EU ETS and confirm the results of our model.[2] However, unlike Böhringer and Rosendahl (2008), we also investigate impacts on the sectors' total costs.

Moreover, in a second approach, in Section 5.2, we extend the analysis for imperfect commodity markets and consider that the allocation of emission permits is also used as a substitute for missing trade policies on the integrated European commodity markets. The analysis is based on the general equilibrium model with imperfect competition of Chapter 4 and points out that the allocation process results in an inefficient outcome if member states only maximize their own welfare. However, even if a benevolent planner decides on the overall welfare-maximizing allocation, we get the astonishing result that the optimal environmental taxes differ across the different countries' *NTr*-sectors. This can be explained by the fact that a reduced allocation to a member state's *NTr*-sector has a different impact on the commodity demand functions of the households in different member states.

5.1 Member States with Market Power

Before we investigate the effect of imperfect commodity markets on the allocation of emissions rights in the case of several member states, we first analyze the simplified case of no interactions between the different sectors of the economy, except for the permit market. Hence, it is assumed that emission abatement costs of a sector only depend on the amount of emissions available for this sector and that abatement efforts of other sectors have no impact on costs. The model is based on the idea that member states try to influence the permit price through

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[2] Böhringer and Rosendahl (2008) investigate strategic behavior of 27 member states participating in the second trading period, whereas the model in the following section is restricted to 14 EU member states participating in the first trading period. Moreover, they show that individual member states have an incentive to unilaterally deviate from the actual NAPs.

their initial allocations, depending on whether they are permit buyers or sellers. The idea of permit price manipulation was first analyzed by Hahn (1984), who investigates the case that one dominant firm has market power on the permit market. He derives the result that the equilibrium permit price is lower (higher) compared to a perfectly competitive permit market, if the dominant firm initially owns too few (many) permits. Westskog (1996) extends the model to n dominant firms.[3] In this section, we modify the approach of Hahn such that all firms are price takers on all markets and only the national regulators possess market power on the permit market by strategically deciding on the permit allocations. From anticipating firms' behavior on the permit market, the national regulators are aware of how the permit price reacts in response to changes of the allocation.

The following subsection presents the general assumptions of the analysis. In Subsection 5.1.2, the cost-efficient allocation is determined. In Subsection 5.1.3, the allocation is compared to a scenario in which member states decide strategically on their emission allocations. Subsection 5.1.4 investigates the relevance of the theoretical results for the European Emissions Trading Scheme in a numerical example.

5.1.1 General Framework

The analyzed Emissions Trading Scheme consists of C member states and each member state $c \in \{1,..,C\}$ consists of two sectors: the *Tr*-sector and the *NTr*-sector. For each sector of each member state exists an emission abatement cost function $F_i^c : \mathbb{R}_{\geq 0} \rightarrow \mathbb{R}_{\geq 0}$, depending on the sector's emissions ($i \in \{Tr, NTr\}$ and $c \in \{1,..,C\}$). The emissions of a state's *Tr*-sector after trading are denoted by e_{Tr}^c with $c \in \{1,..,C\}$. The emissions assigned to a state's *NTr*-sector are denoted by h^c.[4] The costs of each sector decrease if more emissions are available (i.e., $F_i^c(\cdot)' < 0$), which is intuitive, since the possibility to emit more coincides with fewer abatement efforts. Furthermore, it is assumed that the cheapest emission abatement measures within a sector are always realized first (i.e., $F_i^c(\cdot)'' > 0$).

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[3] For a detailed overview of imperfect permit markets see Section 3.2.

[4] Similar to the approach in Böhringer et al. (2005), we assume that the costs of the *Tr*-sector and of the *NTr*-sector of each member state only depend on the amount of CO_2 emissions available for the respective sector.

First, we derive the permit price function and its properties. The resulting slope of the permit price function is equal to the slope used in the numerical example in Chapter 4. We assume that the total amount of emissions $\bar{E}^c$ available for a state $c \in \{1,..,C\}$ is exogenously given, e.g. by the Kyoto Protocol and the burden-sharing agreement in the European Union.[5] As in Chapter 4, a member state's total amount of emissions $\bar{E}^c$ must be allocated to its *Tr*- and *NTr*-sectors. The allocated amount of emissions to the *Tr*-sector of a state c is denoted by E^c_{Tr}, for the *NTr*-sector by h^c. The emission allowances assigned to a state's *Tr*-sector are grandfathered to the firms and are internationally tradeable by the economic entities. Since we assume that all related markets are perfectly competitive, we can apply the well-known result for emission permit markets, that in a market equilibrium after trading, the marginal abatement costs of a *Tr*-sector are equal to the marginal abatement costs of the individual polluters and also to the permit price.[6] Thus, in equilibrium we have

$$-F^c_{Tr}(e^c_{Tr})' = \sigma \tag{5.1}$$

for all $c \in \{1,..,C\}$. This condition implicitly defines the cost-minimizing emissions level of a sector for a certain permit price, $e^{c*}_{Tr}(\sigma)$. Applying the theorem of implicit functions yields

$$e^{c*}_{Tr}(\sigma)' = -\frac{1}{F^c_{Tr}(e^{c*}_{Tr})''}. \tag{5.2}$$

The total amount of permits available for the emissions trading scheme is $E_{Tr} = \sum_{c=1}^{C} E^c_{Tr}$. The market-clearing condition for the permit market

$$E_{Tr} = \sum_{c=1}^{C} e^{c*}_{Tr}(\sigma) \tag{5.3}$$

implicitly determines the permit price function $\sigma^*(E_{Tr})$. With the theorem of implicit functions we have

$$\sigma^*(E_{Tr})' = -\left(\sum_{c=1}^{C} \frac{1}{F^c_{Tr}(e^{c*}_{Tr})''}\right)^{-1}. \tag{5.4}$$

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[5] For more details, see Section 2.2.

[6] This result was initially derived in Montgomery (1972). See also Section 3.1.

We see that the emission abatement costs of a state's *Tr*-sector depend on the permit price and thus only on the *sum* of emissions assigned to *all* *Tr*-sectors, $E_{Tr} = \sum_{c=1}^{C} E_{Tr}^{c}$. The abatement costs are independent of the individual allocation of each state.

Emitters in the *NTr*-sectors do not participate in emissions trading. Thus, their emission abatement costs are solely determined by the amount of emissions assigned to the respective sector, h^c.

5.1.2 Central Planner

Before we analyze the case of member states individually deciding their allocation plans on their own, we first derive the cost-minimizing allocation of a central planner as a benchmark.

The objective of a benevolent central planner is to choose an allocation that minimizes the sum of all sectors' costs. The central planner anticipates the equilibrium on the permit market, given by (5.1) and (5.3). Thus, we have the following cost-minimization problem:

$$\min_{E_{Tr}^{c},h^{c}\ (\forall c\in\{1,\dots,C\})} \sum_{c=1}^{C} F_{Tr}^{c}(e_{Tr}^{c*}(\sigma^{*}(E_{Tr}))) + \sum_{c=1}^{C} F_{NTr}^{c}(h^{c}) \tag{5.5}$$

$$\begin{array}{rrcll} \text{s.t.} & \bar{E}^{c} & = & E_{Tr}^{c} + h^{c} & \\ & E_{Tr} & = & \sum_{c=1}^{C} E_{Tr}^{c} & \\ & E_{Tr}^{c}, h^{c} & \geq & 0 & \forall c \in \{1,\dots,C\}. \end{array}$$

Including the side conditions in the objective function yields

$$\min_{E_{Tr}^{c}\ (\forall c\in\{1,\dots,C\})} \sum_{c=1}^{C} F_{Tr}^{c}(e_{Tr}^{c*}(\sigma^{*}(\sum_{j=1}^{C} E_{Tr}^{j}))) + \sum_{c=1}^{C} F_{NTr}^{c}(\bar{E}^{c} - E_{Tr}^{c})$$

$$\text{s.t.} \quad 0 \ \leq \ E_{Tr}^{c} \ \leq \ \bar{E}^{c} \quad \forall c \in \{1,\dots,C\}.$$

The (interior) solution of this minimization problem is implicitly given by the system of first-order conditions:

$$\sum_{j=1}^{C} \left(F_{Tr}^{c}(\cdot)' \cdot e_{Tr}^{c*}(\cdot)' \cdot \sigma^{*}(\cdot)' \right) - F_{NTr}^{c}(\cdot)' = 0,$$

for all $c \in \{1,...,C\}$. Using (5.1), (5.2) and (5.4) we get

$$-\sigma^*(\cdot) - F^c_{NTr}(\cdot)' = 0$$

for all $c \in \{1,...,C\}$, which leads to the following result.

Result 5.1. *A total cost-minimizing solution results in equal marginal abatement costs for all sectors of all member states, i.e.,*

$$\sigma^* \quad = \quad -F^c_{Tr}(\cdot)' \quad = \quad -F^c_{NTr}(\cdot)'$$

for all $c \in \{1,...,C\}$.

Comparing this result with the model in Chapter 4, we see that the outcomes coincide: in cases where there are perfectly competitive product markets, an efficient allocation yields equal marginal abatement costs for all emitters in all sectors. The case of individually allocating member states and imperfectly competitive markets is analyzed in Section 5.2.

5.1.3 Member States Possessing Market Power

We now assess the situation during the first two trading periods of the EU ETS where each member state individually decides on its National Allocation Plan. We assume that each regulator is only interested in minimizing the costs of its own country, thus each regulator faces the following minimization problem:

$$\min_{E^c_{Tr},h^c} \; F^c_{Tr}(e^{c*}_{Tr}(\sigma^*(E_{Tr}))) + F^c_{NTr}(h^c) + \sigma^*(E_{Tr}) \cdot [e^{c*}_{Tr}(\sigma^*(E_{Tr})) - E^c_{Tr}] \tag{5.6}$$

$$\begin{array}{rrcl} \text{s.t.} & E^c_{Tr} + h^c & = & \bar{E}^c \\ & E_{Tr} & = & \sum_{c=1}^{C} E^c_{Tr} \\ & E^c_{Tr}, h^c & \geq & 0 \end{array}$$

In contrast to a central planner, the national planners also take the trade balances from emissions trading into account. Therefore, a country having initially more permits than it needs may benefit from the Emission Trading Scheme by selling superfluous permits.

Simplifying the minimization problem yields:

$$\begin{aligned}\min_{E^c_{Tr}} \ & F^c_{Tr}(e^{c*}_{Tr}(\sigma^*(\sum_{j=1}^{C} E^j_{Tr}))) + F^c_{NTr}(\bar{E}^c - E^c_{Tr}) \\ & \qquad + \sigma^*(\sum_{j=1}^{C} E^j_{Tr}) \cdot [e^{c*}_{Tr}(\sigma^*(\sum_{j=1}^{C} E^j_{Tr})) - E^c_{Tr}] \\ & \text{s.t.} \quad 0 \ \leq \ E^c_{Tr} \ \leq \ \bar{E}^c.\end{aligned}$$

The (interior) equilibrium solution is given by the system of first-order conditions:

$$\begin{aligned}& F^c_{Tr}(\cdot)' \cdot e^{c*}_{Tr}(\cdot)' \cdot \sigma^*(\cdot)' - F^c_{NTr}(\cdot)' \\ & \qquad + \sigma^*(\cdot)' \cdot [e^{c*}_{Tr}(\cdot) - E^c_{Tr}] + \sigma^*(\cdot) \cdot [e^{c*}_{Tr}(\cdot)' \cdot \sigma^*(\cdot)' - 1] = 0,\end{aligned}$$

for all $c \in \{1,...,C\}$. Including (5.1) yields

$$-F^c_{NTr}(\cdot)' - \sigma^*(\cdot) + \sigma^*(\cdot)' \cdot (e^{c*}_{Tr}(\cdot) - E^c_{Tr}) = 0$$

for all $c \in \{1,...,C\}$, which leads with (5.1) to the following result.

Result 5.2. *A member state c chooses an allocation plan that leads to lower (higher) marginal abatement costs for its NTr-sector compared to the Tr-sector, if the state is a permit seller (buyer). More precisely,*

$$\sigma^* \ = \ -F^c_{Tr}(\cdot)' \ = \ -F^c_{NTr}(\cdot)' + \sigma^{*'} \cdot (e^{c*}_{Tr} - E^c_{Tr})$$

for all $c \in \{1,...,C\}$.

This means that emitters in the *NTr*-sector of a state with initially more permits than necessary to cover its emissions face a lower burden than emitters in the *Tr*-sector. For a state that has too few permits, the situation is vice versa. Hence, the sign of the difference between marginal abatement costs depends only on the slope of the permit price function and the trade volume of the state ($e^{c*}_{Tr} - E^c_{Tr}$). Since cost efficiency requires equal marginal abatement costs for all emitters in all sectors, strategic behavior results in an inefficient solution, except in the case $e^{c*}_{Tr} = E^c_{Tr}$ for all $c \in \{1,..,C\}$.

The equilibrium strategy of member states can be motivated as a permit-selling state has an incentive to increase the permit price. A higher permit price means a stricter reduction goal for the *Tr*-sector. Therefore, a regulator has to assign fewer permits to the *Tr*-sector and thus more permits to the *NTr*-sector, which results in lower marginal abatement costs of the *NTr*-sector.

	BaU Emissions 2005 (in Mt_{CO_2})			Emission Budget
	***Tr*-sector**	***NTr*-sector**	**Total**	**(in Mt_{CO_2})**
Austria	23.50	36.81	60.32	47.9
Belgium	59.07	54.52	113.59	98.3
Denmark	24.20	24.20	48.40	41.7
Finland	34.36	21.05	55.40	53.2
France	85.76	304.15	389.91	354.1
Germany	481.21	334.40	815.61	745.0
Greece	58.67	39.12	97.79	88.9
Ireland	14.26	30.32	44.59	33.6
Italy	212.52	204.20	416.72	365.4
Netherlands	87.23	77.37	164.60	143.7
Portugal	26.33	34.87	61.20	49.5
Spain	118.51	174.09	292.60	234.4
Sweden	15.25	37.36	52.62	52.6
U.K.	242.37	284.53	526.90	498.0
EU	1483.24	1657.00	3140.24	2806.3

Table 5.1: *Member states' business as usual emissions in 2005 and the emission budgets per year according to the burden-sharing agreement. (Taken from Böhringer et al., 2005.)*

5.1.4 Numerical Example

This section shows to what extent strategic behavior of member states influences the outcome of the European ETS. Therefore, a numerical example is applied based on abatement costs functions from Böhringer et al. (2005). They derive marginal abatement cost functions for the *Tr*- and *NTr*- sectors of 14 EU member states from the PACE model, a standard multi-region, multi-sector computational general equilibrium model.[7]

These functions calculate marginal costs in units of *US dollar* per ton of *carbon*. The sectors' marginal costs depend on the difference between the business

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[7] PACE is an acronym for Policy Analysis based on Computable Equilibrium. For details on the model, see Böhringer (2002b).

