Wirtschaftswissenschaftliche Diskussionspapiere

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V – 337 – 11

June 2011

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Abstract: We consider an international emissions trading scheme with partial sectoral and regional coverage. Sectoral and regional expansion of the trading scheme is beneficial in aggregate, but not necessarily for individual countries. We simulate international CO_2 emission quota markets using marginal abatement cost functions and the Copenhagen 2020 climate policy targets for selected countries that strategically allocate emissions in a bid to manipulate the quota price. Quota exporters and importers generally have conflicting interests about admitting more countries to the trading coalition, and our results indicate that some countries may lose substantially when the coalition expands in terms of new countries. For a given coalition, expanding sectoral coverage makes most countries better off, but some countries (notably the USA and Russia) may lose out due to loss of strategic advantages. In general, exporters tend to have stronger strategic power than importers.

Keywords: Emissions Trading; Allocation of Quotas; Strategic Behavior

JEL: C61; C72; Q25

Acknowledgement: We are grateful to Odd Godal, Carsten Helm and Erling Holmøy for valuable comments on an earlier draft. Financial support from the Renergi programme of the Research Council of Norway and the German Research Foundation (BO 1713/5-1) is appreciated.

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1. Introduction

International emissions trading is considered a key instrument to combat global warming because it promotes cost-effectiveness of emission abatement and thereby increases political feasibility of stringent emission reduction objectives.

Since 2005 the EU has been a forerunner in the implementation and operation of a multi-jurisdictional emissions trading scheme. While the EU emissions trading scheme (EU ETS) has been critically observed as a "New Grand Experiment" (Kruger and Pizer, 2004) in the early stage, it is meanwhile perceived as a success story which could be the nucleus for a gradually expanding system towards global coverage (Convery, 2009). As a matter of fact, the EU strongly pushes policy initiatives to link the EU ETS with other regional greenhouse gas cap-and-trade systems outside the EU (EU, 2007).[1]

With respect to cost-effectiveness of emission abatement, an important characteristic of the EU ETS is its incomplete coverage. The EU ETS focuses on energy-intensive installations and thereby covers only around 40% of the EU-wide greenhouse gas emissions. To achieve its reduction target of 20% by 2020 (compared to 1990 emission levels), the EU must undertake complementary regulation of emission sources outside the EU ETS. The segmentation of emission regulation into one EU-wide ETS market and multiple national non-ETS markets has given rise to concerns on adverse implications for cost-effectiveness of EU emission abatement: While the allocation of emission allowances across sources would not matter for cost-effectiveness in the case of comprehensive trading, it may induce substantial additional costs of emission abatement in the case of unlinked markets should the regulator not be able or willing to choose the cost-effective split of the emission budget between ETS and non-ETS segments (see e.g. Böhringer et al., 2005).[2]

Even in the case of perfect planner information the segmentation of regional emissions into an international ETS market and unconnected non-ETS markets can have adverse efficiency implications as regions obtain incentives to manipulate emission prices through strategic

[1] For example, RGGI and WCI in the USA, GGAS in Australia, or JVETS in Japan (for an overview see Schüle and Sterk, 2009).

[2] Note that we use the terms "allowances", "permits" and "quotas" interchangeably throughout the paper.

segmentation (Böhringer and Rosendahl, 2009): Importers of emission allowances have incentives to over-allocate emissions to the international ETS in order to lower the emission price whereas exporters of emission allowances would like to do the opposite.[3] Each country would then trade off the benefits from price manipulation with the costs of driving apart the marginal abatement cost between the ETS and their domestic non-ETS emission sources.

For the first two phases of the EU ETS (2005-2007 and 2008-2012), each Member State had to submit a National Allocation Plan to the European Commission, detailing how many emissions allowances of the national budget under the Kyoto Protocol are allocated to its ETS sectors and how these allowances are spread across the ETS sectors. For the third phase of the EU ETS (2013-2020), the National Allocation Plans will be replaced by an EU-wide cap for ETS sectors with harmonized allocation rules. The determination of the allowance allocation is then completely out of the hands of the individual Member States avoiding incentives for strategic partitioning. However, if other countries outside the EU start joining the trading scheme, the EU as a whole as well as the joining countries might still want to set their allocation strategically.

