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Strategic Partitioning of Emissions Allowances
Under the EU Emission Trading Scheme

Abstract:
The EU Emission Trading Scheme (ETS) is breaking new ground in the experience with emission trading regimes across multiple jurisdictions. Since the EU ETS covers only some industries, it implies a hybrid emission control scheme where EU member states must apply complementary domestic emissions regulation for the non-trading sectors of their economies in order to comply with their national emission reduction targets. The EU ETS thus opens up for strategic partitioning of national emissions budgets by the member states between trading and non-trading sectors. In this paper we examine the potential effects of such strategic behavior on compliance cost and emissions prices. We show that concerns on efficiency losses from strategic partitioning are misplaced if all the member states behave in a Nash-Cournot manner. However, if a single country takes the official partitioning of the other countries as a reference point, there is substantial scope for exploiting market power.

Keywords: Emissions Trading; Allocation of Quotas; Strategic Behavior

JEL classification: C61; C72; Q25

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1. Introduction

Over the last two decades emissions trading has become increasingly popular as an environmental policy instrument for air pollution control. The central advantage of emissions trading is that firms can flexibly choose to meet their targets, thereby achieving in principle the lowest overall cost for an aggregate emissions cap. In a historical context, the U.S. sulfur dioxide (SO_2) cap-and-trade program initiated in the mid 1990ies under the Clean Air Act Amendments is considered as a successful "Grand Policy Experiment" proving substantial economic efficiency gains of market-based emission control policies over command-and-control policies, i.e., predetermined technologies or standards (Stavins, 1998).

Emissions trading can provide particularly high efficiency gains in climate change mitigation: Carbon dioxide (CO_2) and other greenhouse gases have the same effect for global warming wherever they are emitted and compliance costs differ dramatically across sources. Given the considerable potential for cost savings (Weyant, 1999), where-flexibility through emissions trading has become a condition-sine-qua-non for the adoption of the Kyoto Protocol in 1997.

Striving for cost-effectiveness of its climate policy, the European Union (EU) has launched an EU-internal emission trading scheme (EU ETS) for emission-intensive installations as the central pillar to comply with the Kyoto Protocol (EU, 2003a). The EU ETS was established in 2005 and entered its second phase in 2008. As the first large-scale international greenhouse gas (GHG) trading program, the EU ETS represents a landmark environmental policy. To date the EU ETS covers more than 12,000 installations in 6 major industrial sectors across 27 EU countries. Each EU country must partition its national emissions budget under the Kyoto Protocol between sectors covered by the EU ETS and the rest of the economy within the so-called national allocation plans (NAPs). The EU ETS thus implies a hybrid regulation scheme as sectors (e.g., households or transport) that are not covered, require complementary regulation in each EU member state to comply with the national emission reduction targets under the Kyoto Protocol.

Given its size and institutional complexity, the EU ETS has been referred to as the "Grand New Policy Experiment" for market-based mitigation programs (Kruger and Pizer, 2004). In fact, the performance of the EU ETS may be pivotal for the prospects of a global greenhouse gas trading system: Environmental policy makers around the world view the EU ETS as a unique opportunity to gain critical insights into the design and implementation of a market-based environmental program. The outstanding policy relevance of the EU ETS also explains the huge interest of the academic community to draw viable lessons on actual experiences of emissions trading including key issues such as allowance allocation rules, banking and borrowing provisions, firm-level market power, provisions for monitoring, reporting and verification, innovation incentives, implications on competitiveness of firms and sectors, or global environmental effectiveness of unilateral climate policies, i.e., leakage (for an overview see, e.g., the symposium on the EU ETS by Ellerman et al., 2007).[1]

One central feature of the EU ETS that has so far received little attention in the literature is the decentralized structure of emissions regulation across multiple jurisdictions. Kruger et al. (2007) discuss in qualitative terms some of the induced political, economic and administrative challenges. They argue that linking of national systems will make it increasingly difficult to

[1] A bibliography on tradable permits, which covers a larger part of the pertinent academic publications, is provided by T. Tietenberg under http://www.colby.edu/~thtieten/trade.html.

achieve an efficient balance of the emission reduction burden across trading and non-trading sources.[2] The alternative – potentially more efficient – coordination mechanism might therefore be price harmonization across multiple jurisdictions rather than the linking of emission trading systems.

Like Kruger et al. (2007) we are concerned with the efficient balance of the emission reduction burden across trading and non-trading sectors in a multi-jurisdictional trading system, but we adopt a strategic game-theoretic perspective: Emission trading systems that comprise several countries – such as the EU ETS or likewise an international quota market under the Kyoto Protocol – raise a strategic question as to how many quotas a country should allocate into the trading system. A country that expects to be a net seller of quotas can find it profitable to restrict the number of quotas issued such as to raise the equilibrium price of quotas in the market. If a quota market only covers a subgroup of domestic emissions (e.g., EU ETS), the relevant question is how to partition the national emissions cap on the sectors within and outside the trading system: When a large net seller reduces its number of allowances in order to raise the price of quotas, it simultaneously increases the emissions allowances available for its non-trading sectors, reducing the marginal abatement costs there. Consequently, we end up with different marginal abatement costs across countries in the sectors outside the EU ETS.

We employ a numerical model of the European carbon market to examine the effects of strategic partitioning in the EU ETS. Based on quantitative simulation results our main insights can be summarized as follows:

If all EU member states were to behave strategically in a Nash-Cournot manner, or if there is a Stackelberg leader (where the other countries act as followers playing a Nash-Cournot game), the outcome of strategic partitioning is close to the cost-effective cooperative trading system including all sectors and countries. This result follows from the large number of EU member states (with sufficiently large shares in overall EU emissions) and limited scope of terms of trade effects related to the price of emissions only. Strategic partitioning by all countries has only minor effects on total compliance cost and the price of tradable emissions allowances. However, compared to the cost-effective outcome, marginal abatement costs in the non-trading sectors become markedly differentiated and more abatement takes place in the old member states that are importers of emissions allowances.
Single countries can nevertheless substantially affect the outcome of the EU ETS: If the reference point for strategic partitioning of a single country is the bundle of actual NAPs by the remaining countries, our quantitative results indicate substantial scope for exploiting market power. This finding relates to the following insight.
Implementation of the actual national allocation plans approved for the second ETS trading phase from 2008 to 2012 will lead to drastic overall efficiency losses as compared to a cost-effective comprehensive EU cap-and-trade system: The reason is that the partitioning of national emissions budgets based on actual NAPs leads to huge differences between the harmonized carbon value in the trading sectors and the marginal abatement costs in non-

[2] The efficiency cost of hybrid emissions regulation has been discussed by various other authors before (see e.g. Böhringer et al., 2005, 2006): Obviously, the segmentation of the EU carbon market will induce efficiency losses from restricted where-flexibility in so far as marginal abatement costs in non-trading sectors are different from the marginal abatement costs in the trading sectors.

trading sectors as well as to drastic differences of marginal abatement costs across non-trading sectors in different EU member states.[3]

Our game-theoretic investigation is complementary to previous empirical analyses of the national allocation plans. The latter stress that allowance allocation to the trading scheme has been quite generous compared to a cost-effective strategy, indicating that lobbying from industries has been influencing the member states' NAPs. This has been particularly the case in the first phase, but also applies to some degree in the second phase (e.g., Böhringer et al., 2006; Betz et al., 2006; Neuhoff et al., 2006, Anger et al. 2008). Our analysis clearly confirms the political economy forces behind EU climate policy, as strategically motivated NAPs are far off from the actual NAPs.