	***Tr*-sector**			***NTr*-sector**		
	$a_{1,c,Tr}$	$a_{2,c,Tr}$	$a_{3,c,Tr}$	$a_{1,c,NTr}$	$a_{2,c,NTr}$	$a_{3,c,NTr}$
Austria	33.90	6.24	9.39	153.68	11.28	34.90
Belgium	13.60	-0.49	0.99	32.68	2.28	0.35
Denmark	8.57	-1.82	0.46	94.97	29.05	-0.78
Finland	26.44	3.41	1.01	104.07	30.23	16.55
France	11.27	0.59	0.25	8.86	0.24	0.00
Germany	1.60	0.00	0.00	5.77	0.08	0.00
Greece	19.52	-1.08	0.45	61.59	2.87	2.36
Ireland	8.55	19.52	15.70	169.53	61.00	41.43
Italy	4.41	0.10	0.01	12.78	-0.40	0.11
Netherlands	3.61	1.22	0.08	18.22	0.52	0.07
Portugal	29.20	-1.44	9.85	83.66	28.48	-1.27
Spain	6.29	-0.01	0.07	18.32	0.78	0.01
Sweden	49.51	0.32	38.26	104.01	14.25	-0.06
U.K.	4.08	0.08	0.01	6.97	0.12	0.00

Table 5.2: *Coefficients for marginal cost functions. (Taken from Böhringer et al., 2005.)*

as usual (BaU) carbon input in the year 2005 and the actual carbon input.[8] The actual carbon input of a sector is denoted by χ_i^c. The BaU emissions are denoted by χ_i^{c2005}. Based on the ratio of the corresponding molar masses, carbon can be converted into the corresponding amount of CO_2 emissions generated after combustion.[9] The applied marginal cost functions have the following form:

$$-F_i^c(\chi_i^c) = a_{1,ci} \cdot (\chi_i^{c2005} - \chi_i^c) + a_{2,ci} \cdot (\chi_i^{c2005} - \chi_i^c)^2 + a_{3,ci} \cdot (\chi_i^{c2005} - \chi_i^c)^3 \quad (5.7)$$

with $c \in \{1, ..., 14\}$ and $i \in \{Tr, NTr\}$.

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[8] The BaU amount of carbon is the amount of carbon a sector would have consumed in the absence of any regulation.

[9] Since carbon dioxide cannot be separated yet, the amount of emitted carbon dioxide is determined by the amount of carbon in the fossil fuel. The conversion factor from carbon to carbon dioxide is 44/12.

	Optimal Marginal Costs (in €/t$_{CO_2}$)		**Strategic Marginal Costs (in €/t$_{CO_2}$)**		**Optimal Emissions (in Mt$_{CO_2}$)**		**Strategic Emissions (in Mt$_{CO_2}$)**	
	Tr	***NTr***	***Tr***	***NTr***	***Tr***	***Ntr***	***Tr***	***Ntr***
Austria	13.9	13.9	14.1	14.7	20.2	35.8	20.2	35.8
Belgium	13.9	13.9	14.1	14.2	50.5	50.2	50.4	50.1
Denmark	13.9	13.9	14.1	13.1	8.0	22.8	7.9	22.8
Finland	13.9	13.9	14.1	13.7	29.6	19.7	29.6	19.7
France	13.9	13.9	14.1	14.8	75.5	288.7	75.4	287.7
Germany	13.9	13.9	14.1	11.4	399.6	310.2	398.7	314.2
Greece	13.9	13.9	14.1	13.9	50.7	36.7	50.6	36.7
Ireland	13.9	13.9	14.1	14.6	10.7	29.5	10.6	29.5
Italy	13.9	13.9	14.1	15.0	186.1	192.1	185.9	191.2
Netherlands	13.9	13.9	14.1	13.9	72.0	69.6	71.9	69.5
Portugal	13.9	13.9	14.1	14.6	22.4	33.3	22.4	33.2
Spain	13.9	13.9	14.1	16.6	99.7	166.4	99.5	165.1
Sweden	13.9	13.9	14.1	13.7	12.9	36.0	12.9	36.0
U.K.	13.9	13.9	14.1	12.5	212.9	264.5	212.5	266.3
EU					1250.8	1555.5	1248.4	1557.9

Table 5.3: *Marginal abatement costs and emissions for the cases of a central planner (optimal) and strategic member states (strategic).*

Estimated BaU emissions of the states' *Tr*- and *NTr*-sectors for the year 2005 are given in Table 5.1. The coefficients $a_{1,ci}, a_{2,ci}$ and $a_{3,ci}$ for each sector of each considered member state are presented in Table 5.2. These coefficients are calibrated in a way that the function (5.7) delivers the marginal costs of a sector in US dollars. For comparability reasons, we use the same \$/€ exchange rate of 1.213 as used in Böhringer et al.

Based on these cost functions, we analyze the scenarios from the Sections 5.1.2 and 5.1.3: a central planner and individually deciding member states.[10]

Table 5.3 shows the resulting marginal abatement costs and the emissions in each sector for both scenarios. For the central planner scenario, we derive analogous to Böhriner et al. a cost-minimizing permit price of 13.9 € per ton of CO_2. Strategic behavior of member states yields an equilibrium permit price of 14.1 € per ton of CO_2. Interestingly, strategic behavior has only a limited impact on the permit price.

The consequences of strategic behavior for the marginal abatement costs of the *NTr*-sectors are more significant. In cases where there is a central planner, marginal abatement costs of the *NTr*-sectors are, of course, equal to the permit price of 13.9 €. In the strategic scenario, as shown in Section 5.1.3, marginal abatement costs for the *NTr*-sector are lower or higher compared to the permit price, depending whether a state is a permit seller or buyer.

Thereby, Germany has the highest deviation between marginal costs of the *Tr*- and *NTr*-sectors. The emitters in Germany's *NTr*-sector have 2.7 € lower costs per ton of CO_2 than in the *Tr*-sector. Spain's *NTr*-sector has the overall highest marginal emission abatement costs of 16.6 €. Comparing Germany's and Spain's *NTr*-sectors, we have marginal costs that are 5.2 € higher for Spain, i.e., nearly 50%. The huge deviation between these countries can be ascribed to their high trade volumes, which are shown in Table 5.4.[11] The states with the highest trade volumes are Germany and the U.K. as the largest permit buyers and Spain as the largest permit seller. Comparing Table 5.3 and Table 5.4 confirms that the member

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[10] The case of a central planner minimizing overall costs is also considered in Böhringer et al. (2005). Due to rounding errors, some of their results slightly differ to ours.

[11] The overall sum of countries' trade volumes in Table 5.4 is not exactly zero since values are rounded.

	Optimal Trade Volume	Strategic Trade Volume
Austria	8.1	8.0
Belgium	2.3	2.2
Denmark	-10.9	-11.0
Finland	-3.8	-3.9
France	10.1	9.1
Germany	-34.8	-31.8
Greece	-1.4	-1.6
Ireland	6.6	6.6
Italy	12.8	11.6
Netherlands	-2.1	-2.3
Portugal	6.1	6.0
Spain	31.7	30.2
Sweden	-3.8	-3.8
U.K.	-20.6	-19.0

Table 5.4: *Member state's trade volumes* ($e_{Tr}^{c*} - E_{Tr}^{c}$) *in* MT_{CO_2}.

states with the highest trade volumes also have the highest difference in marginal costs, which is in accordance with the theoretical analysis in Section 5.1.3.

Analyzing sectors' emissions in both scenarios shows that strategic behavior has only a limited impact on emissions. The highest deviation between emissions is again for the German *NTr*-sector. In case of strategic behavior, the German *NTr*-sector emits 4 Mt$_{CO_2}$ more than in the cost-minimizing scenario, which is an increase of less than 1.3%. Also, the change in member states' trading volumes is rather small, as shown in Table 5.4. Of all investigated member states, Germany has the highest change in its trade volume. In case of strategic behavior, Germany decreases its permits sales by 3 Mt$_{CO_2}$, which is slightly more than 8%. These in comparison strong effects for Germany can be motivated by Germany's marginal cost functions have the smallest slopes of all countries.

	Total Abatement Costs [M €]			**Costs *Tr*-Sector [M €]**			**Costs *NTr*-Sector [M €]**		
	Opt.	**Strat.**	**Rel. Change**	**Opt.**	**Strat.**	**Rel. Change**	**Opt.**	**Strat.**	**Rel. Change**
Austria	139.2	140.8	*1.01*	132.6	133.4	*1.01*	6.6	7.4	*1.12*
Belgium	113.0	113.5	*1.00*	84.3	83.2	*0.99*	28.8	30.2	*1.05*
Denmark	-51.1	-53.2	*0.96*	-60.8	-62.0	*0.98*	9.7	8.7	*0.91*
Finland	-13.8	-14.5	*0.95*	-22.5	-23.1	*0.97*	8.7	8.6	*0.98*
France	307.2	309.4	*1.01*	204.1	192.8	*0.94*	103.2	116.7	*1.13*
Germany	206.9	205.6	*0.99*	44.8	93.2	**2.08**	162.1	112.4	**0.69**
Greece	50.6	50.3	*0.99*	34.3	33.9	*0.99*	16.2	16.4	*1.01*
Ireland	114.3	115.6	*1.01*	108.8	109.5	*1.01*	5.6	6.1	*1.10*
Italy	424.1	426.9	*1.01*	341.3	330.9	*0.97*	82.8	96.1	*1.16*
Netherlands	103.5	103.1	*1.00*	50.8	50.3	*0.99*	52.7	52.7	*1.00*
Portugal	119.5	120.7	*1.01*	108.9	109.1	*1.00*	10.6	11.6	*1.10*
Spain	606.6	614.3	*1.01*	554.9	542.1	*0.98*	51.7	72.2	**1.40**
Sweden	-28.1	-28.9	*0.97*	-37.7	-38.3	*0.98*	9.6	9.4	*0.98*
U.K.	35.9	33.5	*0.93*	-98.5	-76.7	**1.28**	134.4	110.2	**0.82**
EU	2127.8	2137.1	*1.00*	1445.2	1478.2	*1.02*	682.6	658.8	*0.97*

Table 5.5: *Member states' and sectors' emission abatement costs in M €.*

Table 5.5 lists total emission abatement costs of each state and how the costs are distributed between the *Tr*- and *NTr*-sectors.[12] Looking at the overall abatement costs for the EU, there is no significant difference between the central planner and the strategic scenario. Also on the member states' level, there are only small changes in the abatement costs between the two scenarios. Strategic behavior is most beneficial to the U.K. Its costs decrease by 7%. However, for most member states, the change in costs is less than 1%.

Although total costs of member states are only slightly affected by strategic behavior, there is a significant redistribution of costs between the *Tr*- and *NTr*-sector in some states. For instance, the costs for the German *Tr*-sector are more than twice as high if states behave strategically. This change in costs can mainly be ascribed to the change in Germany's trade volume. Costs of the German *NTr*-sector decrease by more than 30%, whereas the Spanish *NTr*-sector's costs increase by 40%. Thus, we can summarize that strategic behavior has only a small impact on the EU's and a member state's total costs. However, for states with large trade volumes, there is a huge impact on the distribution of costs between sectors.

A comparison of the equilibrium allocation of strategically deciding member states in this section with the actual NAPs of the member states in Figure 2.4 in Section 2.3.1 shows that there are no similarities. Due to the too generous allocation in the first trading period, emission permits had no value and estimated marginal abatement costs in the different *NTr*-sectors were much higher than in our model. This indicates that the allocation in the first period was driven less by strategic considerations, as described in this section, than by, e.g., lobbying efforts of the industry.[13]

Recapitulating this analysis, the numerical example confirms the result of Viguier et al. (2006) that strategic behavior has only a limited impact on the Emissions Trading Scheme and overall costs. The permit price is hardly affected by strategic behavior. Only for member states with higher trading volumes does a decentralized allocation have a noteworthy impact on both marginal and absolute

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[12] Clearly, the distribution of costs between sectors depends on the assumption that permits are grandfathered. If permits are auctioned, the regulator can redistribute costs of emission abatement.

[13] Anger et al. (2006) show in a theoretical model that lobbying could also be the driver behind a discriminatory allocation.

costs. However, these results support the assumption in Chapter 4 that firms are price takers in the permit market, since even entire member states cannot influence the permit price significantly.

5.2 Oligopoly Output Markets and Strategic Member States

Thus far, we have abstracted from interactions between sectors, except via the permit market. In this section, the analysis is extended to account for such effects based on the model in Chapter 4. We consider international imperfect commodity markets and elaborate the effects of such markets on a decentralized and a centralized emissions allocation.

If member states strategically decide on their allocations, we show that the instrument of emissions allocation is abused as a substitute for missing trade policies on the integrated European market. This result is in line with the literature analyzing the correlation between environmental and trade policies.[14] In contrast to the existing models, we apply a general equilibrium model with imperfect competition matching the special circumstances of the European Emissions Trading Scheme. Interestingly, in the case of a central planner, the model shows that cost efficiency not only requires a differentiation between the permit price and the environmental taxes but also between the different member states' taxes.

This section is organized as follows. Subsection 5.2.1 provides the general framework of the analysis. The case of strategic member states individually deciding on their own allocation is investigated in Subsection 5.2.2. Subsection 5.2.3 derives the condition for a welfare optimal allocation that a central planner would choose.

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[14] A short overview of the literature of environmental policies and international trade is given in Section 3.4.

5.2.1 General Framework

Most of the assumptions in this model are similar to those in Chapter 4. Thus, we sometimes refer to the corresponding sections from the previous chapter.

The analyzed economy is again a small open economy that produces two commodities, X and Y. In contrast to Chapter 4, this economy consists of two member states, a and b, with an integrated market for commodity X. Capital, raw materials and commodity Y are traded internationally, i.e., their prices are fixed and given by the world market. The exchange rate between the world and national markets is again assumed to be one. Each state is divided into a *Tr*- and a *NTr*-sector. Each *NTr*-sector consists of a representative household, whose emissions are regulated by a national environmental tax. The combined *Tr*-sector consists of a set of firms $M = \{1, ..., m\}$, in which the subset M^a represents the firms located in state a and M^b the firms in state b. ($M^a \cup M^b = M$ and $M^a \cap M^b = \oslash$.) The firms in state $c \in \{a, b\}$ can be divided into two groups: the firms in subset $N^c \subseteq M^c$ producing commodity X and the firms in subset $\bar{N}^c := M^c \backslash N^c$ producing commodity Y. $N := N^a \cup N^b$ is the set of all firms producing commodity X and $\bar{N} := \bar{N}^a \cup \bar{N}^b$ is the set of all firms producing commodity Y.