The strategic incentives in a hybrid regulation scheme where countries can divide up national emission budgets between international trading sectors and domestically ruled sectors provide the conceptual background for our analysis. Given the wide-spread policy interest in expanding the EU ETS towards a global emissions trading system, we investigate the prospects for sectoral and regional expansion when countries decide strategically on how to allocate their emission budget. Can we expect that the EU ETS will be easily expanded to include more regions and sectors, thereby increasing overall cost-effectiveness of emission reductions? If self-interests of regions impede more comprehensive coverage, how severe are the foregone gains in aggregate cost savings?

For answering these questions we complement basic theoretical analysis with numerical simulations on international CO_2 emission quota markets using sector- and region-specific (marginal) abatement cost functions. As to regional coverage, we point out that quota exporters and importers tend to have conflicting interests about admitting more countries to the trading coalition. When expanding sectoral coverage, the bulk of potential cost reductions

[3] The mechanism is similar to the "optimal tariff" argument (e.g. Bhagwati et al., 1998, Ch. 21).

is achieved in the first step: going from “No trade” to a trading scheme that includes one sector with a sufficiently large emission share (in our case: the electricity sector). Most countries gain from sectoral expansion; however, we identify several cases in our applied analysis where countries might lose. The latter occurs if sectoral expansion makes the marginal abatement costs in the remaining non-trading sectors of these countries less elastic, so that they are less able to manipulate the quota price in their preferred direction. The economic implications of sectoral expansion are more significant when only few countries take part in the emissions trading coalition, because an individual country has more market power in a smaller coalition. The quota price for partial sectoral coverage is higher under strategic allowance allocation than in a competitive setting but sectoral expansion reduces the quota price (in most of the simulations). Exporters thus have more market power than importers, but their influence decreases when more sectors are added to the trading scheme. The reasoning behind this result is twofold. Firstly, as will be shown in our theoretical analysis for the case of symmetric countries, convex marginal abatement cost functions imply that it is less costly for exporters to over-supply their non-trading sectors than for importers to under-supply their non-trading sector. Secondly, as will be evident from our applied policy analysis, exporters are often bigger countries than importers, and thus have stronger market power.

The seminal study on market power in markets of transferable property rights is Hahn (1984). Assuming a single firm has market power, he demonstrates that the inefficiency of the permit market increases as the number of permits allocated to this firm deviates further from the amount it uses in the competitive equilibrium. Hahn’s (1984) model has been extended by Westskog (1996) to allow for several dominant firms and by Malueg and Yates (2009a) to allow for market power by all firms. Maeda (2003) analyzes a permit market consisting of one large buyer, one large seller and many price-taking parties. He finds that the large seller has effective market power if and only if the volume of its excess permits exceeds the net shortage of permits in the market. The large buyer cannot have effective market power.

In common with our paper, Helm (2003) models the endogenous choice of emission allowances by non-cooperative countries for a global pollutant in regimes with and without permit trading. The major difference from our paper is that Helm assumes that each country can choose its own national emission target strategically while the permit trading regime covers all sectors of the economy in all countries. Helm shows that environmentally less (more) concerned countries tend to choose more (fewer) allowances if these are tradable. The effect on overall emissions of introducing permit trade is ambiguous. Individual countries may lose from emissions trading if total emissions increase. In our paper, by contrast, international emissions trading always increases the welfare of the country joining the trading coalition, because each country's emissions target remains fixed at an exogenous policy level (in our case provided by official emission reduction pledges of countries up to 2020). Godal and Holtsmark (2010) show, within a similar context as Helm (2003), that if countries can tax domestic emissions, allowing for permit trade does not change emission levels as countries re-adjust domestic tax rates.

Babiker et al. (2004) illustrate in a computable general equilibrium analysis that countries exporting emission permits may lose from joining an international emissions trading scheme if efficiency costs associated with the pre-existing distortionary taxes are larger than the primary gains from emissions trading. Similarly, Böhringer et al. (2008) and Eichner and Pethig (2009) point to potentially large efficiency losses from the imposition of emission taxes in sectors that are covered by the EU ETS whenever tax rates differ across trading regions.