Starting from the seminal paper by Hahn (1984), there is a large literature on market power and emissions trading. Contrary to our setting, the bulk of the literature focuses on strategic behavior among firms that are covered by the emission trading system, and not on strategic allocation of quotas into the system (see e.g. Misiolek and Elder, 1989; Hagem and Westskog 1998; Eshel, 2005).

Helm (2003) examines the outcome of introducing trade in permits between countries without any emissions obligations, compared to a non-cooperative outcome without trade in permits. He shows that countries that are most environmentally concerned tend to reduce the number of permits, whereas less concerned countries tend to increase the number. Even though cost-effectiveness is increased, the effects on total emissions and total welfare are ambiguous.

Strategic behavior in the quota market has been widely discussed and analyzed in relation to Russia's dominant position in the international quota market (under Kyoto), see, e.g., Böhringer and Löschel (2003), Maeda (2003), Hagem and Mæstad (2006), or Böhringer et al. (2007). Being a large seller of quotas, it may be profitable for the country to restrict the export of quotas. This would imply that marginal abatement costs in Russia are below the international quota price, and it is even possible that Russia finds it optimal not to use all its quotas.

Viguier et al. (2006) investigate the strategic allocation of emissions allowances in the EU ETS. They consider four (groups of) countries, which can choose between four explicit allowance allocation rules. A Nash equilibrium in pure strategies is searched for, and a global CGE model is used to evaluate the different outcomes. Their focus is on the choice of discrete allocation rules and incentives to subsidize energy-intensive industries through generous allocation. They find that different country groups end up choosing different allocation rules.

The remainder of our paper is organized as follows. In Section 2, we present an analytical framework and lay out strategic considerations with respect to the partitioning of emissions allowances. In Section 3, we briefly describe our numerical model for the EU carbon market that is used to investigate our theoretical propositions based on empirical data. In Section 4, we present policy scenarios and discuss simulation results. In Section 5, we conclude.

[3] The member states have got limited access to trade allowances outside the EU. Access to a common offset market will probably reduce some of the efficiency cost.

2. Theoretical model

In our theoretical analysis we consider N countries. Each country has a national emissions obligation given by $\hat{e}_n$. Furthermore, the countries agree to establish an emission trading scheme (ETS), which covers specific firms (hereafter interchangeably used with sectors) in these countries. Each country is free to choose how many allowances q_n it wants to issue in the ETS. Allowances are distributed to ETS sectors (T sectors) in a lump-sum way, e.g. through pure grandfathering.[4] Note that the number of allocated allowances determines the emissions obligation for the non-trading part of the domestic economy (NT sectors), which are not covered by the trading scheme, i.e., $e_{n,NT} = \hat{e}_n - q_n$. We ignore the possibility of any emissions trading outside the ETS (i.e., firms within the ETS can only trade with other firms within the ETS, and the emissions obligation for the rest of the economy must be fulfilled domestically).[5]

We assume that ETS firms do not have market power – consequently, each firm will reduce emissions until marginal abatement costs are equal to the allowance price σ. Thus, emissions $e_{n,T}$ from the T sectors in country n are a function of the allowance price, given by $e_{n,T} = e_{n,T}(\sigma)$. The country's abatement costs in the T sectors can then be represented by the function $C_{n,T}(e_{n,T})$. We further assume that abatement within each country's NT sectors takes place in a cost-effective way, i.e., marginal abatement costs are equalized across NT sectors within a country (e.g., by means of a domestic allowance market or carbon tax). Thus, we may also represent a country's abatement costs in the NT sectors by $C_{n,NT}(e_{n,NT})$.

The allowance price σ can be expressed as a function of the total number of allowances, i.e., $\sigma=\sigma(\sum q_n)$, where the functional form depends on the national emissions captured by $e_{n,T}(\sigma)$. We now want to consider the optimization problem of country n, where the only control variable is the number of allocated allowances, i.e., q_n. We assume that country n takes into account its influence on the allowance price through its choice of q_n, and that it considers the other countries' choice of q_n as exogenous. That is, we consider a Nash-Cournot equilibrium where all countries choose their allocation decision simultaneously. The optimization problem for country n is then given by:

(1) $$\min_{q_n}\left[C_{n,T}(e_{n,T})+C_{n,NT}(e_{n,NT})+\sigma\left(q_n+\sum_{m\neq n}q_m\right)\left(e_{n,T}-q_n\right)\right]=$$

$$\min_{q_n}\left[C_{n,T}\left(e_{n,T}\left(\sigma\left(q_n+\sum_{m\neq n}q_m\right)\right)\right)+C_{n,NT}\left(\hat{e}_n-q_n\right)+\sigma\left(q_n+\sum_{m\neq n}q_m\right)\left(e_{n,T}\left(\sigma\left(q_n+\sum_{m\neq n}q_m\right)\right)-q_n\right)\right]$$

The first part of the objective function – as restated in the second line of formula (1) – is the costs of abatement in the T sectors, which depend on the allowance price, which again depends on the total number of allowances. The second part is the costs of abatement in the NT sectors, which depend on country n's number of allowances. The third part is the net import of allowances, which depends on the allowance price, and country n's emissions in the T sector and number of allowances.

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4 Auctioning of allowances would give the same conclusions. Other allocation schemes may lead to different results as the allocation rule itself may influence the behaviour of the companies so that marginal abatement costs no longer equal the allowance price (see, e.g., Böhringer and Lange, 2005, and Rosendahl, 2008).

5 If there were no limitations to such external trading at a fixed price, any strategic behaviour would be pointless, and we would end up with the cost-effective outcome with a price equal to the external price. With limited access to external trading, which is the reality in the EU, the outcome would be somewhere between the cost-effective outcome and the outcome analysed here.

The first order condition with respect to q_n is given by:

(2) $$C_{n,T}'e_{n,T}'\sigma' - C_{n,R}' + \sigma' \cdot \left(e_{n,T} - q_n\right) + \sigma \cdot \left(e_{n,T}'\sigma' - 1\right) = 0 .$$

As $-C_{n,T}' = \sigma$, this reduces to:

(3) $$-C_{n,NT}' = \sigma - \sigma' \cdot \left(e_{n,T} - q_n\right) .$$

We assume that all reaction curves are downward sloping, i.e., $dq_n / dq_m < 0$ for all n,[6] and there is a stable and unique Nash equilibrium (our simulations confirm that this is the case).

If country n has no influence on the allowance price (i.e., σ' is approximately zero), we obtain the standard competitive market outcome: The number of allowances should be set so that marginal abatement costs in the *NT* sectors equal the allowance price. Consequently, all firms in the economy (inside and outside the ETS) have the same marginal abatement costs. We shall denote this volume of allowances q_n^C, where *C* stands for competitive.

For the case that country n is large enough to influence the allowance price through its allocation of allowances, it is optimal for the country to play strategically by allocating more or less allowances than q_n^C. If country n is a net importer with $q_n = q_n^C$, then the last part of equation (3) is positive. Hence, the marginal abatement costs in the *NT* sectors should exceed the allowance price, implying that it is optimal to increase the number of allowances compared to q_n^C. The reason is that an increased number of allowances reduces the price of allowances, which then drives down the import costs for country n. In effect, the country is able to influence its terms of trade by regulating the number of allowances.