Each country has an exogenously given emission budget of $\bar{E}^c$, which must be allocated to its *Tr*- and *NTr*-sectors. In the following paragraphs, we define the exact properties of all subjects in the economy and determine the equilibrium, depending on the allocation of emissions.

The Non-Trading-Sectors

The *NTr*-sector of each state $c \in \{a, b\}$ consists of a representative household consuming an amount of commodity X ($x^c \in \mathbb{R}_{\geq 0}$), commodity Y ($y^c \in \mathbb{R}_{\geq 0}$) and energy ($h^c \in \mathbb{R}_{\geq 0}$). Additionally, it supplies the firms in state c with labor ($l^c \in \mathbb{R}_{\leq 0}$). Depending on these variables, the household has a certain utility, determined by the utility function $U^c(H^c(x^c, y^c, h^c), l^c)$. For the assumptions about the functions $U^c(\cdot)$ and $H^c(\cdot)$, see Section 4.2.1.

We assume that each household maximizes its utility subject to its budget I^c, which consists of the firms' net profits in state c, $(1 - \theta^c) \sum_{k \in M^c} \Pi_k$, and an exogenous part, I_e^c.[15] The price for commodity X is denoted by p, the price for commodity Y by q, and the energy price by s. The *NTr*-sectors' emissions are regulated through a national emissions tax t^c, which results in a total energy price for the household of $s+t^c$. The wage in state c is denoted by w^c.

The solution of the utility maximization of a household in state c is denoted by $\tilde{x}^c(p,q,w^c,s,t^c,I^c)$, $\tilde{y}^c(p,q,w^c,s,t^c,I^c)$, $\tilde{h}^c(p,q,w^c,s,t^c,I^c)$, and $\tilde{l}^c(p,q,w^c,s,t^c,I^c)$.

The Trading-Sector

The *Tr*-sector consists of two types of firms that can be located in each state. Firms producing an amount x_i of commodity X (with $i \in N$) and firms producing an amount y_j of commodity Y (with $j \in \bar{N}$). The firms in N are assumed to have market power in their output market, whereas the firms in $\bar{N}$ are price takers and obtain the commodity price from the world market.

All firms use capital, energy and labor as input factors. The price for capital (r) and energy (s) is given by the world market. A function $C^k(z_k,e_k,w^c,s,r) : \mathbb{R}^5_{\geq 0} \rightarrow \mathbb{R}_{\geq 0}$ describes the costs of a firm $k \in M^c$, with properties similar to Section 4.2.2.[16] In addition to the production costs, firms must cover the emissions generated by the consumption of energy with the corresponding amount of emission permits. Each firm $k \in M^c$ gets an initial amount of permits, $e_k^0 \in \mathbb{R}_{\geq 0}$. The total amount of initially assigned permits in state c equals the amount of permits the state assigns to its *Tr*-sector (i.e., $\sum_{k \in M^c} e_k^0 = E_{Tr}^c$). Grandfathering is assumed to be the allocation mechanism for the *Tr*-sector. Firms can trade permits on a permit market in which all firms in M participate. Hence, the overall amount of permits in the trading scheme is $E_{Tr} = E_{Tr}^a + E_{Tr}^b$. The permit price is denoted by σ and all firms are assumed to be price takers on the permit market.

The firms in set $\bar{N}$ are also price takers on the product market, i.e., each firm $j \in \bar{N}^c$ maximizes its profit

$$\Pi_j = q \cdot y_j - C^j(y_j,e_j,w^c,s,r) - \sigma \cdot (e_j - e_j^0)$$

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[15] For reasons of simplicity, we neglect the possibility of internationally owned firms in our framework . The main results of this model are independent of this assumption.

[16] The variable z_k denotes x_k for $k \in N^c$ and y_k for $k \in \bar{N}^c$.

taking all prices as fixed and given. The firms in set N compete in an imperfect product market where they possess market power. Similar to Section 4.2.4, we assume that commodity X is only consumed by the two representative households and that the firms are able to anticipate the households' utility-maximizing behavior. Thus, firms know $\tilde{x}^a(p,q,w^a,s,t^a,I^a)$ and $\tilde{x}^b(p,q,w^b,s,t^b,I^b)$. We assume that firms fail to internalize the impact of their decisions on other prices and the households' incomes. Hence, they take the households' incomes and all prices, except p, as fixed and given. Solving $x = \tilde{x}^a(p,q,w^a,s,t^b,I^b) + \tilde{x}^b(p,q,w^b,s,t^b,I^b)$ for p yields the inverse demand function $\Psi(x,q,w^a,w^b,s,t^a,t^b,I^a,I^b)$ with $x = \sum_{i\in N} x_i$. Given the inverse demand function, each firm $i \in N^c$ maximizes its own profit

$$\Pi_i = \Psi(\sum_{i\in N} x_i,q,w^a,w^b,s,t^a,t^b,I^a,I^b)x_i - C^i(x_i,e_i,w^c,s,r) - \sigma \cdot (e_i - e_i^0)$$

by choosing its own output and emissions level. When maximizing their profits, each firm $i \in N^c$ conjectures a certain change v^i in the other firms' output if its own output increases, i.e., $v^i = \frac{d}{dx_i}\sum_{j\in N\setminus\{i\}} x_j$.[17]

The Governments

Both governments offer certain services to its citizens, which result in costs of g^a and g^b, respectively. To finance these expenditures, each government uses the income from the environmental tax t^c in its *NTr*-sector and from an additional profit tax θ^c. The environmental tax t^c is chosen in a way that the emissions target of the *NTr*-sector is achieved (i.e., $h^c = \bar{E}^c - E^c_{Tr}$).

Equilibrium of the Economy

An equilibrium of this economy is given by the following system of equations:

$$H^c_{x^c} - \frac{U^c_{l^c}}{U^c_{H^c}} \cdot \frac{p}{w^c} = 0 \quad \forall c \in \{a,b\} \tag{5.8}$$

$$H^c_{y^c} - \frac{U^c_{l^c}}{U^c_{H^c}} \cdot \frac{q}{w^c} = 0 \quad \forall c \in \{a,b\} \tag{5.9}$$

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[17] For a survey on conjectural variations, we again refer to Dixit (1986).

$$H^c_{h^c} - \frac{U^c_{l^c}}{U^c_{H^c}} \cdot \frac{s+t^c}{w^c} = 0 \quad \forall c \in \{a,b\} \tag{5.10}$$

$$p \cdot x^c + q \cdot y^c + (s+t^c) \cdot h^c + w^c \cdot l^c - (1-\theta^c) \sum_{k \in M^c} \Pi_k - I^c_e = 0$$
$$\forall c \in \{a,b\} \tag{5.11}$$

$$q - C^j_{y_j}(\cdot) = 0 \quad \forall j \in \bar{N} \tag{5.12}$$

$$-C^j_{e_j}(\cdot) - \sigma = 0 \quad \forall j \in \bar{N} \tag{5.13}$$

$$\Psi(\sum_{i \in N} x_i, \cdot) + (1+v^i) x_i \Psi_x(\sum_{i \in N} x_i, \cdot) - C^i_{x_i}(\cdot) = 0 \quad \forall i \in N \tag{5.14}$$

$$-C^i_{e_i}(\cdot) - \sigma = 0 \quad \forall i \in N \tag{5.15}$$

$$g^c = t^c \cdot h^c + \theta^c \cdot \sum_{k \in M^c} \Pi_k \quad \forall c \in \{a,b\} \tag{5.16}$$

$$\bar{E}^c = E^c_{Tr} + h^c \quad \forall c \in \{a,b\} \tag{5.17}$$

$$E^a_{Tr} + E^b_{Tr} - \sum_{k \in M} e_k = 0 \tag{5.18}$$

$$x^a + x^b - \sum_{i \in N} x_i = 0 \tag{5.19}$$

$$l^c + \sum_{k \in M^c} \frac{\partial C^k(\cdot)}{\partial w^c} = 0 \quad \forall c \in \{a,b\} \tag{5.20}$$

The equations (5.8) to (5.11) describe the utility-maximizing behavior for the households. (5.12) and (5.13) are the first-order conditions of the profit maximization of the competitive firms. The conditions for a profit maximization of the imperfectly competitive firms are given by (5.14) and (5.15). Equation (5.16) guarantees balanced national budgets for states *a* and *b*. Equation (5.17) ensures that all emission rights are allocated to the *Tr*- and *NTr*-sectors. The market-clearing conditions for the emission permit market, the market for commodity *X* and the national labor markets are given by (5.18) to (5.20).

Definition 5.3. *Given an allocation E^a_{Tr} and E^b_{Tr} for the Tr-sector a configuration of values* $\left(\{x^{c*}, y^{c*}, h^{c*}, l^{c*}\}_{c\in\{a,b\}}, \{x^*_i, e^*_i\}_{i\in N}, \{y^*_j, e^*_j\}_{j\in\bar{N}}\right)$, *and prices and taxes* $\left(p^*, \sigma^*, \{w^{c*}, t^{c*}, \theta^{c*}\}_{c\in\{a,b\}}\right)$ *is an equilibrium of the economy if it satisfies the conditions (5.8)-(5.20)*

For reasons of simplicity, we assume in this Chapter that for every feasible allocation of emission rights to the *Tr*-sector, E^a_{Tr} and E^b_{Tr}, a *unique* equilibrium of the economy exists. However, multiplicity of equilibria is possible (see, e.g., Section 4.5).

5.2.2 Decentralized Allocation of Emissions

Based on the equilibrium described in Section 5.2.1, we first analyze the case in the first two trading periods of the EU ETS. Each member state decides individually on its own National Allocation Plan. Thereby, we assume that regulators in both states are able to anticipate the equilibrium of the economy, as defined in Definition 5.3. The objective of a member state $c \in \{a,b\}$ is to choose an allocation $E^c_{Tr} \leq \bar{E}^c$ that maximizes its national wealth, i.e., the utility of its household

$$W^c(E^a_{Tr}, E^b_{Tr}) := \\ U^c\left(H^c\left(x^{c*}(E^a_{Tr}, E^b_{Tr}), y^{c*}(E^a_{Tr}, E^b_{Tr}), h^{c*}(E^a_{Tr}, E^b_{Tr})\right), l^{c*}(E^a_{Tr}, E^b_{Tr})\right).$$

To define an equilibrium for this strategic decision problem, we use the concept of Nash-equilibrium, i.e.,

$$\begin{aligned} W^a(E^a_{Tr}, E^{b*}_{Tr}) &\leq W^a(E^{a*}_{Tr}, E^{b*}_{Tr}) \\ W^b(E^{a*}_{Tr}, E^b_{Tr}) &\leq W^b(E^{a*}_{Tr}, E^{b*}_{Tr}) \end{aligned} \tag{5.21}$$

with $E^c_{Tr} \leq \bar{E}^c$ for all $c \in \{a,b\}$.

Proposition 5.4. (Equilibrium Allocation): *If an interior solution E^{a*}_{Tr}, E^{b*}_{Tr} of (5.21) exists and $W^c(E^a_{Tr}, E^b_{Tr})$ is continuously differentiable in E^c_{Tr} at E^{a*}_{Tr}, E^{b*}_{Tr} for $c \in \{a,b\}$ the equilibrium allocation of emissions leads to a difference between the tax rate of the non-trading sector of state c and the permit price in the trading* *sector of*

$$t^{c*}-\sigma^{*}=\underbrace{-\sum_{i\in N^c}(1+v^i)x_i^*\Psi_x(\cdot)\frac{\partial x_i^*}{\partial E_{Tr}^c}}_{(1)}\underbrace{-\frac{\partial p^*}{\partial E_{Tr}^c}(x^{c*}-\sum_{i\in N^c}x_i^*)}_{(2)}\underbrace{-\frac{\partial \sigma^*}{\partial E_{Tr}^c}(\sum_{k\in M^c}e_k^*-E_{Tr}^{c*})}_{(3)}.$$

Proof. If an interior solution E_{Tr}^{a*}, E_{Tr}^{b*} of (5.21) exists and $W^c(E_{Tr}^a,E_{Tr}^b)$ is continuously differentiable in equilibrium with respect to E_{Tr}^c, the best response of a member state to the equilibrium allocation of the other state is implicitly given by the first-order condition

$$U_{H^c}^c H_{x^c}^c\frac{\partial x^{c*}}{\partial E_{Tr}^c}+U_{H^c}^c H_{y^c}^c\frac{\partial y^{c*}}{\partial E_{Tr}^c}+U_{H^c}^c H_{h^c}^c\frac{\partial h^{c*}}{\partial E_{Tr}^c}+U_{l^c}^c\frac{\partial l^{c*}}{\partial E_{Tr}^c}=0.$$

Applying conditions (5.8)-(5.10) and (5.17) yields

$$p^*\frac{\partial x^{c*}}{\partial E_{Tr}^c}+q\frac{\partial y^{c*}}{\partial E_{Tr}^c}-(s+t^{c*})+w^{c*}\frac{\partial l^{c*}}{\partial E_{Tr}^c}=0. \tag{5.22}$$

Combining the budget constraint of the household (5.11) and (5.16) yields

$$sh^{c*}+p^*(x^{c*}-\sum_{i\in N^c}x_i^*)+q(y^{c*}-\sum_{j\in\bar N^c}y_j^*)$$
$$+\sum_{k\in M^c}C^k(\cdot)+w^{c*}l^{c*}+\sigma^*\sum_{k\in M^c}(e_k^*-e_k^0)+g-I_e^c=0.$$

Due to Shepard's lemma, the cost function of a firm $k\in M^c$ can be written as $C^k(\cdot)=s\cdot e_k^*+w^*\cdot\frac{\partial C^k(\cdot)}{\partial w}+r\cdot\frac{\partial C^k(\cdot)}{\partial r}$. Including this, (5.17) and (5.20) in the modified budget constraint of the household yields

$$s\bar E^c+p^*(x^{c*}-\sum_{i\in N^c}x_i^*)+q(y^{c*}-\sum_{j\in\bar N^c}y_j^*)$$
$$+r\sum_{k\in M^c}C_r^k(\cdot)+(s+\sigma^*)(\sum_{k\in M^c}e_k^*-E_{Tr}^c)+g-I_e^c=0.$$