Finally let us review the theoretical and empirical literature analyzing international emissions trading schemes that only covers a part of all polluting sectors (like the EU ETS). Malueg and Yates (2009b) compare centralized and decentralized emission allocations under perfect and under asymmetric information from an economic efficiency perspective. They find that if countries do not behave strategically, the permit market should be decentralized (whether there is full or asymmetric information). If they do behave strategically, however, then either centralization or decentralization might be preferred.

Dijkstra et al. (2011) examine in a theoretical framework whether a country could lose when the international trading scheme expands to cover more sectors. They find that if the expansion results in a country's marginal abatement cost curve for the remaining non-trading sectors becoming much steeper, this country will lose its ability to manipulate the international permit price in its favor, and may thus see its overall cost increase.[4]

[4] We will illustrate this point in Section 2.

In an empirical application, Bernard et al. (2004) use a computable general equilibrium model (GEMINI-E3) to investigate the economic impacts of market power in emissions trading for the EU-15. They identify three major players: Germany operates as a potential seller while Italy and the Netherlands are assumed to collude as potential buyers. The three countries' deviations from the competitive allocation are rather negligible, however, as are the associated overall welfare losses. Using the same model, Viguier et al. (2006) show that EU Member States with high abatement costs could be tempted to give a generous initial allocation of allowances to their energy-intensive industries; yet, the economic incentives to act strategically are relatively small.

Böhringer and Rosendahl (2009) quantify the implications of strategic emission allocation between trading and non-trading sectors for the EU-27. They find that strategic behavior leads to substantial differentiation of marginal abatement costs across EU Member States in the non-trading sectors. However, the effects of strategic allowance allocation on the quota price and total abatement costs are quite modest.

The present paper provides an extension to the theoretical analysis by Dijkstra et al. (2008) and the numerical study by Böhringer and Rosendahl (2009). We consider the effects of both regional and sectoral coverage. Beyond addressing a larger variety of sectoral coverage, we investigate the impacts of strategic allowance allocation within a global setting featuring all major climate policy players. Furthermore, we show analytically that exporters tend to have stronger strategic power than importers which helps us to explain the policy-relevant outcome of our numerical simulations.

The remainder of this paper is organized as follows. In Section 2 we present a stylized theoretical framework to study key mechanisms of strategic allowance allocation in multi-sector, multi-region emission markets. Then in section 3 we lay out the structure and the data for our numerical model in use for applied policy analysis. In section 4 we describe our policy scenarios and provide an economic interpretation of the simulation results. Finally, in section 5 we conclude.

2. Theoretical Considerations

We use the same analytical model as in Dijkstra et al. (2008) and Böhringer and Rosendahl (2009). Let there be n countries, $i = 1,\ldots,n$. Country i has an exogenously given emission ceiling E_i. In policy practice, the latter could reflect legally binding commitments such as the Kyoto targets or prospective Post-Kyoto pledges such as the national communications to the Copenhagen Accords (UNFCCC, 2009 – cf. section 3). The main point in our context is that the total ceiling is assumed to be unaffected by sectoral or regional expansions of the emissions trading scheme. Polluters in each country are divided into a trading segment T and a non-trading segment NT.[5] The rules according to which polluters (or polluting activities) are divided into the two segments are exogenous. Total abatement costs of reducing emissions from business-as-usual to the emission level $e_{i,T}$ in country i's trading segment are $C_{i,T}(e_{i,T})$, with marginal abatement costs $MC_{i,T}$ positive ($MC_{i,T} \equiv -C'_{i,T}(e_{i,T}) > 0$) and decreasing in emissions ($-C''_{i,T}(e_{i,T}) < 0$). Total abatement costs of emissions $e_{i,NT}$ in the non-trading segment of country i are $C_{i,NT}(e_{i,NT})$, again with $MC_{i,NT} \equiv -C'_{i,NT}(e_{i,NT}) > 0$, $-C''_{i,NT}(e_{i,NT}) < 0$.

When there is an international permit trading scheme, the polluters in the trading segment can trade internationally with each other, but the polluters in the non-trading segment cannot. We assume that firms that do not trade permits internationally can be regulated efficiently at the domestic level such that all firms within a country have the same marginal abatement costs. The latter could be achieved through a domestic trading scheme or a domestic emission tax for the non-trading segment.