Obviously, strategic behavior implies that abatement no longer takes place in a cost-effective way. Marginal abatement costs are still equal across firms and countries in the *T* sectors. However, marginal abatement costs in the *NT* sectors will in general differ across countries, and also differ compared to the *T* sectors. The larger the import or export of allowances is for a country in the cost-effective outcome, the more will marginal abatement costs in the *NT* sector differ from the allowance price in the ETS. We should expect this to be particularly relevant for large countries and countries with either very cheap or very expensive abatement target.

How will the allowance market be affected by such strategic behavior? As some countries are exporters and some are importers, the strategic effect will pull in different directions for different countries. Thus, the allowance price can either rise or fall as a consequence of strategic behavior. As a matter of fact, it will depend on how steep the marginal abatement cost curves are in the *NT* sectors of the different countries.[7] By summing equation (3) over all countries we obtain:

(4) $$\sigma = \frac{1}{n}\sum_n \left(-C_{n,NT}'\right) .$$

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[6] The reaction curves are somewhat different from a regular Nash-Cournot game in quantities, as a change in another countries' allocation affects domestic firms' demand for permits (via changed permit price). This effect bears an influence on the optimal reaction for country n.

[7] By "steep" we mean how much ($-C_{n,NT}$) increases when emissions decline by one unit.

That is, the quota price in the Nash equilibrium will equal the un-weighted average of marginal abatement costs in the *NT* sectors of all countries. Assume that σ rises compared to the competitive outcome. Then the total number of allowances must be lower, which again implies that total abatement in the *NT* sectors will be lower. On the other hand, we see from equation (4) that the average marginal abatement costs must increase. Therefore, a higher σ requires countries with an increased number of allowances[8] (compared to q_n^C) to have on average steeper marginal abatement cost functions than the other countries. As a consequence, we should expect rather small effects on the equilibrium price compared to the competitive outcome.

So far we have assumed that the *N* countries take part in a Nash-Cournot game. Alternatively, we might assume that only a subgroup N^* of the *N* countries (where $1 \leq N^* < N$) play Nash-Cournot, whereas the other countries behave differently. If the latter decide on their allocation prior to the Nash-Cournot players (i.e. their allocation is determined independently of the other N^* countries' allocation), we get the same optimization problem as before (but only for the N^* countries).

A different game will occur if we instead assume that one – presumably large – country *S* acts as a Stackelberg leader, and that the remaining countries act as followers (still playing a Nash-Cournot game). This could be the case if one country decides on its allocation before the other countries. For instance, member states in the EU ETS have typically delivered their NAPs to the EU Commission at different points in time. An interesting question is therefore to what degree a country may benefit from being a Stackelberg leader (compared to the Nash solution).

The Stackelberg leader knows that the other countries will take into account its decision regarding the number of allowances q_S. For downward sloping reaction curves, we can express q_m as a decreasing function of q_S, i.e., $q_m = q_m(q_S)$ with $q_m' < 0$. Replacing the fixed q_m by $q_m(q_S)$ in the optimization problem (1) gives the following first-order condition for q_S:

$$(5) \qquad -C_{S,NT}' = \sigma - \sigma' \cdot \left(1 + \sum_{m \notin S} q_m'(q_S)\right) \cdot \left(e_{S,T} - q_S\right).$$

Compared to the Nash-Cournot outcome in equation (3), the last part has changed: A given import (or export) of allowances has less of an impact on the allowance price because the other countries will respond so as to dampen the price effect (the first parenthesis is less than one). Consequently, it is optimal for the Stackelberg leader to deviate less from the competitive outcome than in the case where q_m is considered fixed (i.e., the Nash-Cournot game), since the benefits of deviating from its cost-effective solution is reduced. In effect, marginal abatement costs in the *NT* sectors of country *S* will be closer to the marginal abatement costs in the *T* sectors. If country *S* is a net importer (exporter) of allowances, then the allowance price will be higher (lower) than in the Nash-Cournot solution.[9]

[8] Note that the increased number of allowances allocated to *T* sectors implies increased abatement in the *NT* sectors.

[9] Our Nash and Stackelberg solutions above share similarities with the outcome of strategic behaviour examined in various studies of the Kyoto Protocol. For instance, it is optimal for large allowance sellers such as Russia to restrict its sales of allowances in order to push the price upwards (see, e.g., Maeda, 2003). However, there is one important difference. In the Kyoto-studies all domestic firms are treated equally, so that marginal abatement costs should be equal (and possibly zero) inside the large allowance seller. In our case, the marginal abatement costs will differ between the two sectors of the economy, both in the country being a Stackelberg leader and in the countries playing Nash-Cournot.

3. Numerical Framework

In order to quantify the potential effects of strategic behavior in the EU ETS, we employ a simple numerical partial equilibrium model of the EU-27 carbon market. The model is based on marginal abatement cost curves for trading sectors (labeled: *T*) that are covered by the ETS and non-trading sectors (labeled: *NT*) outside the EU ETS. The cost curves are calibrated to empirical data (see e.g. Böhringer et al. (2005) for an algebraic documentation).

Marginal costs of emissions abatement may vary considerably across countries and sectors due to differences in carbon intensity, initial energy price levels, or the ease of carbon substitution possibilities. Continuous marginal abatement cost curves for the *T* and *NT* sectors in EU countries can be derived from a sufficiently large number of discrete observations for marginal abatement costs and the associated emissions reductions in the *T* and *NT* sectors. In applied research these values are often generated by partial equilibrium models of the energy system (such as the POLES model by Criqui and Mima (2001) or the PRIMES model by Capros et al. (1998)) that embody a detailed bottom-up description of technological options. Another possibility is to derive marginal abatement cost curves from computable general equilibrium (CGE) models (see e.g., Eyckmans et al., 2001). We adopt the latter approach and generate a reduced form of complex CGE interactions in terms of marginal abatement cost curves that are directly accessible to the non-CGE specialist. In order to obtain such marginal abatement cost curves for the *T* and *NT* sectors across EU countries, we make use of the PACE model - a standard multi-region, multi-sector CGE model for the EU economy (for a detailed algebraic exposition see e.g. Böhringer, 2002) based on most recent consistent accounts of EU member states' production and consumption, bilateral trade and energy flows (see the GTAP6 database – Dimaranan and McDougall, 2006). With respect to the analysis of carbon abatement policies, the sectors in the model have been carefully selected to keep the most carbon-intensive sectors in the available data as separate as possible. The energy goods identified in the model include primary energy carriers (coal, natural gas, crude oil) and secondary energy carriers (refined oil products and electricity). Furthermore, the model features three additional energy-intensive non-energy sectors (iron and steel; paper, pulp and printing; non-ferrous metals) whose installations – in addition to the primary and secondary energy branches – are subject to the EU Emission Trading Scheme. The remaining manufacturers and services are aggregated to a composite industry that produces a non-energy-intensive macro good, which together with final demand captures the activities (*NT* segments) that are not included in the EU ETS.