Differentiating the previous condition with respect to E_{Tr}^c yields

$$\frac{\partial p^*}{\partial E_{Tr}^c}(x^{c*}-\sum_{i\in N^c}x_i^*)+p^*(\frac{\partial x^{c*}}{\partial E_{Tr}^c}-\sum_{i\in N^c}\frac{\partial x_i^*}{\partial E_{Tr}^c})$$
$$+q(\frac{\partial y^{c*}}{\partial E_{Tr}^c}-\sum_{j\in\bar N^c}\frac{\partial y_j^*}{\partial E_{Tr}^c})+r\sum_{k\in M^c}\frac{\partial C_r^k(\cdot)}{\partial E_{Tr}^c}+\frac{\partial\sigma^*}{\partial E_{Tr}^c}(\sum_{k\in M^c}e_k^*-E_{Tr}^c)$$
$$+(s+\sigma^*)(\sum_{k\in M^c}\frac{\partial e_k^*}{\partial E_{Tr}^c})-(s+\sigma^*)=0. \tag{5.23}$$

Partial differentiation of $C^k(\cdot) = s \cdot e_k^* + w^* \cdot \frac{\partial C^k(\cdot)}{\partial w} + r \cdot \frac{\partial C^k(\cdot)}{\partial r}$ with respect to E_{Tr}^c yields

$$C_{z_k}^k \frac{\partial z_k^*}{\partial E_{Tr}^c} + C_{e_k}^k \frac{\partial e_k^*}{\partial E_{Tr}^c} = s \cdot \frac{\partial e_k^*}{\partial E_{Tr}^c} + r \cdot \frac{\partial C_r^k}{\partial E_{Tr}^c} + w^* \cdot \frac{\partial C_w^k}{\partial E_{Tr}^c}. \tag{5.24}$$

Summing up the system of equations given by (5.24) over $k \in M^c$ and combining the result with the equations (5.13), (5.15), and (5.23), we have

$$\begin{aligned} &\frac{\partial p^*}{\partial E_{Tr}^c}(x^{c*} - \sum_{i \in N^c} x_i^*) + p^*(\frac{\partial x^{c*}}{\partial E_{Tr}^c} - \sum_{i \in N^c} \frac{\partial x_i^*}{\partial E_{Tr}^c}) + q(\frac{\partial y^{c*}}{\partial E_{Tr}^c} - \sum_{j \in \bar{N}^c} \frac{\partial y_j^*}{\partial E_{Tr}^c}) \\ &\qquad + \frac{\partial \sigma^*}{\partial E_{Tr}^c}(\sum_{k \in M^c} e_k^* - E_{Tr}^c) - (s + \sigma^*) + \sum_{k \in M^c} C_{z_k}^k \frac{\partial z_k^*}{\partial E_{Tr}^c} + w^* \frac{\partial l^{c*}}{\partial E_{Tr}^c} = 0. \end{aligned} \tag{5.25}$$

Inserting this result in (5.22) yields

$$\begin{aligned} &\sum_{i \in N^c}(p^* - C_{x_i}^i)\frac{\partial x_i^*}{\partial E_{Tr}^c} + \sum_{j \in \bar{N}^c}(q - C_{y_j}^j)\frac{\partial y_j^*}{\partial E_{Tr}^c} - \frac{\partial p^*}{\partial E_{Tr}^c}(x^{c*} - \sum_{i \in N^c} x_i^*) \\ &\qquad\qquad - (t^{c*} - \sigma^*) - \frac{\partial \sigma^*}{\partial E_{Tr}^c}(\sum_{k \in M^c} e_k^* - E_{Tr}^{c*}) = 0. \end{aligned}$$

With (5.12), (5.14) and $p^* = \Psi^*(\cdot)$, we have

$$t^{c*} - \sigma^* = -\sum_{i \in N^c}(1 + v^i)x_i^* \Psi_x(\cdot)\frac{\partial x_i^*}{\partial E_{Tr}^c} - \frac{\partial p^*}{\partial E_{Tr}^c}(x^{c*} - \sum_{i \in N^c} x_i^*) - \frac{\partial \sigma^*}{\partial E_{Tr}^c}(\sum_{k \in M^c} e_k^* - E_{Tr}^{c*}).$$

□

There are three effects determining the non-cooperative difference between a state's environmental tax and the equilibrium permit price: the imperfect competition effect (1), the terms-of-trade effect for the market of commodity X (2) and the terms-of-trade effect for the permit market (3).[18] In the following, we consider all effects in turn.

The imperfect competition effect already appears in Proposition 4.3 in Section 4.3.2. The governments want to reduce negative effects from market distortions

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[18] These effects are consistent with the literature on international trade under oligopoly, based on the seminal work of Brander and Spencer (1985). Section 3.4 gives a brief survey on environmental policies and international trade.

due to imperfect competition. In Section 4.3.3 we have seen that the sign of this effect is ambiguous if firms are asymmetric. Only in the symmetric case is the effect definitely positive. However, the analysis in Section 4.3.3 and the numerical example in Section 4.4 show that for most relevant cases, the imperfect competition effect is positive.

The impact of the terms-of-trade effect for the market of commodity X depends on the derivative of the commodity price and whether the state is a net exporter or importer. An increased allocation of emissions to the *Tr*-sector has a direct impact on the permit price.[19] Although Lemma 4.9 in Section 4.5.1 shows that the effect on the permit price is ambiguous, Lemmata 4.10 and 4.11 support the assumption of a decreasing permit price. A lower permit price means fewer abatement efforts for the firms. Therefore, it is reasonable to assume that the firms' output increases. Lemma 4.5 confirms this conjecture for a duopoly industry in a partial market, individual state scenario. Since an increasing output coincides with a lower commodity price, it can be assumed that the derivative of the commodity price with respect to the allocation to the *Tr*-sector is negative. Hence, the terms-of-trade effect for the market of commodity X is very likely to be positive (negative) for a net-importing (exporting) state. This can be motivated by the fact that a net-importing state is primarily interested in a lower commodity price for its households, whereas a net-exporting state is mainly interested in a higher price to increase the firms' profits.

The third effect, the terms-of-trade effect for the permit market, corresponds to the difference between *Tr*- and *NTr*-sectors' marginal costs in Result 5.2 in Section 5.1.3. The sign of this effect depends on the derivative of the permit price function and the state's balance of permit trade. As discussed in the previous paragraph, for relevant cases it can be assumed that the permit price decreases with an increasing emissions allocation to the *Tr*-sector. Hence, the terms-of-trade effect is positive (negative) if a state is a net importer (exporter) of emission permits. This can be explained by the fact that a net importer (exporter) has an advantage of a lower (higher) permit price.[20]

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[19] Of course, there are also indirect effects on the permit price from changed households' incomes or from substitution effects, which are neglected here.

[20] The numerical example in Section 5.1.4 shows that this terms-of-trade effect for the permit

The analysis of the equilibrium allocation of strategically acting member states shows that the overall sign of the difference between the tax rates and the permit price in Proposition 5.4 cannot be determined in general. In contrast to the individual country case in Chapter 4, individually deciding member states in the multi-country scenario additionally abuse the allocation of emissions as non-cooperative trade policy. This makes predictions about the resulting differences in marginal abatement costs even more difficult.

Comparing the equilibrium tax rates in the different *NTr*-sectors shows that if states are not symmetric, environmental taxes vary between member states,

$$\begin{aligned} t^{a*} - t^{b*} = &\sum_{i\in N^b}(1+v^i)x_i^*\Psi_x(\cdot)\frac{\partial x_i^*}{\partial E^b_{Tr}} - \sum_{i\in N^a}(1+v^i)x_i^*\Psi_x(\cdot)\frac{\partial x_i^*}{\partial E^a_{Tr}} \\ &+ (\frac{\partial p^*}{\partial E^a_{Tr}} + \frac{\partial p^*}{\partial E^b_{Tr}})(x^{b*} - \sum_{i\in N^b} x_i^*) \\ &+ (\frac{\partial \sigma^*}{\partial E^a_{Tr}} + \frac{\partial \sigma^*}{\partial E^b_{Tr}})(\sum_{k\in M^b} e_k^* - E^{b*}_{Tr}). \end{aligned}$$

This is especially interesting from a legal point of view, since discrimination between emitters in the different *NTr*-sectors means a competitive advantage for some emitters. Therefore, tax differentiation could be considered as state aid and could be in conflict with European primary law.

5.2.3 Welfare Optimal Allocation

This section analyzes the welfare optimal allocation a central planner would choose. Due to the recently decided climate package of the European Union, this case is even more interesting as future allocations of emissions will be determined by a central authority.[21]

The objective of the central planner is to maximize overall social welfare, which is defined by a purely utilitarian approach, i.e., social welfare is the un-

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market could exceed 2 €/t_{CO_2} for states with high trade volumes. For example, the terms-of-trade effect for Germany, as the largest permit buyer in the numerical example, is 2.7 €/t_{CO_2}.

[21] See Section 2.2.

weighted sum of all households' utilities:[22]

$$W(E^a_{Tr}, E^b_{Tr}) := W^a(E^a_{Tr}, E^b_{Tr}) + W^b(E^a_{Tr}, E^b_{Tr})$$

Given the social-welfare function, the regulator's optimization problem is:

$$\begin{aligned} &\max_{E^a_{Tr}, E^b_{Tr}} W(E^a_{Tr}, E^b_{Tr}) \\ &\quad \text{s.t. } E^c_{Tr} \leq \bar{E}^c \;\; \forall c \in \{a, b\}. \end{aligned} \tag{5.26}$$

From the conditions of an interior solution, we can derive the following proposition.

Proposition 5.5. (Welfare-Maximizing Allocation): *If an interior solution E^{a*}_{Tr}, E^{b*}_{Tr} of (5.26) exists and $W(E^a_{Tr}, E^b_{Tr})$ is at E^{a*}_{Tr}, E^{b*}_{Tr} continuously differentiable, the welfare-maximizing allocation of emissions leads to a difference between the tax rate for the non-trading sector of state c and the permit price in the trading sector of*

$$\begin{aligned} t^{c*} - \sigma^* = -\Psi_x(\cdot) &\left(\sum_{i \in N^c} (1 + v^i) x^*_i \frac{\partial x^*_i}{\partial E^c_{Tr}} + \frac{\lambda^{-c}}{\lambda^c} \sum_{i \in N^{-c}} (1 + v^i) x^*_i \frac{\partial x^*_i}{\partial E^c_{Tr}} \right) \\ & - (1 - \frac{\lambda^{-c}}{\lambda^c}) \frac{\partial p^*}{\partial E^c_{Tr}} \left(x^{c*} - \sum_{i \in N^c} x^*_i \right) \\ & \qquad - (1 - \frac{\lambda^{-c}}{\lambda^c}) \frac{\partial \sigma^*}{\partial E^c_{Tr}} \left(\sum_{k \in M^c} e^*_k - E^{c*}_{Tr} \right). \end{aligned}$$

with $\lambda^c = \frac{U^c_{l^c}}{w^{c*}}$.

Proof. If an interior solution E^{a*}_{Tr}, E^{b*}_{Tr} of (5.26) exists and $W(E^a_{Tr}, E^b_{Tr})$ is at E^{a*}_{Tr}, E^{b*}_{Tr} continuously differentiable, the welfare optimal allocation is implicitly given

---

[22] Of course, interpersonal comparability of the households' utility functions is required for such an approach. However, since we have already assumed a representative household in each member state, we have also implicitly assumed interpersonal comparability of the utility functions. To construct a representative household as an aggregate of different consumers' preferences, interpersonal comparability is a necessary assumption on the utility functions. See Mas-Colell et al. (1995).

by the system of first-order condition:

$$
\begin{aligned}
&U^a_{H^a} H^a_{x^a} \frac{\partial x^{a*}}{\partial E^a_{Tr}} + U^a_{H^a} H^a_{y^a} \frac{\partial y^{a*}}{\partial E^a_{Tr}} + U^a_{H^a} H^a_{h^a} \frac{\partial h^{a*}}{\partial E^a_{Tr}} + U^a_{l^a} \frac{\partial l^{a*}}{\partial E^a_{Tr}} \\
&\qquad + U^b_{H^b} H^b_{x^b} \frac{\partial x^{b*}}{\partial E^a_{Tr}} + U^b_{H^b} H^b_{y^b} \frac{\partial y^{b*}}{\partial E^a_{Tr}} + U^b_{H^b} H^b_{h^b} \frac{\partial h^{b*}}{\partial E^a_{Tr}} + U^b_{l^b} \frac{\partial l^{b*}}{\partial E^a_{Tr}} = 0
\end{aligned}
$$

$$
\begin{aligned}
&U^a_{H^a} H^a_{x^a} \frac{\partial x^{a*}}{\partial E^b_{Tr}} + U^a_{H^a} H^a_{y^a} \frac{\partial y^{a*}}{\partial E^b_{Tr}} + U^a_{H^a} H^a_{h^a} \frac{\partial h^{a*}}{\partial E^b_{Tr}} + U^a_{l^a} \frac{\partial l^{a*}}{\partial E^b_{Tr}} \\
&\qquad + U^b_{H^b} H^b_{x^b} \frac{\partial x^{b*}}{\partial E^b_{Tr}} + U^b_{H^b} H^b_{y^b} \frac{\partial y^{b*}}{\partial E^b_{Tr}} + U^b_{H^b} H^b_{h^b} \frac{\partial h^{b*}}{\partial E^b_{Tr}} + U^b_{l^b} \frac{\partial l^{b*}}{\partial E^b_{Tr}} = 0
\end{aligned}
$$

With the utility-maximizing conditions of the households (5.8)-(5.10) and (5.17), we have

$$
\begin{aligned}
&\frac{U^c_{l^c}}{w^c} \left(p^* \frac{\partial x^{c*}}{\partial E^c_{Tr}} + q \frac{\partial y^{c*}}{\partial E^c_{Tr}} - (s + t^{c*}) + w^{c*} \frac{\partial l^{c*}}{\partial E^c_{Tr}} \right) \\
&\qquad + \frac{U^{-c}_{l^{-c}}}{w^{-c}} \left(p^* \frac{\partial x^{-c*}}{\partial E^c_{Tr}} + q \frac{\partial y^{-c*}}{\partial E^c_{Tr}} + w^{-c*} \frac{\partial l^{-c*}}{\partial E^c_{Tr}} \right) = 0 \quad (5.27)
\end{aligned}
$$

for all $c \in \{a, b\}$.[23] Analogously to (5.25), we can derive

$$
\begin{aligned}
&\frac{\partial p^*}{\partial E^{-c}_{Tr}} (x^{c*} - \sum_{i \in N^c} x^*_i) + p^* (\frac{\partial x^{c*}}{\partial E^{-c}_{Tr}} - \sum_{i \in N^c} \frac{\partial x^*_i}{\partial E^{-c}_{Tr}}) + q (\frac{\partial y^{c*}}{\partial E^{-c}_{Tr}} - \sum_{j \in \bar{N}^c} \frac{\partial y^*_j}{\partial E^{-c}_{Tr}}) \\
&\qquad + \frac{\partial \sigma^*}{\partial E^{-c}_{Tr}} (\sum_{k \in M^c} e^*_k - E^c_{Tr}) + \sum_{k \in M^c} C^k_{z_k} \frac{\partial z^*_k}{\partial E^{-c}_{Tr}} + w^{c*} \frac{\partial l^{c*}}{\partial E^{-c}_{Tr}} = 0.
\end{aligned}
$$