Let us start with the benchmark case NTR in which there is no international emissions trading. Each country i has to decide how to divide its total emission ceiling E_i between the trading and the non-trading segment. It allocates $e_{i,T} > 0$ emissions to the trading segment and the rest $e_{i,NT} = E_i - e_{i,T} > 0$ to the non-trading segment. Each country i minimizes total costs of abatement:

$$\text{Min}\left[C_{i,T}\left(e_{i,T}\right)+C_{i,NT}\left(E_i-e_{i,T}\right)\right] \tag{1}$$

Let $e_{i,T}^{NTR}$ be the emissions allocated to and taking place in the trading segment without international emissions trading. From (1), $e_{i,T}^{NTR}$ is given by the well-known first-order condition:

$$MC_{i,T}\left(e_{i,T}^{NTR}\right)=MC_{i,NT}\left(E_i-e_{i,T}^{NTR}\right) \tag{2}$$

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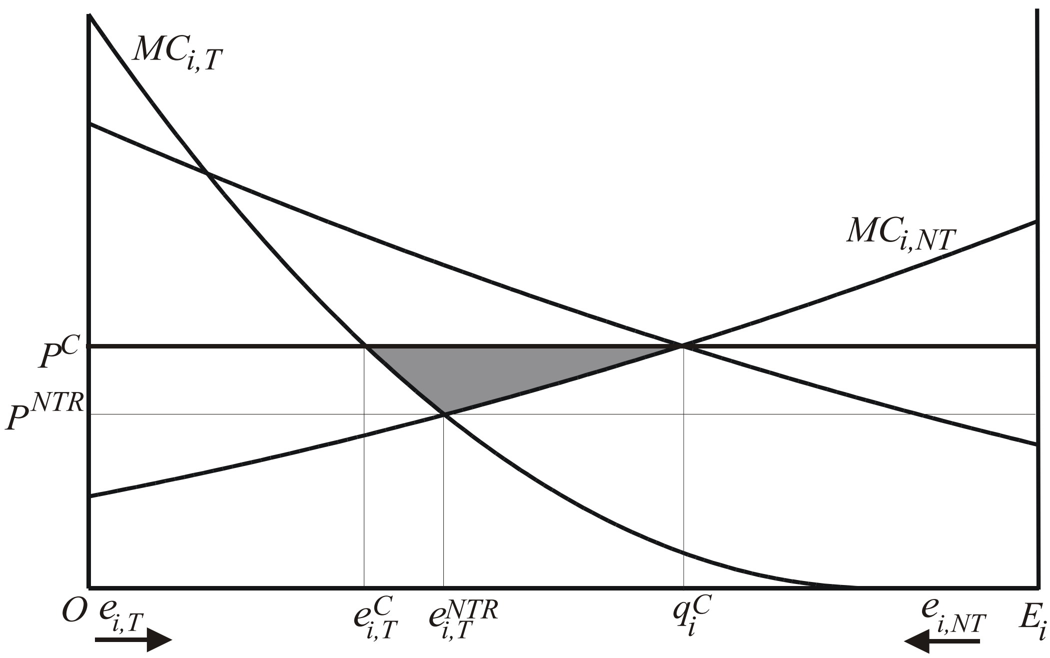
[5] In line with our previous discussion, the segment T obviously comprises the ETS sectors while the segment NT covers the non-ETS sectors. Throughout the theoretical considerations we keep with notations T and NT for the sake of brevity.

Figure 1 shows country i's marginal abatement costs $MC_{i,T}$ as a function of emissions $e_{i,T}$ in the trading segment, measured from left to right. Further, the figure shows the country's marginal abatement costs $MC_{i,NT}$ as a function of emissions $e_{i,NT}$ in the non-trading segment, measured from right to left. The national ceiling is given by the distance OE_i. Without international trading, country i sets $MC_{i,T} = MC_{i,NT}$ by (2), so that emissions in the trading segment are $e_{i,T}^{NTR}$ and marginal costs in both segments are P_i^{NTR}.