To generate our reduced form model, we perform a sequence of carbon tax scenarios for each region (most regions consist of only one EU country), where we impose uniform carbon taxes (starting from \$0 to \$100 per ton of carbon in steps of \$1). We thereby generate a large number of marginal abatement costs, i.e., carbon taxes, and the associated emissions reductions in *T* and *NT* sectors. The final step involves a fit to the set of "observations". Various types of functional forms could be employed (see e.g., Böhringer and Löschel, 2003).[10] For our numerical framework, we apply a least-square fit by a polynomial of third degree, which provides sufficient flexibility.

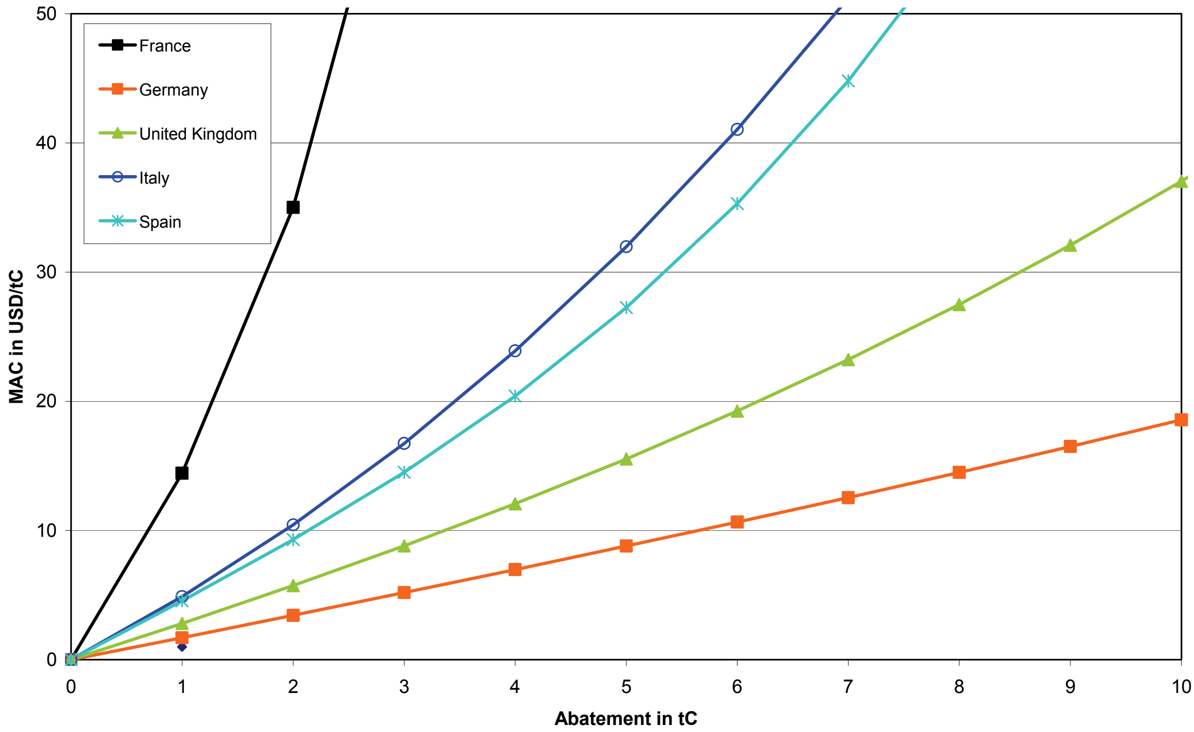
[10] Baseline emissions levels e^0 do not impose a binding emissions reduction – hence, the associated marginal abatement costs for emissions use at the baseline level are zero. Clearly, zero marginal abatement costs also hold for emissions levels $e > e^0$.

The functional form of the marginal abatement cost curves in region n for the T and NT sectors is, thus, given by: [11]

(6) $$-C'_{n,i}(e_{n,i}) = a1_{n,i}(e^0_{n,i} - e_{n,i}) + a2_{n,i}(e^0_{n,i} - e_{n,i})^2 + a3_{n,i}(e^0_{n,i} - e_{n,i})^3 \qquad i \in \{T, NT\}$$

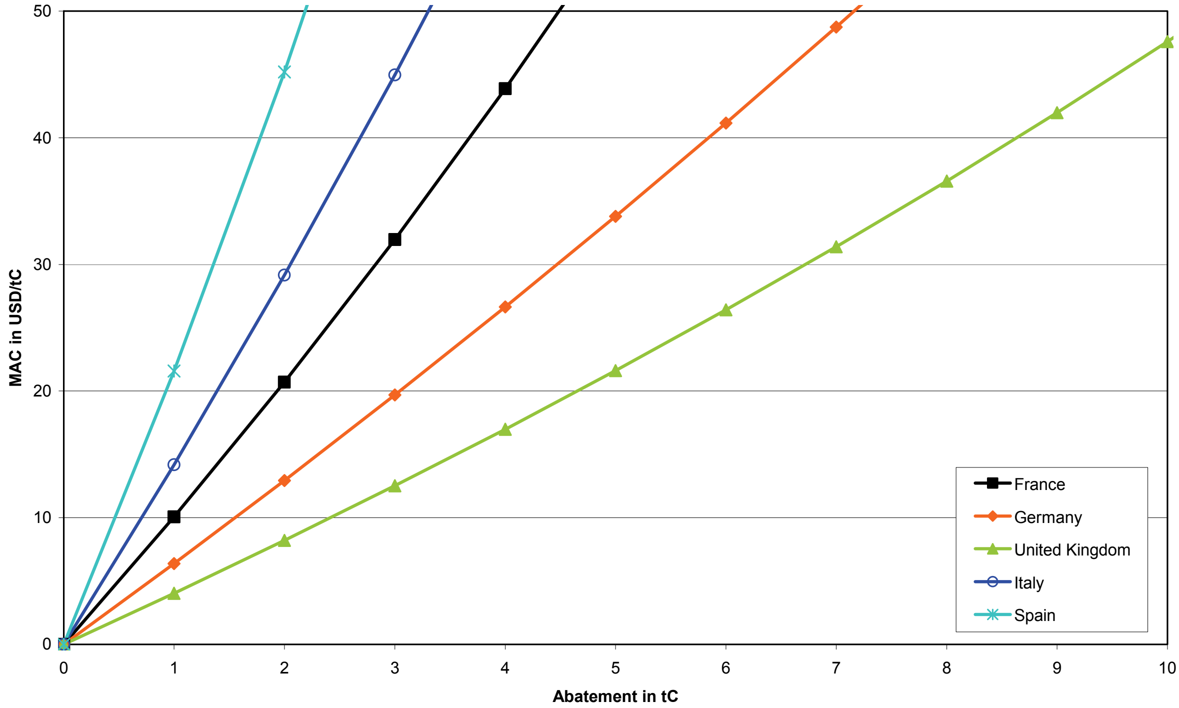
Figures 1a and 1b show the associated marginal abatement cost curves for the top-five carbon emitting EU countries. Obviously, (marginal) abatement cost curves together with the effective reduction requirements for T and NT sectors are critical elements for the concrete quantitative simulation results. One immediate observation from Figures 1a and 1b is that the marginal abatement cost curves are steeper in the NT sectors than in the T sectors, except in France (where most power production is carbon-free).

Figure 1a. Marginal Abatement Cost Curves for *T* Sectors across the Top 5 EU Emitters



[11] The coefficients for region- and sector-specific marginal abatement costs curves are provided in the Appendix so that the reader can reproduce the numerical results based on the data in Table 1. The model and data to reproduce our results are also available from the authors upon request.