Inserting the previous condition and (5.25) in (5.27) yields

$$
\begin{aligned}
&\frac{U^c_{l^c}}{w^c} (\sum_{i \in N^c} (p^* - C^i_{x_i}) \frac{\partial x^*_i}{\partial E^c_{Tr}} + \sum_{j \in \bar{N}^c} (q - C^j_{y_j}) \frac{\partial y^*_j}{\partial E^c_{Tr}} - \frac{\partial p^*}{\partial E^c_{Tr}} (x^{c*} - \sum_{i \in N^c} x^*_i) \\
&\qquad - (t^{c*} - \sigma^*) - \frac{\partial \sigma^*}{\partial E^c_{Tr}} (\sum_{k \in M^c} e^*_k - E^{c*}_{Tr})) \\
&\quad + \frac{U^{-c}_{l^{-c}}}{w^{-c}} (\sum_{i \in N^{-c}} (p^* - C^i_{x_i}) \frac{\partial x^*_i}{\partial E^c_{Tr}} + \sum_{j \in \bar{N}^{-c}} (q - C^j_{y_j}) \frac{\partial y^*_j}{\partial E^c_{Tr}} \\
&\qquad - \frac{\partial p^*}{\partial E^c_{Tr}} (x^{-c*} - \sum_{i \in N^{-c}} x^*_i) - \frac{\partial \sigma^*}{\partial E^c_{Tr}} (\sum_{k \in M^{-c}} e^*_k - E^{-c*}_{Tr})) = 0.
\end{aligned}
$$

---

[23] The index $-c$ denotes the competitor of member state c.

Using (5.12), (5.14), (5.18), (5.19) and $p^* = \Psi^*(\cdot)$ yields

$$\begin{aligned}
t^{c*} - \sigma^* = -\Psi_x(\cdot) &\left(\sum_{i \in N^c} (1+v^i) x_i^* \frac{\partial x_i^*}{\partial E_{Tr}^c} + \frac{\lambda^{-c}}{\lambda^c} \sum_{i \in N^{-c}} (1+v^i) x_i^* \frac{\partial x_i^*}{\partial E_{Tr}^c} \right) \\
&- \frac{\partial p^*}{\partial E_{Tr}^c} \left(x^{c*} - \sum_{i \in N^c} x_i^* + \frac{\lambda^{-c}}{\lambda^c} \left(x^{-c*} - \sum_{i \in N^{-c}} x_i^* \right) \right) \\
&- \frac{\partial \sigma^*}{\partial E_{Tr}^c} \left(\sum_{k \in M^c} e_k^* - E_{Tr}^{c*} + \frac{\lambda^{-c}}{\lambda^c} \left(\sum_{k \in M^{-c}} e_k^* - E_{Tr}^{-c*} \right) \right)
\end{aligned}$$

with $\lambda^c = \frac{U_{l^c}^c}{w^{c*}}$, for all $c \in \{a, b\}$. With the equilibrium conditions (5.18) and (5.19), we have

$$\begin{aligned}
t^{c*} - \sigma^* = -\Psi_x(\cdot) &\left(\sum_{i \in N^c} (1+v^i) x_i^* \frac{\partial x_i^*}{\partial E_{Tr}^c} + \frac{\lambda^{-c}}{\lambda^c} \sum_{i \in N^{-c}} (1+v^i) x_i^* \frac{\partial x_i^*}{\partial E_{Tr}^c} \right) \\
&- (1 - \frac{\lambda^{-c}}{\lambda^c}) \frac{\partial p^*}{\partial E_{Tr}^c} \left(x^{c*} - \sum_{i \in N^c} x_i^* \right) \\
&- (1 - \frac{\lambda^{-c}}{\lambda^c}) \frac{\partial \sigma^*}{\partial E_{Tr}^c} \left(\sum_{k \in M^c} e_k^* - E_{Tr}^{c*} \right).
\end{aligned}$$

□

Comparing the welfare-maximizing difference between marginal costs in Proposition 5.5 with the result of a decentralized allocation in Proposition 5.4 discloses that a decentralized allocation of strategic member states will not lead to a welfare optimal outcome.

We also see that the allocation of a central planner is again triggered by the imperfect competition effect and two terms-of-trade effects. However, in contrast to the case of decentralized decision makers, all effects additionally depend on the ratio of λ^{-c} and λ^c. The factor λ^c corresponds to the Lagrangean multiplier of household c's utility-maximization problem and can be interpreted as the sensitivity of the household's utility to changes in its income. Thereby, the fraction λ^{-c}/λ^c corrects the respective effects in Proposition 5.4 for their impact on the other household's utility. If $\lambda^{-c} < \lambda^c$ terms-of-trade effects are reduced in absolute terms . If $\lambda^{-c} > \lambda^c$ the signs of the terms-of-trade effects even change compared to Proposition 5.4.

Interestingly, Proposition 5.5 shows that also a welfare-maximizing allocation requires unequal tax rates between member states for most cases. This surprising result is in contrast to the usual result in literature that an efficient regulation of externalities requires equal marginal abatement costs for all non-strategic emitters. Interestingly, this result even holds if all firms are price takers (i.e., $v^i = -1, \forall i \in N$). In the Appendix of this chapter, an example for unequal taxes under a central planner is provided. This result is in contrast to the result of the model in Section 5.1.2, which neglects to consider interdependencies between sectors. In this model, an efficient allocation yields a uniform tax for all emitters outside the *Tr*-sector. The extended model in this section shows that such a simplified allocation rule probably leads to unnecessary efforts to achieve the emission target.[24]

For $\lambda^{-c} = \lambda^c$, e.g., if member states are symmetric, the optimal difference between sectors' marginal costs are equal to the individual country case in Chapter 4.

$$t^{c*} - \sigma^* = -\Psi_x(\cdot) \sum_{i \in N} (1 + v^i) x_i^* \frac{\partial x_i^*}{\partial E_{Tr}^c}$$

The terms-of-trade effects vanish and the optimal difference is only triggered by the imperfect competition effect. For unequally sensitive utility function, the regulator also takes states' asymmetry into account to increase overall welfare.

To sum up, the analysis in this section reveals that also a welfare optimal allocation requires in most cases a differentiation between environmental taxes in the *NTr*-sectors. Of course, the result strongly depends on the social welfare function. In our approach, we use a utilitarian approach. Surely, other approaches, e.g., a Rawlsian type or a social welfare function where marginal utilities have constant elasticities, are imaginable. However, it is assumable that also other types of social welfare functions result in a discriminatory allocation of emission rights. This is especially interesting from a legal point of view very. In cases where emitters in the *NTr*-sector of one state have an advantage whereby they

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[24] The result of discriminatory environmental taxes is confirmed with the model of Duval and Hamilton (2002). However, they only analyze the case of a uniform tax in each country and abstract from a hybrid approach as applied in the EU. Moreover, we additionally show that a discriminatory allocation is also necessary if all firms are price takers.

face a lower environmental tax than emitters in other states' *NTr*-sectors, it could be that EU primary law is violated.

5.3 Conclusion

The analysis presented in this chapter deals with the specific characteristic of the European ETS to connect different states via a newly established permit market. This approach could motivate member states to act strategically. This is particularly relevant as the participating member states were allowed to decide individually on their allocation of emissions in the early periods of the EU ETS.

In a first approach to analyze possible incentives for strategic behavior, we abstract from any dependencies between sectors, except for the permit market. We investigate the incentive for permit price manipulating behavior and show that permit-selling member states reduce their allocation to the *Tr*-sector if they decide strategically and permit-buying states increase their allocation. Hence, an efficient allocation cannot be achieved under strategic behavior. However, the numerical example indicates that the impact of strategic behavior is rather limited since the changes in member states' costs are very small. Only the impact on the distribution of total abatement costs between *Tr*- and *NTr*-sectors are of significant relevance.

In a second step, we extend the analysis to account for imperfect commodity markets. We show that individual decisions of member states on their allocation of emissions to sectors yields three effects that trigger the difference between marginal costs. First, analogous to the individual state scenario in Chapter 4, we have the imperfect competition effect: Member states use the allocation to reduce market distortions through imperfect competition. Second, there is an incentive for states to abuse the allocation as a substitute for abolished trade policies on the integrated European market. Depending on whether a state is a net importer or exporter, it tries to influence the commodity price through the distribution of emissions among sectors. Third, similar to the multi-country model without imperfect competition in this chapter, we have a permit-trading effect. Depending on whether a state is a net permit buyer or seller on the European emissions market, it tries to influence the permit price in the desired way. The direction of the overall effect of strategic behavior, i.e., which sector faces the higher marginal abatement costs, is ambiguous and even more difficult to determine than in the individual country case in Chapter 4.

However, it can be stated that strategic behavior leads to discrimination between the *Tr*-sector and the different national *NTr*-sectors. This result is of particular interest, since due to ETL, the allocation of emissions must not constitute state aid which could distort or threaten to distort competition.[25] Various papers believe that the free allocation of emission permits in the EU distorts competition, e.g., through *windfall profits*. Thus, free allocation probably conflicts with state aid law.[26] Weishaar (2007) also indicates that a discriminatory allocation between sectors may constitute state aid. If this is the case, only an allocation resulting in equal marginal costs for all emitters conforms with European state aid law.[27]

Comparing the equilibrium solution of strategically deciding member states with a central planner shows that strategic behavior results in an inefficient outcome. The solution of a central planning authority is also triggered by the imperfect competition effect to reduce the negative impact of oligopoly markets and the terms-of-trade effects on the markets for commodity X and emission permits. The results for a central planner are even more interesting, since according to the EU climate package, this scenario will be implemented in the future. One surprising result thereof is that a welfare optimal allocation of emissions requires a discrimination not only between the marginal emission abatement costs of the *Tr*- and *NTr*-sectors, but also between the different households in the *NTr*-sectors. Even if all firms are price takers, optimal taxes probably differ between states. This can be motivated by different consumption behavior in the different national *NTr*-sectors.

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[25] See Annex III of the EU Directive 2003/87/EC.

[26] See for example Woerdman (2001), Koenig et al. (2003), Johnston (2006), Sepibus (2007) and Weishaar (2007).

[27] There are two possible interpretations as to how competition can be distorted by the allocation. Either the allocation results in an inefficient use of resources or the allocation leads to unequal starting conditions of firms. (See Laan & Nentjes, 2001.) The distortion of competition through free allocation refers to the argument of unequal starting conditions, whereas the strategic allocation of permits by member states refers to the inefficient use of permits. Böhringer and Lange (2005) suppose that under free allocation, efficiency and equal starting conditions are impossible.

In contrast to individually deciding member states, a discriminatory allocation by a central planner cannot constitute state aid. A necessary condition for state aid is that the states have some discretionary power concerning the allocation. Since in cases where there is a central planner, the allocation decision is not a unilateral and autonomous decision by the member state and therefore it cannot constitute state aid.[28]

To conclude, the commonly used simplifying allocation rule of equal marginal abatement costs for all emitters cannot be applied in cases where there are imperfect commodity markets, especially in a multi-country context. If more than one country participates in the Emission Trading Scheme, tax differentiation for the emitters in the *NTr*-sectors is necessary to achieve an efficient outcome. Furthermore, the results of this analysis support the decision of the EU to centralize the allocation decision, since a decentralized allocation can provide a loophole for member states to replace abolished trading policies through the strategic abuse of environmental policies. These insights are also important if we think of a possible future linkage of the EU ETS with other hybrid emission trading schemes, e.g., in the US or Japan. In this case, we would again have regulators individually deciding on their own allocation plans.

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[28] See Sepibus (2007).

Appendix

A. Example for Unequal Emission Taxes under a Central Planner

Additional to the assumptions in Section 5.2, we assume that the *Tr*-sector consists of only two firms, i.e., $N = M = \{1,2\}$. Each firm is located in one state, $N^a = \{1\}$ and $N^b = \{2\}$. For the households' utility function, we assume the most simple case, analogous to Section 4.3.3: $U^c_{HH} = U^c_{Hl} = 0$, $H^c_{xh} = H^c_{yx} = H^c_{yh} = H^c_{yy} = 0$ and $U^c_{ll}, H^c_{xx}, H^c_{hh} < 0$ for all $c \in \{a,b\}$. The labor demand of firms 1 and 2 is assumed to be constant, i.e., $C^i_w(\cdot)$ is constant. Both firms conjecture price-taking behavior ($v^1 = v^2 = -1$).

Under these assumptions, we have the following Lagrangean multiplier from household c's utility-maximization problem:

$$\lambda^c = \frac{U^c_H H^c_y}{q}.$$

Since the price of commodity Y is given by the world market, the Lagrangean multiplier λ^c is constant. We further assume that $\lambda^a \neq \lambda^b$.

The difference between the optimal environmental tax levels is then

$$t^a - t^b = (\lambda^a - \lambda^b)((x^a - x_1)\left(\frac{1}{\lambda^b}\frac{\partial p}{\partial E^b_{Tr}} - \frac{1}{\lambda^a}\frac{\partial p}{\partial E^a_{Tr}}\right) + (e_1 - E^a_{Tr})\left(\frac{1}{\lambda^b}\frac{\partial \sigma}{\partial E^b_{Tr}} - \frac{1}{\lambda^a}\frac{\partial \sigma}{\partial E^a_{Tr}}\right)).$$

With the additional assumptions in this example, (5.8) and (5.9) yield

$$p = H^a_x \frac{q}{H^a_y} \text{ and } p = H^b_x \frac{q}{H^b_y}.$$

Since H^c_x only depends on x^c, and H^c_y and q are constant, solving the equations yields the utility-maximizing demand of the households depending on the commodity price, $\tilde{x}^a(p)$ and $\tilde{x}^b(p)$.