Figure 1: The switch from no international emissions trading to competitive trade



With international emissions trading, country i's trading segment emissions $e_{i,T}$ will in general differ from the emissions budget q_i allocated to the trading segment by country i's emission authority.[6] The allocated emissions budget q_i for the trading segment plus emissions $e_{i,NT}$ for the non-trading segment must add up to the national ceiling E_i. After each country has set its q_i and distributed the permits among its trading segment, the polluters in the trading segments trade the permits among each other. We assume that each individual polluter is too small to have market power, and so each polluter takes the permit price P as given. Emissions $e_{i,T}$ are then determined by:

$$MC_{i,T}\left(e_{i,T}\right)=P \qquad (3)$$

[6] It makes no difference to our analysis whether the national government auctions or grandfathers the permits to its firms, or (in the latter case) how it distributes the permits among its firms. This is because we assume the permit market is perfectly competitive for firms, and because we are only interested in the welfare of the country as a whole.

under the restriction:

$$e_T \equiv \sum_{j=1}^{n} e_{j,T} = \sum_{j=1}^{n} q_j \qquad (4)$$

That is, marginal abatement costs equal the permit price, and total emissions in all trading segments equal the total amount of permits for the trading segments. Equations (3) and (4) implicitly define P and $e_{i,T}$ as function of the total emissions e_T in the trading segment with:

$$P'(e_T) = -\frac{1}{\sum_{j=1}^{n} \frac{1}{C''_{j,T}\left(e_{j,T}\right)}} \qquad (5)$$

Country i now chooses q_i to minimize overall abatement costs in the trading and non-trading segments plus net expenditures on buying (selling) permits from (to) abroad:

$$\text{Min}\left[C_{i,T}\left(e_{i,T}\right) + C_{i,NT}\left(E_i - q_i\right) + P(e_T)\cdot\left(e_{i,T} - q_i\right)\right] \qquad (6)$$

Assuming an interior solution $0 < q_i < e^0_{i,T}$,[7] the first-order condition, taking (3) into account, is:

$$MC_{i,NT}\left(e_{i,NT}\right) = MR_i(q_i) \equiv P(e_T) - P'(e_T)\cdot(e_{i,T} - q_i) \qquad (7)$$

where $P'(e_T)$ is given by (5) and $MR_i(q_i)$ is country i's marginal revenue of allocating more permits to its trading segment. When country i is exporting permits, its marginal revenues are below the international permit price (as for any seller with market power), because the extra permits it allocates to its trading segment depress the price at which it can sell permits. Correspondingly, when country i is importing permits, its marginal revenues exceed the permit price.

Figures 1 and 2 illustrate how a country gains when it joins the international emissions trading scheme. First consider the change from no international trading to competitive international trade where country i takes the international permit price P^C as given. This is illustrated in Figure 1, where we have assumed $P^C > P_i^{NTR}$. The country then minimizes overall costs by setting its marginal costs in the non-trading segment equal to P^C, as is clear from (7) with P'

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[7] In the numerical simulations (cf. section 4) there is one occasion (Brazil in region coverage variant C4 and sector coverage variant *ELE*) where $q_i = 0$, as the optimal allocation is negative. Then marginal costs in the non-trading segment are above the marginal revenue, and we have an inequality in (7). We assume that countries are not allowed to overallocate, i.e., to allocate more allowances to the trading segment than their business-as-usual emissions in that segment ($q_i \leq e^0_{i,T}$). However, this restriction is never binding in the numerical simulations.

= 0. Thus, it allocates q_i^C permits to its trading segment and the rest ($E_i - q_i^C$) to its non-trading segment. Firms in country *i*'s trading segment trade permits and emit $e_{i,T}^C$ themselves, which in the Figure 1 is lower than q_i^C since $P^C > P_i^{NTR}$. Compared to the case without international emissions trading, country *i*'s total costs have decreased by the shaded triangle above the *MC*-curves and below the P^C-line, i.e., export revenues minus increased abatement costs.