Figure 1b. Marginal Abatement Cost Curves for *NT* Sectors in the Top 5 EU Emitters



4. Policy Scenarios and Numerical Results

The EU ETS is the main instrument of EU climate policy to comply with its Kyoto emission reduction target. Under the Kyoto Protocol the European Union is legally committed to cut back EU-wide greenhouse gas emissions by 8 per cent from 1990 emissions levels during the Kyoto commitment period 2008-2012. The aggregate EU reduction requirement has been redistributed among individual member states according to an EU-internal Burden Sharing Agreement (BSA) (EU, 1999). Table 1 summarizes the country-specific data for the BSA (column [5]) together with historic CO_2 emissions in 1990 (column [1]) and future business-as-usual (*BaU*) CO_2 emissions in 2010 (columns [2] – [4]), the central year for meeting the EU climate policy targets under the EU BSA.[12] The figures for future *BaU* emissions in 2010 are based on official EU projections (EU, 2003b) incorporating country-specific developments and regulations apart from the EU ETS.

The average annual national emissions budgets for the Kyoto commitment period follow from the BSA and the historic emissions levels in 1990. These budgets were partitioned within the national allocation plans for the second phase of the EU ETS between the trading (*T*) and non-trading (*NT*) sectors. Columns [6] – [8] of Table 1 report the implied CO_2 reduction requirements in absolute quantities based on recent information by the EU Commission (EU 2007). Finally, columns [9] – [11] translate the absolute quantities into per cent reduction requirements from 2010 *BaU* emissions levels.

[12] In our quantiative analysis, we use the greenhouse gas emission reduction targets of the EU member states interchangeably as reduction targets for CO_2, which is by far the most relevant greenhouse gas for the EU.

Table 1. Historical$_{1990}$ and BaU_{2010} Emissions, EU Burden Sharing Agreement (BSA), and NAP Reduction Requirements

	Emissions (mill. tons of CO_2)				*BSA*	*NAP Reduction Requirements*[1]					
	1990	*2010*			*Per cent cut (from 1990)*	*Mill. tons of CO_2*			*Per cent cut (from BaU in 2010)*		
	Total	*Total*	*T*	*NT*		*Total*	*T*	*NT*	*Total*	*T*	*NT*
	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]
European Union	4115.8	3930.9	1804.0	2126.9	8.3	157.8	251.6	-93.8	4.0	13.9	-4.4
Austria	55.1	60.7	22.0	38.7	13.0	12.8	4.1	8.6	21.0	18.7	22.3
Belgium	106.3	112.2	44.1	68.1	7.5	13.9	2.5	11.4	12.4	5.7	16.7
Denmark	52.8	46.6	23.4	23.2	21.0	4.9	4.2	0.7	10.5	17.8	3.1
Finland	53.2	51.4	30.1	21.3	0.0	-1.8	2.4	-4.2	-3.5	7.9	-19.6
France	354.1	406.4	108.7	297.7	0.0	52.3	10.1	42.2	12.9	9.3	14.2
Germany	943.0	823.6	402.2	421.4	21.0	78.6	49.9	28.8	9.5	12.4	6.8
Greece	71.1	105.6	63.1	42.5	-25.0	16.7	12.2	4.5	15.8	19.3	10.7
Ireland	29.7	46.5	18.4	28.1	-13.0	12.9	4.6	8.3	27.8	25.0	29.7
Italy	390.8	422.2	180.4	241.8	6.5	56.8	27.2	29.6	13.5	15.1	12.2
Netherlands	152.9	174.0	74.0	100.0	6.0	30.3	7.9	22.4	17.4	10.7	22.4
Portugal	39.0	67.9	32.9	35.0	-27.0	18.4	5.3	13.1	27.1	16.1	37.4
Spain	203.8	302.6	115.5	187.1	-15.0	68.2	35.5	32.8	22.5	30.7	17.5
Sweden	50.6	54.0	20.9	33.1	-4.0	1.4	1.3	0.1	2.5	6.0	0.4
United Kingdom	569.1	519.4	202.4	317.0	12.5	21.4	20.2	1.2	4.1	10.0	0.4
Bulgaria	73.6	42.9	32.9	10.0	8.0	-24.8	2.0	-26.8	-57.8	6.0	-267.9
Czech Republic	158.8	103.1	64.7	38.4	8.0	-43.0	11.3	-54.3	-41.7	17.5	-141.5
Hungary	68.5	62.2	31.4	30.8	6.0	-2.2	3.5	-5.7	-3.5	11.3	-18.6
Poland	340.1	286.2	192.1	94.1	6.0	-33.5	32.1	-65.6	-11.7	16.7	-69.7
Romania	168.6	90.3	52.1	38.2	8.0	-64.8	3.1	-67.9	-71.8	6.0	-177.8
Slovakia	51.4	41.6	27.8	13.8	8.0	-5.7	2.0	-7.7	-13.7	7.1	-55.5
Baltic States	85.7	39.7	25.0	14.7	8.0	-39.1	5.4	-44.5	-98.6	21.5	-302.8
Rest of Europe[2]	97.6	71.8	39.9	31.9	10.2	-15.9	4.8	-20.7	-22.1	12.1	-64.9

[1] The total reduction requirement in column [6] is calculated as the difference between *BaU emissions* in 2010 and the member state's commitment according to *EU's BSA*. The allocation of the total reduction requirement between *T* and *NT* sectors is based on the member states' NAP sand *BaU emissions* for the *T* and *NT* sectors.
[2] Cyprus, Luxemburg, Malta, Slovenia

Column [9] of Table 1 provides evidence on huge cross-country differences with respect to per cent emission reduction requirements in 2010. The old EU member states except for Finland show all positive reduction requirements ranging from less than 5 per cent (Sweden and United Kingdom) up to more than 25 per cent (Portugal and Ireland). The large differences in reduction requirements clearly indicate that efficiency gains from trade in allowances between these countries may be large. When we account for the new member states, the differences become even bigger: All new member states stand out for negative total abatement requirements, which can be traced back to significant reductions in *BaU* emissions compared to 1990. Incorporating these countries into a pan-European trading scheme should provide substantial cost reductions compared to domestic abatement only. It must be noted though that part of the cost reduction might come from trade in hot air, i.e., unused emissions allowances of new member states for the case of domestic action only. Another observation from Table 1 is that the allocation of abatement requirements between sectors within the EU ETS (*T*) and the non-trading sectors (*NT*) varies a lot. Thus, one might suspect that the NAP allocations may lead to rather cost-inefficient emissions reductions in the EU.

For our numerical analysis of strategic allowance allocation we define six policy scenarios that differ in assumptions on the scope of EU-wide emissions trading (i.e., no international emissions trading, partial international emissions trading across *T* sectors, and comprehensive international emissions trading across *T* as well as *NT* sectors) and the carbon market structure (i.e., perfect competition vis-à-vis Cournot competition with or without a Stackelberg leader).

Table 2 provides a summary of the key differences across the six specified scenarios.

NoTrade: All EU member states achieve their reduction target domestically in an efficient way. This is equivalent to a situation in which countries apply domestic carbon taxes that are high enough to meet their individual commitments under the EU BSA. National carbon markets are assumed to work perfectly competitive. The *NoTrade* scenario provides a useful reference point for the potential cost savings from international emissions trading.