From equation (5.15), we can derive $\hat{e}_1(x_1,\sigma)$ and $\hat{e}_2(x_2,\sigma)$. Including $\hat{e}_1(x_1,\sigma)$ and $\hat{e}_2(x_2,\sigma)$ in (5.14) and with $v^1 = v^2 = -1$ and $p^* = \Psi^*(\cdot)$, the solution of the system of equations yields the equilibrium output levels only depending on the prices of commodity X and permits, $x_1(p,\sigma)$ and $x_2(p,\sigma)$.

With the market-clearing condition for commodity X,

$$\tilde{x}^a(p) + \tilde{x}^b(p) - x_1(p,\sigma) - x_2(p,\sigma) = 0,$$

we can derive the equilibrium commodity price depending on the permit price $p(\sigma)$. Including $p(\sigma)$, $x_1(p,\sigma)$ and $x_2(p,\sigma)$ in $\hat{e}_1(x_1,\sigma)$ and $\hat{e}_2(x_2,\sigma)$, we have the equilibrium firms' emission levels only depending on the permit price, $e_1(\sigma)$ and $e_2(\sigma)$. With the market-clearing condition for the permit market,

$$E^a_{Tr} + E^b_{Tr} - e_1(\sigma) - e_2(\sigma) = 0,$$

we get the equilibrium permit price σ^*. Total differentiation of the permit market-clearing condition with respect to E^a_{Tr} yields

$$1 - \frac{de_1(\sigma)}{d\sigma}\frac{d\sigma^*}{dE^a_{Tr}} - \frac{de_2(\sigma)}{d\sigma}\frac{d\sigma^*}{dE^a_{Tr}} = 0.$$

Hence, we have $\frac{d\sigma^*}{dE^a_{Tr}} = \frac{1}{\frac{de_1(\sigma)}{d\sigma} + \frac{de_2(\sigma)}{d\sigma}}$. Analogous, total differentiation of the permit market-clearing condition with respect to E^b_{Tr} yields $\frac{d\sigma^*}{dE^b_{Tr}} = \frac{1}{\frac{de_1(\sigma)}{d\sigma} + \frac{de_2(\sigma)}{d\sigma}}$. Thus, we have $\frac{d\sigma^*}{dE^a_{Tr}} = \frac{d\sigma^*}{dE^b_{Tr}}$. Since the commodity price $p(\sigma)$ only depends on the permit price, we have $\frac{dp}{dE^a_{Tr}} = \frac{dp}{dE^b_{Tr}}$.

With these results, the difference between the optimal national emission taxes in this example can be simplified to

$$t^a - t^b = \frac{(\lambda^a - \lambda^b)^2}{\lambda^a \lambda^b}((x^a - x_1)\frac{\partial p}{\partial E^a_{Tr}} + (e_1 - E^a_{Tr})\frac{\partial \sigma}{\partial E^a_{Tr}}).$$

In Section 5.2.2, we have already argued that it is reasonable to assume $\frac{\partial p}{\partial E^a_{Tr}}$ and $\frac{\partial \sigma}{\partial E^a_{Tr}}$ are negative. If trade is not balanced ($x^a \neq x_1$ and $e_1 \neq E^a_{Tr}$) and since we assume $\lambda^a \neq \lambda^b$, this example shows that it can be optimal for a central planner to differentiate taxes across the different *NTr*-sectors. This result is especially interesting since, in this example, all firms are price takers in all markets.

Chapter 6

Firms' Profits and Possible Abuses of the EU ETS

The following chapter is taken from Ehrhart et al. (2008) and analyzes possible effects of the EU Emissions Trading Scheme on firms' profits in the *Tr*-sector.[1] Thereby, some parts, especially in Section 6.3, are largely unchanged. The main result of this analysis is that EU ETL can enable oligopolistic firms to collude on commodity markets. EU ETL allows these entities to corporately reduce their output levels and therefore raise their profits by restricting the use of emission permits. Through this kind of tacit collusion, the firms create welfare losses even without explicitly establishing a cartel. The collusive arrangements are "tacit" in a way that they affect commodity markets but are cloaked in the institutional framework of the EU Emissions Trading Scheme. Thus, there is no direct conflict with the competition laws that generally prohibit price or distribution cartels. This result is even more important since, according to Anger (2008), the EU system could become a blueprint for future trading schemes in Japan or Canada.

Also, the German antitrust authority believes that collusive behavior enabled by EU ETL is one reason behind high electricity prices.[2] This is possible due to the fact that the relevant markets of most obliged industries, like electricity and also cement, steel and petroleum, are dominated by only a few firms and are more

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[1] With kind permission from Springer + Business Media.

[2] See E&M (2006).

or less geographically restricted to the EU.[3] In addition, Yandle (1998) recognizes the potential for collusion in similar regulatory schemes, e.g. in markets for property rights to fish and water pollution rights in trading communities in North America.

In order to understand possible impacts of the EU ETS on firms, two related partial market models are analyzed. As before, firms are assumed to be price takers on the allowance market. As we will see, firms are able to abuse emissions trading for tacit collusion on their product markets *even* if they are price takers on the allowance market. At this point, the approach differs from the contributions by Hahn (1984), Misiolek and Elder (1989), von der Fehr (1993) and Sartzetakis (1997), who analyze the distortion of competition on (product or permit) markets caused by price-setting firms on the allowance market.[4]

In the first model in Section 6.2, the assumption of the previous chapters is maintained that duopolistic firms simultaneously set their output levels and decide on their cost-minimizing abatement levels. Astonishingly, for certain parameter ranges, comparative statics yield increasing firm profits when the allowance price rises. Increasing permit prices result in higher costs and therefore induce oligopolistic firms to adjust their output decisions. The results are an overall lower production level, a higher product market price and probably higher profits for the firms.[5] Although firms can clearly benefit individually, overall welfare probably decreases. These effects are critical for competition, because the current institutional EU ETL framework provides firms with different options for raising the price of allowances within their sector (e.g. lobbying for a lower emissions cap or project-based mechanisms).

In the second model in Section 6.3, the firms first agree in a cooperative way on the number of permits they will ultimately submit (i.e., set their actual emission levels). In a second stage, they simultaneously choose their production levels.

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[3] See European Commission (2007d) and Smale et al. (2006).

[4] For a survey on tradeable permits and market power, see Section 3.2.

[5] This idea also corresponds to the econometric tax analysis by Krzyzaniak and Musgrave (1963) and to a general tax result by Katz and Rosen (1985). Carraro and Soubeyran (1996) formulate the same idea for emissions taxes and Cournot competition. Sijm et al. (2005) describe an analogous observation in a rich electricity-market simulation. In addition to these contributions, we model emissions trading oligopolists via a conjectural variations approach.

The firms' strategic emissions decisions in the first stage influence their output choices in the second. According to EU ETL, firms do not need to set their emissions levels before production; however, firms have been permitted to "pool" their activities in the first two trading periods and act as one participant on the permit market. They corporately agree on emission levels before deciding individually on their output levels. In comparison to the situation in which permit holdings could not be determined in advance (i.e. in our first model) their profits are expected to be higher. The results of this model suggest that emissions coordination induces firms to buy fewer permits and abate more in this scenario than in the abatement cost-minimizing solution. Although the pooling option has not been carried out on a grand scale during the first two trading periods, this analysis shows that such a legal option could trigger a monopolization tendency on the product market.[6]

In a brief conclusion, it is argued that every affected oligopolistic industry has an incentive to apply exactly one of the two described types of collusion via emissions trading institutions. Insofar as the two effects do not reinforce each other, regulatory authorities can concentrate on the more probable choice for the respective sector.

6.1 General Assumptions

The following general assumptions hold for both models in this Chapter. The investigated oligopoly market in the *Tr*-sector is restricted to a symmetric duopoly ($N = \{1,2\}$). Both firms have an identical cost function $C(x_i, e_i)$, which satisfies similar assumptions as in Chapter 4.

- $C_{x_i}(\cdot) > 0, C_{e_i}(\cdot) < 0$

---

[6] According to Van Long and Soubeyran (1997), the model in Section 6.3 belongs to a class of two-stage games, where firms or a regulator have the option, in the first stage, to influence marginal costs in the second stage. In the vein of the seminal R&D model of d'Aspremont and Jacquemin (1988), Van Long and Soubeyran (2000) investigate firms of an oligopolistic industry that lobbies in order to obtain a certain number of permits and that coordinates industry output as well as marginal production costs by redistributing allowances and profits. The model in this work retraces their model and focuses on pooling without the possibility of side payments.

- $C_{x_ix_i}(\cdot) > 0, C_{e_ie_i}(\cdot) > 0, C_{x_ie_i}(\cdot) < 0$

The cost functions are convex with respect to firm's emissions e_i, which means that cheapest abatement measures realized first and fewer emissions induce higher production costs for the next output unit. The only assumption, which is relaxed compared to Chapter 4, is that the cost function is not necessarily positive definite, i.e.,

$$C_{x_ix_i}(\cdot)C_{e_ie_i}(\cdot) - C_{x_ie_i}(\cdot)^2$$

can either be positive or negative. The only restriction for the cost function is that it must be sufficiently less concave so that the second-order conditions for firms' profit maximization are satisfied. The inverse demand is given by a well-defined decreasing function $P(x)$.[7]

Furthermore, it is assumed that the permit price σ is determined by the allocation of emissions to the *Tr*-sector and that the investigated industries in this chapter are too small to influence the permit price through their behavior. Thus, the permit price σ is fixed and given. For simplicity, there is no initial endowment of permits to the firms in N assumed, which does not pose a restriction on the model in this Chapter and its results (i.e., $e_i^0 = 0 \ \ \forall i \in N$).

6.2 Permit Price Manipulation

In this subsection, we consider the case where firms simultaneously decide on their amount of output and emissions. This structure is assumable through the EU ETL; firms are not required to provide permits before pollution occurs.[8]

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[7] As mentioned above, the analysis is restricted to a partial market analysis. In the context of the model in Chapter 4, this is the case if we assume, e.g., that the different commodities are neither substitutes nor complements ($H_{xy} = H_{xh} = H_{yh} = 0$), that H is quasi-linear ($H_{yy} = 0$) and that firms have a constant labor demand. See Section 4.3.3.

[8] See Directive 2003/87/EC of the European Parliament and of the Council, Article 12.

6.2.1 The Model

Each firm has identical conjectures about the reaction of its competitor ($\frac{dx_{-i}}{dx_i} = v$ for all $i \in N$). If firms are price takers $v = -1$, in case of Cournot competition $v = 0$ and in a profit-maximizing cartel $v = 1$.[9] Hence, we have $v \in [-1, 1]$.

Based on this assumption, firms maximize their profits by choosing simultaneously their profit-maximizing output and emission levels, taking the permit price σ as given. The profit function of firm i is

$$\Pi_i(x_i, x_{-i}, e_i, \sigma) = P(x_i + x_{-i}) \cdot x_i - C(x_i, e_i) - \sigma \cdot e_i.$$

Considering the rival's expected response to an output change implies the first-order conditions for maximizing each firm's profit, similar to (4.19) and (4.20) in Chapter 4.3.3:

$$P(x) + (1+v)x_i P_x(x) - C_{x_i}(\cdot) = 0 \tag{6.1}$$

$$-C_{e_i}(\cdot) - \sigma = 0 \tag{6.2}$$

The second-order condition is

$$a_i + v b_i < 0 \tag{6.3}$$

with $a_i := (2+v)P_x(\cdot) + (1+v)x_i P_{xx}(\cdot) - C_{x_i x_i} + \frac{C^2_{x_i e_i}}{C_{e_i e_i}}$ and $b_i := P_x(\cdot) + (1 + v)x_i P_{xx}(\cdot)$. For stability of the, we assume $a_i < 0$ and $a_1 a_2 - b_1 b_2 > 0$.[10]

The cost-minimizing emissions level $\hat{e}_i(x_i, \sigma)$ depending on firm i's emissions e_i and the permit price σ results from solving (6.2) for e_i. For the derivations, we have

$$\frac{\partial \hat{e}_i}{\partial x_i} = -\frac{C_{x_i e_i}}{C_{e_i e_i}} \quad \text{and} \quad \frac{\partial \hat{e}_i}{\partial \sigma} = -\frac{1}{C_{e_i e_i}}.$$

The symmetric equilibrium is given by an (interior) solution $x^* = x_1^* = x_2^*$ and $e^* = e_1^* = e_2^*$, which satisfies the second-order conditions (6.3).

In order to analyze the effects of an emissions trading system on a duopoly product market, we focus on comparative statics, i.e., on changes of the permit

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[9] For a survey on conjectural variations, see Dixit (1986) or Section 4.2.

[10] See Section 4.3.3.

price. Since we have a symmetric solution in equilibrium, we can state for the comparative statics in the following that $a = a_1 = a_2$ and $b = b_1 = b_2$. From the analysis in the previous chapters, we know that for identical firms an increasing permit price will lead to a decreasing output level.[11] Total differentiation of the first-order condition (6.1) and (6.2) yields

$$\frac{dx^*}{d\sigma} = \frac{\partial \hat{e}_i}{\partial x_i} \cdot \frac{1}{a+b}. \tag{6.4}$$

Due to the assumptions on the cost function, the cost-minimizing emissions level always increase with the firm's output. If we have $b < 0$, it is straight forward that $a+b$ is always negative. In case $b > 0$, the sign of $a-b$ is negative. Due to $a^2 - b^2 > 0$, we have $a+b < 0$. Hence, a firm's output always decreases with an increasing permit price ($\frac{dx^*}{d\sigma} < 0$).

In cases where there is an imperfect product market with decreasing price function, this output reduction leads to a higher output price and, as a well-known consequence, to a reduced consumers' surplus.

At this juncture, the question is raised as to how the permit price influences firms' profits. Besides more expensive permit purchasing costs, a higher permit price leads to lower total output. A decreasing output level leads to higher revenues. Thus, there are two counteracting effects on firms' profits. The overall effect is ambiguous, but in certain parameter ranges, it can be shown that the profits of both firms increase. This result is in contrast to Requate (2006), who states that only one firm can profit from a higher permit price.

Proposition 6.1. (Profit changes) *Given a symmetric interior solution* $x^* = x_1^* = x_2^*$ *of firms' profit maximization, let* $B := \frac{(1-v)P_x(2x^*)}{a+b}$, $\hat{e}_i(x^*, \sigma) > 0$ *and* $\varepsilon_x(f(x)) := \frac{\partial f(x)}{\partial x} \cdot \frac{x}{f(x)}$, *then:*

(i) $B = 0$ *if* $v = 1$

(ii) $B > 0$ *if* $v \in [-1; 1)$

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[11] In cases involving heterogeneous firms, a higher permit price can induce a higher output of an individual firm, but the industry's total output always decreases (see Section 4.3.3).