Figure 2: The switch from competitive trade to trade with market power

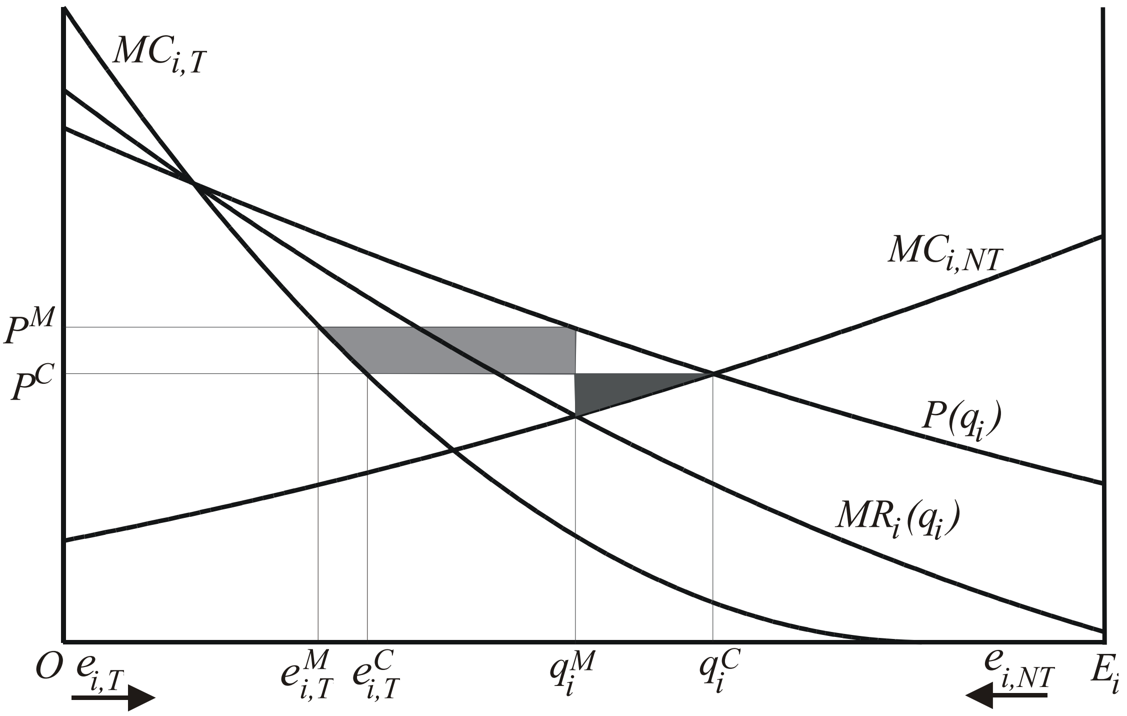

Figure 2 illustrates the switch from competitive trade to trade with market power.[8] As before, the international permit price will be P^C if the country issues q_i^C permits to its trading segment. However, the permit price is now a decreasing function $P(q_i)$ of q_i. Country *i*'s marginal revenue $MR_i(q_i)$ curve is located below (above) $P(q_i)$ when it is exporting (importing) permits. We know from (7) that country *i* will set its marginal abatement costs in the non-trading segment equal to the marginal revenues from selling permits (or buying less permits) in the international market. It thus reduces its permit allocation to the trading segment to q_i^M, driving the permit price up to P^M in Figure 2. The trading segment will now emit $e_{i,T}^M$, whereas the non-trading segment increases its emissions to ($E_i - q_i^M$). The cost

[8] We assume throughout that all reaction curves are downward sloping (i.e., $dq_i / dq_j < 0$ for all i,j), and that there is a stable and unique Nash equilibrium.

reduction compared to competitive behavior is the difference between the light-shaded quadrangle and the dark-shaded triangle. The quadrangle represents the gain from selling permits at a higher price. The triangle represents the efficiency loss from the domestic distortion of letting $MC_{i,NT}$ deviate from the permit price.[9]

So far we have illustrated that a country gains when joining the international emissions trading scheme while taking the permit price as given, and that there is an additional gain should it be able to influence the permit price. It is easily seen that the costs of all participating countries together are minimized when all sectors are included in the international trading scheme.[10] In this case there is no scope for countries to manipulate the permit price by letting marginal cost in their non-trading segment deviate from the international permit price.