Trade: All EU member states are allowed to trade emissions allowances among each other without any trading restrictions between sectors. Countries behave as price takers, i.e., perfect competition in the permit market is assumed. The outcome of scenario *Trade* is the least-cost solution from an EU-wide social planner perspective.

FullNash: EU member states act simultaneously as Nash-Cournot players when designing the national allocation plans. The segmentation of the national emissions budget between *T* and *NT* industries is thus a strategic choice variable. The equilibrium for scenario *FullNash* can be computed as the intersection of regional best-response functions.

Stackelberg: One EU member state acts as a Stackelberg leader, deciding its NAP before the other member states, and knowing their strategic behaviour. The other EU member states act simultaneously as Nash-Cournot players, just as in *FullNash*, taking the Stackelberg leader's NAP as fixed.

NAP: This scenario reflects the actual implementation of EU climate policy through the national allocation plans. It implies one single EU-wide emissions market for industries (*T*) that are covered by the EU ETS, plus a domestic carbon market in *each* EU member state for the remaining industries (*NT*) that are not covered by the EU ETS. The partitioning of the national budgets consistent to the EU BSA follows the most recent approved policy proposals for the second phase of the EU ETS (EU, 2007).

SingleNash: Only one specific EU member state acts as a Nash-Cournot player, taking the approved NAPs of the other EU member states as given. This scenario investigates the incentives for a single country to deviate from the scenario *NAP* in order to minimize its own compliance cost. In the context of the NAP approval and submission process, scenario *SingleNash* portrays a situation where an EU member state may prolong its final NAP to a point where all other countries have already fixed their NAPs.

Table 2. Characteristics of Policy Scenarios

	EU-wide Emissions Trading		Carbon Market Structure
	T sectors	*NT* sectors	
NoTrade	No	No	Perfect competition
Trade	Yes	Yes	Perfect competition
FullNash	Yes	No	Nash-Cournot competition
Stackelberg	Yes	No	Stackelberg and Nash-Cournot competition
NAP	Yes	No	Perfect competition
SingleNash	Yes	No	Nash-Cournot competition

For our subsequent discussion of simulation results,[13] it should be noted that there are two major determinants in our partial equilibrium framework for the country-specific compliance cost: (i) the effective reduction requirement a country has to fulfill as compared to its reference emissions level (here: *BaU* emissions in 2010 – see column [9] of Table 1) – the higher the effective reduction requirement the higher are the associated compliance costs, and (ii) the ease of carbon abatement as captured by the shape of the marginal abatement cost curves – the steeper the marginal abatement cost curve the more costly a given reduction becomes.

Furthermore, it should be kept in mind that countries with zero compliance costs under *NoTrade* do not face a binding emissions target, i.e., they typically dispose of hot air. Countries with hot air mainly comprise the new EU accession states (Baltic States, Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia, Rest of Europe). As we will see below, this implies that total emissions reductions (or likewise environmental effectiveness) differ between the scenarios, since hot air is locked up in the *NT* sectors in three of the scenarios (*NoTrade*, *NAP*, and *SingleNash*).

Throughout our quantitative analysis, we disregard the possibilities to purchase emissions allowances from outside the EU. Under the EU ETS, firms are to some degree allowed to buy project-based emissions reductions in developing countries (via the Clean Development Mechanism – CDM) or other industrialized countries listed in Annex B of the Kyoto Protocol (via Joint Implementation – JI). However, commentators on the CDM and JI market agree that the magnitude of project-based allowance supply from outside the EU during the second

[13] For reasons of data availability two of our model regions consist of several member states, which means that assumptions about strategic behaviour are questionable. Therefore, we omit results for the heterogeneous aggregate 'Rest of Europe' (comprising Cyprus, Malta, Slovenia, and Luxembourg) in our reporting below, but only consider the more homogeneous composite 'Baltic States' (consisting of Estonia, Lithuania, and Latvia).

phase of the EU ETS will be relatively modest for several reasons (including the long-lead times in developing, financing and enacting these projects, investment risks and transaction costs, or increased competition for CDM/JI between non-EU actors and installations in the EU ETS. They conclude that the price effects of CDM/JI offsets will be rather small (Convery and Redmond, 2007). Member state governments, too, are allowed to trade allowances outside the EU, and can also take part in the international quota market under Kyoto. However, the EU has put an upper limit to each member state's total access to external allowances, i.e., the sum of government purchases and the access for domestic firms to buy CDM/JI allowances (cf., EU, 2006).

Tables 3-5 report the main results for the policy scenarios:[14] In Tables 3a and 3b we see how the carbon values or likewise marginal abatement costs vary across countries and sectors;[15] Table 4 depicts the country-specific total compliance cost under the EU burden sharing agreement; Table 5 provides insights into net trade flows of emissions allowances.

Potential Efficiency Gains from Where-Flexibility: *NoTrade versus Trade*

We first look into the economic implications for scenarios *NoTrade* and *Trade* that capture the full range of international where-flexibility on competitive carbon markets: For domestic action only (*NoTrade*), marginal abatement costs vary significantly across the member states reflecting the large differences in effective emission reduction requirements (see column [9] of Table 1) and the differences in marginal abatement cost curves (see Figure 1). Comprehensive emissions trading under *Trade* reduces EU-wide compliance cost by more than one order of magnitude. This is partly due to the gains from unrestricted where-flexibility, i.e., the equalization of marginal abatement costs across all sectors and countries. In addition, the *Trade* scenario exploits all the hot air in the new member states, meaning that total emissions reductions in the EU are substantially lower than in the *NoTrade* scenario – note, however, that the full use of hot air does not conflict with the Kyoto commitment.

Efficiency Losses from Strategic Behavior: *FullNash* and *Stackelberg* compared to *Trade*

Let us now turn to the implications of strategic partitioning of emissions budgets that is opened up under the EU ETS with decentralized national allocation plans.

First, we notice from Table 3a that the carbon equilibrium price in the EU ETS is almost unchanged compared to the competitive full trade outcome (scenario *Trade*) when all countries act as Nash-Cournot players (scenario *FullNash*). Given our theoretical discussion in Section 2, this result does not really come as a surprise. Quota importers have incentives to overallocate to their *T* sectors, trying to reduce the price, whereas quota exporters have the opposite incentives. One consequence of this is reduced trade in allowances: From Table 5 we see that overall trade is slightly reduced in the *FullNash* scenario compared to the *Trade* scenario.

Second, if we look at the marginal abatement costs outside the EU ETS in Table 3b, we note that these vary quite a lot across countries, although at a relatively small absolute level (CO_2 values are ranging from €1.3 to €5.8 per ton of CO_2). In the *Trade* scenario the new member states are large exporters of quotas, and so they underallocate to the *T* sectors in the *FullNash*

[14] In the tables, under *Stackelberg* we only report the effects in the country that acts as a Stackelberg leader. Similarly, under *SingleNash* we only report the effects in the country that acts as a Nash-Cournot player.

[15] The carbon values in Table 3a are equivalent to the quota price in the EU ETS under alternative scenarios (except for scenario *NoTrade*).

scenario, lowering marginal abatement costs in their *NT* sectors. On the other hand, large old member states like Spain, France, Germany and Italy are distinct quota importers in the *Trade* scenario, and thus end up with higher marginal abatement costs in their *NT* sectors in the *FullNash* scenario. This implies that total emissions reductions in the latter four countries are 11 per cent higher than in the cost-effective *Trade* solution.