(iii) The profit Π_i *of firm i increases with an increasing permit price* σ *if and only if* $B \cdot \varepsilon_{x_i}(\hat{e}_i(x^*, \sigma)) > 1$.

Proof. Differentiating the profit function, with equation (6.1), yields

$$\frac{d}{dp}\Pi_i(x_i^*, x_{-i}^*, e_i^*, p) = (1-v)x^* P_x(2x^*)\frac{dx^*}{d\sigma} - \hat{e}_i(x^*, \sigma)\,. \tag{6.5}$$

Then (6.4) and (6.5) lead to

$$\frac{d\Pi_i}{dp} = \left(\frac{(1-v)x^* P_x(2x^*)}{a+b}\right)\frac{\partial \hat{e}_i}{\partial x_i} - \hat{e}_i(x^*, \sigma)\,.$$

The derivation of Π_i is positive if and only if

$$\left(\frac{(1-v)x^* P_x(2x^*)}{a+b}\right)\frac{\partial \hat{e}_i}{\partial x_i} - \hat{e}_i(x^*, \sigma) > 0\,.$$

Multiplying by $\frac{1}{\hat{e}_i(x^*, \sigma)}$ and defining the elasticity $\varepsilon_x(f(x)) = \frac{\partial f(x)}{\partial x} \cdot \frac{x}{f(x)}$, we find

$$\left(\frac{(1-v)P_X(2x^*)}{a+b}\right)\varepsilon_{x_i}(\hat{e}_i(x^*, \sigma)) - 1 > 0\,.$$

By analyzing $B := \frac{(1-v)P_x(2x^*)}{a+b}$, we have $B > 0$ if $v \in [-1; 1)$. If $v \in [-1; 1)$, the numerator of B is strictly negative. The denominator $a+b$ is, due to stability of the equilibrium, strictly negative. Hence, B is never negative and only takes a value of zero if $v = 1$.

□

The result in Proposition 6.1 shows that for certain parameter ranges, a higher permit price generates higher profits for firms for nearly all types of expected competition, except in the case with a monopoly scenario ($v = 1$). Carraro and Soubeyran (1996) explicitly deny the profit-raising effect for perfect competition, which corresponds to the Bertrand competition case in this model ($v = -1$). They implicitly assume that if firms are price takers, the prices are exogenously given (for example, when world market prices prohibit European price adjustments), but in the case of most CO_2-intensive industries, European output prices adjust to higher costs.

For $v \in [-1;1)$, it is easy to show that B grows—and therefore the probability of higher profits due to higher allowance prices—if total costs are less convex or more concave, i.e., the smaller $C_{x_ix_i}(\cdot)C_{e_ie_i}(\cdot) - C_{x_ie_i}(\cdot)^2$ is. However, due to the exception of monopoly, we have $B > 0$.[12] Hence, sufficient conditions for increasing profits are therefore $v \in [-1;1)$ and $\varepsilon_{x_i}(\hat{e}_i(x^*,\sigma)) > \frac{a+b}{(1-v)P_x(2x^*)}$, where the elasticity

$$\varepsilon_{x_i}(\hat{e}_i(x^*,\sigma)) = \frac{x_i}{\hat{e}_i(x^*,\sigma)} \cdot \frac{\partial \hat{e}_i(x^*,\sigma)}{\partial x_i}$$

represents the relative change of *cost-minimized* emissions if output is increased.[13] A high elasticity is fostered by two conditions: first, by a high ratio of output to emissions, which can be interpreted as already strong abatement efforts; second, by a high absolute change in emissions due to output extension,

$$\frac{\partial \hat{e}_i(x^*,\sigma)}{\partial x_i} = -\frac{C_{x_ie_i}(x^*,e^*)}{C_{e_ie_i}(x^*,e^*)}. \tag{6.6}$$

Furthermore, a high value of the derivative in (6.6) additionally aggravated the profit-increasing effect via B. Note that B negatively depends on

$$C_{x_ix_i}(x^*,e^*) - \frac{C_{x_ie_i}(x^*,e^*)^2}{C_{e_ie_i}(x^*,e^*)} = C_{x_ix_i}(x^*,e^*) + \frac{\partial \hat{e}_i(x^*,\sigma)}{\partial x_i} C_{x_ie_i}(x^*,e^*),$$

which negatively depends on $\partial e_i^*(x^*,\sigma)/\partial x_i$, and thus, B positively depends on $\partial e_i^*(x^*,\sigma)/\partial x_i$. Hence, the higher this derivative is, the higher the chance is for rising profits created by an increasing permit price σ. On the one hand, the magnitude of $\partial e_i^*(x^*,\sigma)/\partial x_i$ positively depends on the emission intensity of the industry's technology: the more the marginal production costs are mitigated by higher emissions (i.e. a high absolute value of $C_{x_ie_i}(x^*,e^*)$), the higher the term is. On the other hand, the less expensive further abatement is (i.e. the second derivative $C_{e_ie_i}(x^*,e^*)$ is low), the higher the derivative in (6.6) is. These conditions are, e.g.,

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[12] Without further assumptions about the third derivatives of the cost function, the impact of an increasing degree of competition, represented by (negative) v, on the value of B is ambiguous.

[13] In Ehrhart et al. (2008) the analysis is restricted to linear inverse demand functions. For this case, it can be shown that $B \in (0,1)$ holds and that a necessary condition for increasing profits is $\varepsilon_{x_i}(\hat{e}_i(x^*,\sigma)) > 1$.

fulfilled for the power generating and the cement industries. Both apply carbon-intensive technologies and exhibit nearly constant marginal abatement costs for certain ranges (fuel switch to gas, usage of granulated cinder).

6.2.2 Implications for the European Emissions Trading Scheme

The possibility that profits increase due to a higher permit price leads to rather unusual incentives for oligopolists. First of all, a sector could be more interested in a *higher* allowance price than a lower one, even if there is no free initial allocation and all permits must be purchased.[14] Thus, the results are also relevant if in the future no free allocation is possible.

Rising profits could lead to an abuse of the European permit trading scheme in a way that firms might try to influence the initial allocation of emissions to the *Tr*-sector in a non-expected manner: in every new trading period, fewer permits are assigned to the system. Since a lower total allocation to the *Tr*-sector normally corresponds to a higher permit price, firms can even benefit from an increasingly restricted emissions target and thus be averse to less strict targets.[15] On the other hand, a stronger cap corresponds to lower initial permit allocations and thus, in case of free allocation, to lowers profits for firms. Hence, considering individual initial free endowments, the two effects counteract each other: a firm perhaps profits from a higher permit price, but simultaneously suffers if it receives a lower primary allocation. It is ambiguous, which effect prevails.

Another imaginable abuse of the European system originates from the possibility that firms can not only trade allowances on permit markets but may also receive additional allowances by implementing project-based mechanisms like JI of CDM projects.[16] These mechanisms credit additional permits to firms that conduct or invest in emissions-reducing projects, e.g. environmentally friendly

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[14] In the case of a free initial allocation of permits, it is obvious that profits can increase through an increasing permit price.

[15] The analysis in Section 4.5 shows that, theoretically, the pathological case is possible so that the permit price increases due to a more generous allocation to the *Tr*-sector.

[16] See Sections 2.1.2 and 2.2.5.

technology transfers to developing countries or reforestation initiatives. In cases where there are increasing profits due to a higher permit price, industries have an incentive to jointly conduct such project-based mechanisms, with the objective of paying more for these credits than they would on the market. In cases where there is a contractually binding agreement between firms to gain pollution rights from projects that are relatively expensive compared to the permit price, there exists a lawful way to establish stable collusion. Apart from its negative impact on the partial market, this kind of behavior has unfavorable global effects as well: firms abate emissions in a more costly way than necessary.

Another way that industries increase the effective permit price without having market power on the allowance market is by paying additional emissions duties. This is, for example, the case in the UK, where in addition to the Emissions Trading Scheme, a so-called Climate Change Levy (CCL) is imposed on energy-intensive industries.[17] According to our theoretical model, obliged industries can have an incentive for maintaining the additional duty to avoid profit losses. Apart from this, Böhringer, Koschel, and Moslener (2008) claim that an additional emissions tax for only some industries or one that is levied in some member states but not others always leads to cost-inefficient emission abatement.

Mentionable is that none of the described behavioral patterns is perceived as a collusive instrument; they are even approved by public opinion and thus by politicians. But as the model shows, this can lead to a restriction in the industries' output and ultimately be paid for out of the consumers' pockets.

6.3 Pooling of Permit Purchasing

The following section investigates a two-stage game structure. In the first stage, two identical firms decide on and commit to their permit holdings. In the second stage, these firms compete on the product market. This approach is commonly used in the literature on permits trading systems with oligopoly markets. See for example von der Fehr (1993), who assumes that firms have to commit to a certain

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[17] See UK Climate Change Programme (2006).

amount of emissions before they choose their outputs.[18] In contrast to the model in this section, he analyzes the effects of an imperfect product market in combination with market power on the permit market. We maintain our assumption that both firms are price takers on the permit market.

Although this game structure is quite common in the literature, there exists no convincing reason to model firms' actions as a two-stage game, because firms are also allowed to buy permits *after* production. Note, however, that if firms intend to "pool" their permit purchases, which is explicitly allowed by EU ETL during the first two trading periods,[19] this type of game would provide the appropriate approach. In the European CO_2 trading system, firms are allowed to merge their allowance trading activities, i.e., they engage a trustee to buy or sell permits on behalf of all participating firms. This loophole enables industries to maximize their joint profits, i.e., to coordinate their permit holdings. Monetary side payments within the pool are not considered, since this would raise suspicion in practice.

6.3.1 The Model

In this section, we model the firms' decision process as a two-stage game. In the first stage, firms set jointly the number of permits to be used and, implicitly, abatement activities; in the second stage, the firms' production levels are individually set. The game is solved through backwards induction, whereby in the second stage firms individually choose their profit-maximal output level x_i for every combination of e_i and σ. In anticipation of the profit-maximizing behavior in the second stage and given the permit price σ, both firms coordinate their emissions levels e_i in the first stage. For simplicity reasons, we restrict the analysis in this section to a linear inverse-demand function (i.e., $P_{xx} = 0$).

In the *second stage* of this game, the equilibrium output levels of the firms $i \in \{1,2\}$, denoted by x_i^{**}, are derived, for simplicity, à la Cournot ($v = 0$). The solution satisfies

$$\Pi_i(x_i^{**}, x_{-i}^{**}, e_i, \sigma) = \max_{x_i} \Pi_i(x_i, x_{-i}^{**}, e_i, \sigma) \tag{6.7}$$

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[18] A brief overview to the related literature is given in Section 3.2.

[19] See Directive 2003/87/EC of the European Parliament and of the Council, Article 28.

for $i \in \{1,2\}$. The *stable* interior equilibrium $(x_1^{**}(e_1,e_2,\sigma), x_2^{**}(e_1,e_2,\sigma))$ on the commodity market is characterized by the following necessary and sufficient conditions:

$$P(x_i + x_{-i}) + P_x(x_i + x_{-i})x_i - C_{x_i}(x_i, e_i) = 0 \tag{6.8}$$

$$2P_x(x_i + x_{-i}) - C_{x_i x_i}(x_i, e_i) < 0 \tag{6.9}$$

$$\begin{aligned}[2P_x(x_i + x_{-i}) - C_{x_i x_i}(x_i, e_i)] \cdot [2P_x(x_i + x_{-i}) - C_{x_{-i}x_{-i}}(x_{-i}, e_{-i})]& \\ - P_x(x_i + x_{-i})^2 > 0&\end{aligned} \tag{6.10}$$

for $i \in \{1,2\}$.[20]

Differentiation of the first-order conditions (6.8) yields:

$$\begin{aligned}\frac{\partial x_i^{**}}{\partial e_i} &= \frac{(2P_x - C_{-ix_{-i}x_{-i}}) \cdot C_{ix_ie_i}}{(2P_x - C_{-ix_{-i}x_{-i}})(2P_x - C_{ix_ix_i}) - P_x^2} > 0 \\ \frac{\partial x_{-i}^{**}}{\partial e_i} &= \frac{-P_x \cdot C_{ix_ie_i}}{(2P_x - C_{-ix_{-i}x_{-i}})(2P_x - C_{ix_ix_i}) - P_x^2} < 0\end{aligned} \tag{6.11}$$

due to (6.9) and (6.10).

According to (6.11), the emissions levels, which are set on the first stage, determine the firms' equilibrium output $x_i^{**}(e_1,e_2,\sigma)$ on the second stage. More precisely, if a firm raises its emissions, it will increase its output, while concurrently, the other firm will lower its output. Hence, firms' emissions levels also determine equilibrium profits $\Pi_i(e_i, e_{-i}, \sigma)$, given by

$$P(x_i^{**}(\cdot) + x_{-i}^{**}(\cdot)) \cdot x_i^{**}(\cdot) - C(x_i^{**}(\cdot), e_i) - \sigma \cdot e_i \tag{6.12}$$

for $i \in \{1,2\}$.

In the *first stage* of the model, firms decide cooperatively on their permit levels, anticipating the competitive consequences in the second stage. Joint profit-maximizing emission levels e_i^{**} satisfy

$$\sum_{i \in \{1,2\}} \Pi_i(e_i^{**}, e_{-i}^{**}, \sigma) = \max_{e_1,e_2} \sum_{i \in \{1,2\}} \Pi_i(e_i, e_{-i}, \sigma) \tag{6.13}$$

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[20] See Section 4.3.3 and Dixit (1986).

for $i \in \{1,2\}$. The system of first conditions for an interior solution are given by

$$\frac{d}{de_i} \sum_{i \in \{1,2\}} \Pi_i(e_i^{**}, e_{-i}^{**}, \sigma) = 0$$

for $i \in \{1,2\}$. Since side payments are not allowed, the resulting *natural* profit distribution must Pareto-dominate the pair of non-cooperative profits $\Pi_i(x_i^*, x_{-i}^*, e_i^*, \sigma)$ for $i \in \{1,2\}$.[21] Thus, it can be shown that if firms in the first stage coordinately decide on their permits holdings, their individual profits exceed their non-cooperative profits. If firms can jointly agree to buy fewer permits, they restrict their output, as emissions are a non-avoidable fallout of production. The resulting output restriction in the second stage leads to an increase in the consumers' product price and increases the firms' profits.