From a social planer perspective concerns on larger efficiency losses due to strategic behavior are misplaced should all EU member states behave simultaneously in a Nash-Cournot manner. The overall (net) costs of the *FullNash* solution are only 2.9 per cent higher than in the cost-effective outcome (see Table 4). Exporters of permits stand to lose slightly, whereas permit importers face a small cost reduction (1-2 per cent) because of the allowance price decrease. In a nutshell: As all countries depart from their domestic cost-effective position in order to influence carbon values, the implied changes are very small for all countries (with rather negligible aggregate efficiency losses).

Finally, we find that the benefits from being a Stackelberg leader (compared to the full Nash solution) are insignificant (see Table 4). As laid out in Section 2, the Stackelberg leader will choose an allocation between its allocation in *FullNash* and in *Trade*. Since these two scenarios turn out to be very similar, there is not much room for the Stackelberg leader to gain any advantage. When the Stackelberg leader is an importer of permits, the permit price ends up between the *FullNash*-price and the *Trade*-price (but much closer to the former price). Otherwise, the permit price falls marginally below the *FullNash*-price.

The Grand Pitfall – Efficiency Losses from Carbon Market Segmentation: *NAP*

When we assess the actual partitioning of national emissions budgets under scenario *NAP*, the striking insight is that climate policy practice in the EU comes at very high cost (cf. Table 4). In fact, the outcome for *NAP* is even more costly than the *NoTrade* solution, and thus more than an order of magnitude more costly than the cost-effective outcome under *Trade*. The reason is that segmentation of the EU carbon market in one international market for *T* sectors and 27 domestic markets for *NT* sectors based on the actual national allocation plans creates huge differences between harmonized carbon value in the trading sectors and the marginal abatement costs in non-trading sectors as well as to drastic differences of marginal abatement costs across non-trading sectors in different EU member states (as mentioned before, limited access of EU market segments to a common offset market will probably reduce the magnitude of excess cost to some extent).

From a single country perspective, most of the old member states (EU-15) seem to have overallocated allowances to their *T* sectors. At least, the marginal abatement costs are generally higher in the sectors outside the EU ETS, with the UK as a significant exception (cf. Table 3b). On the other hand, the new member states seem to have underallocated allowances from a cost-efficiency perspective as no abatement is required in the *NT* sectors of these countries. One might argue that this is to avoid the use of hot air, as the emissions reductions in the *NAP* scenario are almost three times higher than in the *Trade* scenario. However, the same overall reduction could obviously be met in a more cost-effective way.

Comparison of the competitive *NAP* outcome with the strategic outcomes under *FullNash* and *Stackelberg* clearly indicates that the actual partitioning of emissions allowances in policy practice has not been driven by mutually consistent strategic behavior of single countries but must be rather traced back to political economy considerations (see Anger et al., 2008).

Strategic Behavior Revisited – Market Power May Matter: *SingleNash*

Finally, we discuss the case when only one country acts as a Nash-Cournot player, taking all the actual NAPs of all other countries as fixed. In this case, we see that market power matters. The effects of strategic partitioning by a single country on the quota price in *T* sectors are much more visible than under *FullNash* (or likewise *Stackelberg*). The price varies between €6.4 and €11.0 per ton of CO_2. Thus, a single country can affect the EU ETS quite significantly by changing its allocation towards the most profitable one, given that other countries have already fixed their allocation. There are two reasons for why we observe greater effects in these *SingleNash* scenarios. First, the starting point is now the *NAP* scenario, which we know is far from cost-effective: When a single country acts as a Nash-Cournot player, it first of all brings marginal abatement costs in its *NT* sector closer to its *T* sector. For some countries, this means significant changes in their allocation. Second, in the *FullNash* scenario the strategic partitioning by one country is more or less cancelled out by strategic partitioning by other countries.

5. Conclusions

The decentralized EU ETS opens up for strategic partitioning of emissions allowances by the member states. Based on simulations with a partial equilibrium model of the EU carbon market, we have examined the potential effects of such strategic behavior on carbon prices and abatement costs. We have found that strategic partitioning of *all* EU member states has only minor effects on total compliance cost and the price of tradable emissions allowances as compared to a cost-effective outcome with comprehensive competitive emissions trading. However, when we refer to actual policy practice, single countries may nevertheless substantially affect the outcome of the EU ETS: Taking the actual – rather cost-ineffective – national allocation plans by other countries as given, some countries can significantly benefit from strategic behavior.

The EU Commission's proposal for a new Post-2012 emission trading directive suggests that there will be no room for strategic behavior among the member states beyond 2012, as the allocation rules, including the number of auctioned quotas, will be determined at the centralized EU level (EU, 2008). On the other hand, future links between the EU ETS and emission trading schemes in other countries (including the USA, Japan, or Canada) are put forward in the proposed directive. With fewer, but larger strategic players, a game in allocation of emissions allowances could in that case lead to more significant strategic effects than what we have found for the EU ETS. Hence, the general issue of strategic allowance allocation may become some leverage when we think about global trading initiatives across multiple jurisdictions.

In our present analysis we have only looked at the terms of trade effects related to the price of emissions allowance. Obviously, climate policies in the EU will also affect prices of emission-intensive goods. Thus, member states might exploit a broader suite of terms-of-trade effects through strategic allowance allocation. While such an analysis is beyond the scope of the present paper with its partial equilibrium framework, it could provide an interesting future research topic for applied general equilibrium analysis.

Table 3a. Marginal Abatement Costs in *T* Sectors in €$_{2007}$ per Ton of CO_2

	NoTrade	*Trade*	*FullNash*	*Stackelberg*	*NAP*	*SingleNash*
Austria	50.6	3.90	3.82	3.82	9.51	9.87
Belgium	18.9	3.90	3.82	3.82	9.51	9.95
Denmark	8.5	3.90	3.82	3.82	9.51	9.51
Finland	-	3.90	3.82	3.82	9.51	9.28
France	45.7	3.90	3.82	3.84	9.51	11.04
Germany	11.8	3.90	3.82	3.84	9.51	10.13
Greece	20.3	3.90	3.82	3.82	9.51	9.69
Ireland	60.8	3.90	3.82	3.82	9.51	9.87
Italy	31.1	3.90	3.82	3.84	9.51	10.58
Netherlands	19.3	3.90	3.82	3.82	9.51	10.28
Portugal	95.5	3.90	3.82	3.82	9.51	10.13
Spain	51.6	3.90	3.82	3.84	9.51	10.87
Sweden	5.8	3.90	3.82	3.82	9.51	9.48
United Kingdom	3.6	3.90	3.82	3.82	9.51	8.69
Bulgaria	-	3.90	3.82	3.82	9.51	8.21
Czech Republic	-	3.90	3.82	3.82	9.51	6.94
Hungary	-	3.90	3.82	3.82	9.51	9.13
Poland	-	3.90	3.82	3.82	9.51	6.38
Romania	-	3.90	3.82	3.82	9.51	6.43
Slovakia	-	3.90	3.82	3.82	9.51	9.09
Baltic States	-	3.90	3.82	3.82	9.51	7.43