Proposition 6.2. (Market distortion if firms behave cooperatively) *There exist joint-profit-maximizing emission levels* e_i^{**}*,* $i \in \{1,2\}$*. For the profit-maximizing emissions and production levels, we have* $e_i^{**} \le e_i^*$ *and* $x_i^{**} \le x_i^*$*; for the firms' profits, it is* $\Pi_i(x_i^{**}, x_{-i}^{**}, e_i^{**}) \ge \Pi_i(x_i^*, x_{-i}^*, e_i^*)$*,* $i \in \{1,2\}$ *and* $v = 0$*.*

Proof. The corresponding first-order condition for the profit-maximization problem on the first stage is:

$$\frac{d}{de_i} \sum_{i \in a,b} \Pi_i(e_i^{**}, e_{-i}^{**}, \sigma) = P_x \cdot \left(x_{-i}^{**} \frac{dx_i^{**}}{de_i} + x_i^{**} \frac{dx_{-i}^{**}}{de_i} \right) - C_{e_i} - \sigma = 0.$$

We assume symmetric firms; therefore, we have in equilibrium $e = e_1 = e_2$, and by (6.11), we have

$$\underbrace{x_i^{**} \cdot P_x \cdot \frac{C_{x_i e_i}}{3P_x - C_{x_i x_i}}}_{\le 0} - C_{e_i} - \sigma = 0\,. \tag{6.14}$$

Due to the assumptions, the first term on the left-hand side is always non-positive. Including the symmetry assumption in the first-order conditions (6.8) yields

$$P(2x_i^{**}(e)) + P_x(2x_i^{**}(e))x_i^{**}(e) - C_x(x_i^{**}(e), e) = 0\,.$$

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[21] From a formal point of view, we select functions that demonstrate collusion by pooling without incorporating a profit-raising effect due to generating asymmetric marginal costs in the first stage for cheaper production in the second stage. This is only possible by allowing for side payments. We refer to Van Long and Soubeyran (1997) for the discussion of asymmetric marginal costs as a possible result in the first stage.

The theorem of implicit functions yields

$$\frac{dx_i^{**}(e)}{de} = \frac{C_{x_i e_i}(x_i^{**}(e), e)}{3P_x(2x_i^{**}(e)) - C_{x_i x_i}(x_i^{**}(e), e)}.$$

Due to the assumptions on the cost function, the derivation $\frac{dx_i^{**}(e)}{de}$ is always positive. The marginal abatement costs $-C_{e_i}(x_i^{**}(e), e)$ in (6.14) decrease in e due to the second-order condition in section 6.2 (i.e., $a < 0$):

$$-\frac{d}{de}C_{e_i}(x_i^{**}(e), e) = -C_{e_i e_i} - \frac{C_{e_i x_i}^2}{3P_x(2x_i^{**}) - C_{x_i x_i}} < 0$$

With these results, we now compare the equilibrium of Section 6.2 given by the equations system (6.1), (6.2) and $v = 0$, with the equilibrium given by (6.8) and (6.14). It is obvious that the optimal emissions level e_i^{**} is never higher than e_i^*, and that x_i^{**} is never higher than x_i^* for $i \in \{1, 2\}$.

In both models, the necessary conditions (6.8) and (6.1) for $v = 0$, respectively, must hold in equilibrium. Therefore, considering symmetric firms, the profit function can be written as a function depending on e:

$$\Pi_i(x(e), e) = P(2x(e)) \cdot x(e) - TC(x(e), e).$$

The first-order condition for the maximization of this function is

$$x \cdot P_x \cdot \frac{C_{x_i e_i}}{3P_x - C_{x_i x_i}} - C_{e_i} - \sigma = 0,$$

which is fulfilled by e_i^{**}, x_i^{**}. Therefore, $\Pi_i(x_i^{**}, x_{-i}^{**}, e_i^{**}) \geq \Pi_i(x_i^*, x_{-i}^*, e_i^*)$. In cases where firms produce strict positive amounts of output, their profits with pooling are always higher than without.

$\square$

Proposition 6.2 shows that if firms find a way to coordinate their behavior on the permit market (e.g. via the abuse of the pooling option in EU ETL), they tend to reduce their output. This generates higher prices for the consumers, whose surplus therefore decreases.[22]

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[22] Similar results are derived by Löschel et al. (2006). They investigate a model in which ex-post-emissions are uncertain. A firm has to pay a fine if it has fewer permits than ex-post emissions. Without pooling, the uncertainty about emissions results in a reduced production. It is shown that pooling permit holdings reduces uncertainty. However, this positive effect is probably outweighed by the incentive of firms to abuse pooling to coordinate their outputs.

6.3.2 Permit Price Manipulation vs. Pooling

In a last step, it is analyzed if there exists an incentive for firms to apply both kinds of tacit collusion described in Sections 6.2 and 6.3.

Proposition 6.3. (Only one type of collusion is profitable) *If* $x_i^{**} > 0$ *and* $e_i^{**} > 0$*, oligopolists always have an incentive for tacit collusion in terms of pooling. Moreover, there exist cases where raising the effective permit price is also advantageous for the oligopolists. Simultaneous application of both effects, however, is never profitable.*

Proof. From the proof of Proposition 6.2 follows that collusion via pooling is always advantageous for firms if $x_i^{**} > 0$ and $e_i^{**} > 0$ for $i \in \{1,2\}$. Furthermore, applying the envelope theorem to (6.12) yields

$$\frac{d}{dp}\Pi_i(e_i^{**}, e_i^{**}, p) = -e_i^{**} < 0.$$

for $i \in \{1,2\}$, i.e. raising permit prices always lowers oligopolistic profits in the case of collusive pooling. Hence, only one type of tacit collusion is profitable at the same time.

□

Proposition 6.3 shows that it is not profitable for firms to apply both permit price manipulation and pooling. If firms tacitly collude via pooling, a higher permit price always decreases their profits.

6.3.3 Implications for the European Emissions Trading Scheme

The pooling option in the first two trading periods of the EU ETS creates a loophole wherein firms can agree on their permits before production as described in the model in this section. Due to EU ETL, it is only lawful to “form a pool of installations from the same activity,”[23] which means that only firms from the *same*

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[23] See Directive 2003/87/EC of the European Parliament and of the Council, Article 28 (1).

industry can pool their trading activities. This is even more interesting if the relevant industry is assumed to be oligopolistic and geographically restricted.

For the first trading period, 2005-2007, two power-generating installations in Slovenia applied for a trading pool that would have covered 74% of the sector's allowances. In the UK, two additional applications for pools were submitted, but since they were received after the deadline, none was realized.[24]

However, Gilbert et al. (2006) do not expect industries to be much interested in trading pools. They argue that there is only an incentive to participate in a pool if firms can benefit from it. Neglecting reduced transaction costs, a firm can only benefit from a pool if it receives additional allowances. But since within a pool permits are only redistributed and no additional permits are created, permits must be contributed by firms with a surplus of permits. However, no firm would voluntarily join a pool if it had more permits than it needed—its first choice would of course be to sell them on the permit markets. Therefore, the authors contend that the pooling option is very unlikely to be used in the European emissions trading system. However, their argumentation does not consider the fact that the number of permits also indirectly determines industry output. Firms can try to use pools to coordinate total output via permit holdings. The pooling option in the EU ETL could thus be misused by industries for collusion, even if they behave competitively on the product market. On the other hand, the pooling option has, of course, positive aspects as well. If firms pool their activities on the permit market, their transaction costs for buying allowances can be reduced, or different kinds of uncertainty inherent to the permit trading system can be minimized.[25] This incentive invites firms to cooperate and thereby increases the risk of collusion. However, it is more advisable to carefully check pooling requests from firms belonging to the same industry than to try to pre-empt the danger of tacit collusion by abolishing pooling altogether.

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[24] For details, see Betz et al. (2004), and Gilbert et al. (2006).

[25] For an example of pooling permits under uncertainty, see Löschel et al. (2006).

6.4 Conclusion

The models presented in this chapter show that there are different possibilities for oligopolistic industries participating in the European emissions trading system to strategically limit their output. Permits might be diverted from their intended use as a vehicle for tacit collusion in two basically different manners: by increasing permit prices (e.g. via stringent caps, project-based mechanisms or emissions duties) or by coordinating the firms' emissions (e.g. via pooling). Therefore, it is important to recognize emissions trading systems not only as instruments for internalizing the costs of pollution; regulators should also view permits as a tool for the strategic manipulation of prices. Since every emissions trading oligopoly is interested in exactly one of the two collusion opportunities analyzed in this chapter, abuses of both effects have to be monitored. For individual sectors, however, either pooling or raising permit prices is relevant.

The crucial question is how to deal practically with these phenomena. The politically created loopholes discussed above are all economically motivated, and not every industry that applies mechanisms such as CDM or pooling tends to cartelize. And even if EU ETL is exploited, it can still result in higher overall welfare than business as usual or command and control approaches. Thus, it is not argued that the EU ETS is inapplicable for regulating emissions, but that allowances can provide an incentive for strategic manipulation, and that is probably not adequately considered by current EU ETL or politics.

Chapter 7

Conclusion

To sum up the main results of this work, the impact of imperfectly competitive markets must be taken into account when investigating the European Emissions Trading Scheme. This conclusion is derived by analyzing the European approach to reduce emissions by means of a general equilibrium model accounting for major industries in the trading scheme consisting of only a few firms. One prominent example is the German power supply industry.

The theoretical analysis shows that imperfectly competitive product markets significantly influence the welfare optimal allocation of emission rights to the different sectors of the economy. Due to the findings of this work, it can be expected that a less strict regulation for emitters inside the Emissions Trading Scheme is necessary to reduce overall costs. A numerical example reveals that if an industry of comparable size to the German power supply industry behaves as à la Cournot, a cost-efficient solution may require a difference in marginal costs between emitters in the Emissions Trading Scheme and in other sectors of the economy of up to 40 € per ton of CO_2. Considering the substitutability of electricity and gas or oil, the necessary difference in marginal costs even increases.

Extending the analysis for the scenario that each member state can individually decide its own emissions allocation shows that there are incentives for strategic behavior. A first, very simple model, in which the only interdependency between states is via the permit market, shows that an incentive for states exists to exert market power on the permit market. A permit-selling state tries to increase the price, whereas a permit-buying state tries to decrease the price. However, a numerical example suggests that the overall effect of strategic deciding states on the permit price and total costs for the EU is rather small. Anyhow, analyzing the costs of the individual sectors reveals a significant redistribution of costs between sectors as a consequence of strategic behavior.

In a second model, imperfect product markets and terms-of-trade effects are considered. It is shown that both (imperfect competition and terms-of-trade) affect the allocation strategies of the member states. This results in a discrimination between emitters in the Emissions Trading Scheme and emitters not assigned to emissions trading. A discrimination between the emitters outside the trading scheme in the different member states is also expectable. In the case of individually deciding member states, such a discriminatory allocation probably violates state aid law. Comparing the equilibrium allocation of strategic-deciding member states with the allocation of a central planner shows that strategic behavior results in an inefficient outcome with a reduced overall welfare. This supports the plan of the EU to centralize the allocation decision in the future. However, even under a central planner, a welfare-efficient allocation of emissions probably requires discrimination between the household and traffic sectors of the different member states. In contrast to individually deciding states, this cannot violate state aid law, since a necessary condition for state aid is unilateral and autonomous decisions by the member states.

Clearly, the supposed conditions for a welfare-efficient allocation of emission rights only leads to a second-best solution. Hence, a major task for future research is to find improved policy measures to achieve a first-best solution. This calls for more sophisticated mechanisms, since EU law prohibits subsidies for firms. Furthermore, a first-best solution with n imperfectly competitive heterogeneous firms and one negative externality requires $n+1$ different instruments.[1]

As long as no practicable policy measures for achieving a first-best solution are developed, we should at least try to achieve a second-best solution using the current regulatory framework. Thus, with the conditions in this thesis for an efficient allocation concerning the current EU ETS, unnecessarily high costs for

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[1] See Schott (2006).

abating CO_2 emissions can be avoided. However, to determine the efficient allocation more precisely, we need further research, especially from an empirical perspective.

The impact of international trade with countries outside the EU was not in the scope of this thesis. It is still a open question as to how to deal with countries with no or weak environmental policies. First, industries in these countries have, of course, a competitive advantage. Second, there is the risk of carbon-intensive industries moving from the EU to countries applying less strict environmental standards (carbon leakage). A currently discussed suggestion to deal with these potential problems concerns border adjustment taxes. E. Peterson and Schleich (2007), Ismer and Neuhoff (2007) and Alexeeva-Talebi et al. (2008) are some of the few papers analyzing border adjustment taxes in the context of the EU ETS. An interesting question for future research is to analyze the interdependencies of border adjustment taxes and imperfect competition. It is expectable that such taxes create incentives for member states to use them as substitutes for trade policy.

Besides the possibility for member states to abuse the EU ETS, e.g. as trade policy, firms can also abuse the current ETL to increase profits. In this thesis, two alternatives for firms are disclosed. On the one hand, they can increase profits by increasing permit prices (e.g. via stringent caps, project-based mechanisms or emissions duties). On the other hand, firms can coordinate their emissions (e.g. via pooling). Both scenarios enable firms to tacitly collude and corporately reduce their output levels, which raises consumers' prices and creates welfare losses.

All these results convey that market structures matter for the European ETS. Since the mitigation of global greenhouse gas emissions is inevitable, we need further research to find solutions to reduce negative effects of imperfect competition and to abate emissions as cheaply as possible. This is of major importance, especially for creating acceptance and ensuring sustainability of the European approach to reduce greenhouse gas emissions.

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List of Abbreviations

AAU	Assigned Amount Unit	10
BaU	business as usual	23
CCL	Climate Change Levy	152
CDM	Clean Development Mechanism	10
CER	Certified Emissions Reduction	11
CES	constant elasticity of substitution	62
CGE	computable general equilibrium	62
COP	Conferences of the Parties	8
ERU	Emission Reduction Unit	11
ETL	Emissions Trading Law	16
ETS	Emissions Trading Scheme	7
EEX	European Energy Exchange	24
EU	European Union	10
EUA	European allowance	16
GWP	Global Warming Potential	10
IPCC	Intergovernmental Panel on Climate Change	8
IET	International Emissions Trading	10
JI	Joint Implementation	10
lhs	left hand side	72
NAP	National Allocation Plan	16
NTr-sector	non-trading-sector	15
OECD	Organisation for Economic Co-operation and Development	8
PACE	Policy Analysis based on Computable Equilibrium	115
rhs	right hand side	87
Tr-sector	trading-sector	15

UNFCCC	United National Framework Convention on Climate Change	7
WCP	World Climate Programme	7

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