Table 3b. Marginal Abatement Costs in *NT* Sectors in €$_{2007}$ per Ton of CO_2

	NoTrade	*Trade*	*FullNash*	*Stackelberg*	*NAP*	*SingleNash*
Austria	50.6	3.90	4.21	4.04	81.1	10.31
Belgium	18.9	3.90	4.17	4.03	57.4	10.20
Denmark	8.5	3.90	3.91	3.82	7.3	9.48
Finland	-	3.90	3.71	3.82	-	9.02
France	45.7	3.90	5.36	5.08	55.1	12.80
Germany	11.8	3.90	5.49	5.17	19.4	10.58
Greece	20.3	3.90	4.30	4.12	50.7	10.09
Ireland	60.8	3.90	4.22	4.20	130.5	10.31
Italy	31.1	3.90	5.42	5.08	48.4	12.17
Netherlands	19.3	3.90	4.59	4.40	43.8	10.86
Portugal	95.5	3.90	4.40	4.25	451.1	10.81
Spain	51.6	3.90	5.83	5.28	94.5	13.09
Sweden	5.8	3.90	3.85	3.82	1.3	9.45
United Kingdom	3.6	3.90	3.77	3.79	0.5	7.57
Bulgaria	-	3.90	2.84	2.96	-	6.76
Czech Republic	-	3.90	1.96	2.54	-	4.35
Hungary	-	3.90	3.63	3.67	-	8.68
Poland	-	3.90	2.07	2.46	-	3.90
Romania	-	3.90	1.32	2.12	-	3.31
Slovakia	-	3.90	3.54	3.65	-	8.59
Baltic States	-	3.90	2.39	3.11	-	5.57

Table 4. Compliance Costs in Million €$_{2007}$

	NoTrade	*Trade*	*FullNash*	*Stackelberg*	*NAP*	*SingleNash*
European Union	5329.3	304.8	314.1		8190.1	
Austria	264.3	46.2	45.4	45.4	332.9	105.2
Belgium	112.8	46.3	45.7	45.7	282.2	91.3
Denmark	19.3	14.1	13.9	13.9	19.3	19.1
Finland	-	-10.3	-10.0	-10.0	7.7	-34.1
France	1021.8	190.1	188.0	187.9	1105.6	475.5
Germany	435.0	248.5	247.2	247.1	487.1	427.3
Greece	162.7	58.9	58.0	58.0	190.7	121.7
Ireland	293.9	46.6	45.8	45.8	474.0	105.2
Italy	759.6	199.8	197.5	197.5	842.0	458.3
Netherlands	259.1	102.2	100.8	100.8	452.8	209.5
Portugal	616.1	67.1	66.0	66.0	2164.5	158.8
Spain	1343.9	244.9	241.8	241.8	1619.6	593.4
Sweden	3.9	3.5	3.3	3.3	5.4	2.4
United Kingdom	37.1	36.7	36.8	36.8	43.4	-32.0
Bulgaria	-	-103.7	-101.7	-101.7	-18.2	-235.1
Czech Republic	-	-188.9	-184.3	-184.3	2.7	-365.9
Hungary	-	-15.5	-15.1	-15.1	6.3	-56.2
Poland	-	-168.0	-162.5	-162.6	145.2	-308.4
Romania	-	-266.3	-260.3	-260.3	-42.5	-454.9
Slovakia	-	-26.8	-26.2	-26.2	-0.4	-75.1
Baltic States	-	-156.3	-153.2	-153.2	33.5	-304.6

Table 5. Net Trade in Emissions Allowances in Million Tons of CO_2

	NoTrade	*Trade*	*FullNash*	*Stackelberg*	*NAP*	*SingleNash*
Austria	-	11.0	11.0	11.0	1.8	8.8
Belgium	-	10.0	10.0	10.0	-3.4	5.1
Denmark	-	2.4	2.4	2.4	-0.2	-0.4
Finland	-	-3.4	-3.4	-3.4	-0.6	-5.4
France	-	45.3	43.9	44.2	4.0	33.0
Germany	-	49.4	47.3	47.7	-0.8	8.7
Greece	-	13.4	13.5	13.5	4.8	8.2
Ireland	-	11.0	11.0	11.0	1.6	8.7
Italy	-	46.1	45.2	45.4	11.0	30.6
Netherlands	-	22.3	22.0	22.1	-3.3	11.3
Portugal	-	16.1	16.1	16.1	1.3	13.4
Spain	-	57.6	56.8	57.1	17.2	41.9
Sweden	-	0.4	0.4	0.4	0.0	-0.7
United Kingdom	-	-2.0	-1.5	-1.5	-8.9	-24.0
Bulgaria	-	-28.5	-28.4	-28.4	-5.3	-32.0
Czech Republic	-	-54.3	-53.1	-53.4	-9.5	-61.5
Hungary	-	-5.8	-5.7	-5.7	-1.7	-9.5
Poland	-	-52.5	-50.1	-50.5	0.2	-60.8
Romania	-	-72.4	-71.5	-71.7	-11.0	-76.6
Slovakia	-	-8.0	-7.9	-7.9	-1.7	-10.4
Baltic States	-	-41.1	-40.9	-41.0	1.7	-42.8

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Appendix

Table A1. Region- and Sector-Specific Marginal Abatement Costs Coefficients. USD_{2001} per Ton of Carbon*

	T Sectors			*NT Sectors*		
	a1	*a2*	*a3*	*a1*	*a2*	*a3*
Austria	32.72	8.71	9.41	64.37	11.24	1.31
Belgium	14.04	-0.47	1.34	36.77	4.13	0.34
Denmark	18.82	-1.03	3.48	98.79	34.63	-0.87
Finland	28.87	4.43	1.38	136.00	37.44	7.86
France	13.01	0.60	0.82	9.78	0.28	0.01
Germany	1.70	0.01	0.00	6.29	0.09	0.00
Greece	15.14	-1.52	0.34	103.31	3.35	6.00
Ireland	25.54	0.54	11.43	86.02	24.69	4.22
Italy	4.57	0.30	0.01	13.80	0.38	0.00
Netherlands	7.15	0.35	0.07	14.67	0.62	0.06
Portugal	19.79	0.26	4.33	132.33	24.93	11.03
Spain	4.54	-0.03	0.04	20.60	0.98	0.01
Sweden	58.84	32.30	74.29	113.79	30.22	2.26
United Kingdom	2.75	0.05	0.00	3.98	0.06	0.00
Bulgaria	14.68	-4.48	2.02	98.93	61.54	43.19
Czech Republic	5.06	-0.45	0.07	20.91	-1.28	1.84
Hungary	16.23	-2.09	2.82	37.48	4.92	2.62
Poland	2.81	-0.01	0.01	8.29	0.27	0.06
Romania	8.79	-2.18	0.45	34.33	-0.72	1.51
Slovakia	23.08	-3.71	7.83	67.43	25.44	13.51
Baltic States	32.82	-17.96	12.04	82.44	-1.06	73.72
Rest of Europe	50.02	-4.42	13.32	94.71	21.13	5.72

* The numerical results are generated in terms of USD_{2001} and we use a conversion factor of 1.28 to convert monetary values into €$_{2007}$ in Tables 3-4 of our paper (the conversion factor is based on information by the EU website http://ec.europa.eu/economy_finance/indicators/annual_macro_economic_database/ameco_applet.htm).