However, a country will not necessarily benefit from the inclusion of additional sectors into the international trading scheme. The discussion of Figure 2 indicates that the permit price for strategic allowance allocation in general will deviate from the cost-effective solution as long as the trading scheme only covers a subset of all sectors. Including more and more sectors into the trading segment changes a country's ability to manipulate the permit price. If a country sees the permit price move in an adverse direction (up for a net importer, down for a net exporter), its loss from this price change may dominate the gain from increased where-flexibility, so that overall the country may lose from the sectoral expansion of the trading scheme.

A country's ability to manipulate the permit price depends on the slope of its marginal abatement cost curve for the non-trading segment. Consider the marginal cost curve for the non-trading segment, $MC_{i,NT}$, in Figure 2. This curve is rather flat. Suppose that country i had a much steeper $MC_{i,NT}$ curve which likewise intersects the $P(q_i)$ curve at q_i^C. The country would still issue q_i^C permits to the trading segment if it took the permit price P^C as given. However, its domestic efficiency loss (i.e., the shaded triangle) from reducing the number of

[9] Obviously, strategic allowance allocation provides additional cost savings for the joining country compared to competitive behaviour, i.e., the difference between the light-shaded quadrangle and the dark-shaded triangle must be positive.

[10] We abstract from transaction costs which may be prohibitively high for the large group of small polluters. Betz et al. (2010) discuss the optimal coverage of the EU ETS, taking transaction costs into account.

permits to the trading segment to q_i^M would now be larger. Thus, the country would go less far in reducing the number of permits in order to drive up the permit price, and so the dark-shaded quadrangle would decrease. Thus, the flatter a country's marginal abatement cost curve in the non-trading segment is, the stronger is the incentive to manipulate the permit price.[11] If an expansion of the trading scheme makes a country's marginal abatement costs in the remaining non-trading segment much steeper, i.e., less elastic, this country will lose its ability to manipulate the permit price in its favor and may see its overall costs increase as a result of the expansion.

Before turning to the numerical analysis, let us briefly summarize what results we may expect based on the theoretical discussion so far. First, we should expect larger countries to have stronger impacts on the permit price than smaller countries. A large country would typically have a larger volume of net trade and therefore a larger benefit from a permit price change. Second, we laid out that a country's incentive to manipulate the international permit price increases with the flatness of the marginal abatement cost curve in its non-trading segment.

Furthermore, we should expect exporters to have more strategic power than importers, given that marginal abatement costs are strictly convex.[12] That is, the permit price will tend to be above the competitive or cost-effective permit price as long as sectoral coverage is partial. Formally, we can state:

<u>Proposition:</u>

Consider n countries with different national emissions targets, having a common trading scheme that covers a subset of all sectors. Assume that countries freely decide on their permit allocation, and play Nash in the allocation game. Assume also that marginal abatement cost curves in the non-trading sectors are convex and identical across countries. Then the emissions price in the trading scheme will be above the cost-effective emissions price level.

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[11] A flat marginal cost curve implies only a small cost of letting the permit allocation deviate from the point where marginal costs equal the permit price.

[12] In our quantitative analysis based on empirical data the aggregate marginal abatement cost functions for the non-trading segment is always strictly convex for any country.

Proof:

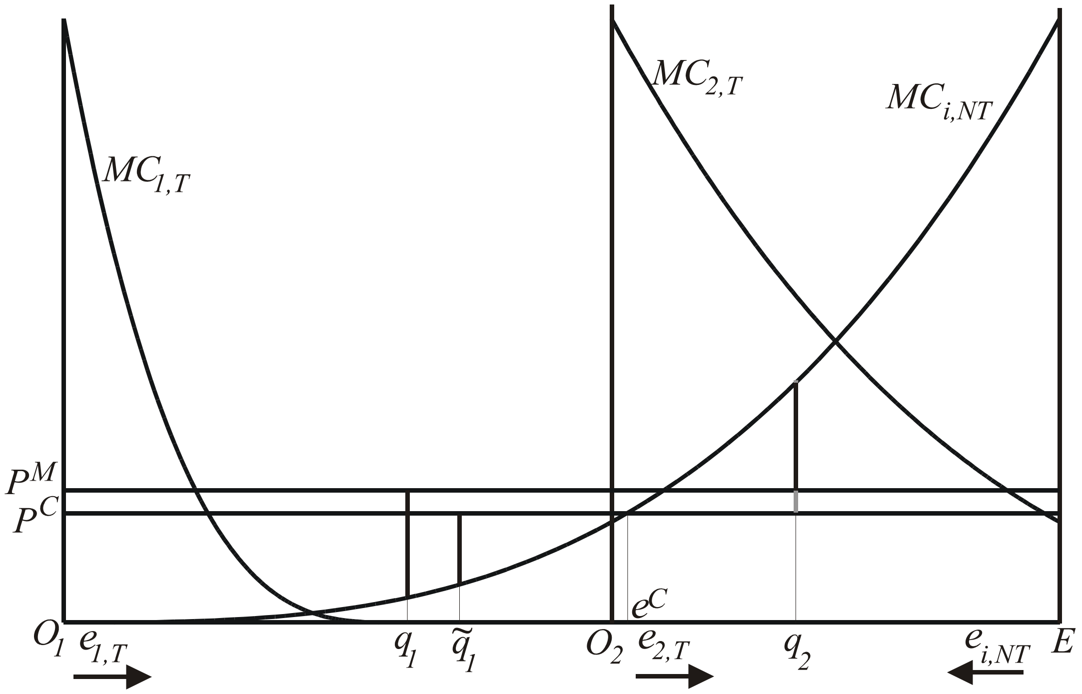
Note that equation (7) implies:

$$P = \frac{1}{n}\sum_{j=1}^{n}\left(MC_{j,NT}\left(e_{j,NT}\right)\right) \qquad (8)$$

In the cost-effective solution, marginal abatement costs are equal across countries and equal to the permit price. Moreover, since the countries have identical marginal cost functions in the non-trading sectors, their emissions in the non-trading segment are identical in the cost-effective solution, and an identical change in emissions will obviously have identical effects on the marginal abatement costs. Let Δ denote differences between the Nash equilibrium and the cost-effective solution. In the Nash equilibrium, exporters allocate less permits to the trading segment ($\Delta q_i^E < 0$), whereas importers allocate more permits ($\Delta q_i^I > 0$). Assume now that $\sum \Delta q_i \geq 0$. Then we know that $\Delta P \leq 0$. However, $\sum \Delta q_i \geq 0$ also implies that total emissions in the non-trading segments of importers must decrease at least as much as the total increase in emissions in the non-trading segments of exporters. But then it follows from the assumed convexity of the marginal abatement cost functions that the right-hand side of equation (8) strictly increases, which contradicts $\Delta P \leq 0$. Thus, the permit price will tend to increase compared to the cost-effective price, as exporters in general have stronger strategic power than importers. ■

Figure 3 illustrates the proposition for a trading scheme between two countries, with country 1 being the net exporter and country 2 the net importer. Country 1 (2) has a national emission ceiling of O_1E (O_2E). Country 1 (2)'s emissions in the trading sector $e_{1,T}$ ($e_{2,T}$) are measured from left to right starting from O_1 (O_2). Country 1 (2)'s marginal abatement costs in the trading segment are given by $MC_{1,T}$ ($MC_{2,T}$). Country i's (i = 1,2) emissions in the non-trading sector $e_{i,NT}$ are measured from right to left starting from E. Both countries have the same marginal abatement cost curves in the non-trading segment (as represented by $MC_{i,NT}$ in Figure 3).

Figure 3: The effect of a convex $MC_{i,NT}$ curve



In the cost-effective outcome, all marginal abatement costs are equal to each other at P^C with emissions e^CE for the non-trading segment in each country. In the non-cooperative equilibrium, it follows from (7) that:

$$P - MC_{1,NT} = -P'\left(q_1 - e_{1,NT}\right) = -P'\left(e_{2,NT} - q_2\right) = MC_{2,NT} - P \qquad (9)$$

The second and third term in equation (9) represent country 1 and 2's marginal benefits of letting their marginal abatement costs in the non-trading segment deviate from the international permit price. The marginal benefits consist of a favorable price change for the internationally traded amount of permits. These marginal benefits are always equal for both countries, because country 1's exports are country 2's imports. The first and fourth term in equation (9) are country 1 and 2's marginal costs of the domestic distortion from letting marginal abatement cost in the non-trading segment deviate from P. In equilibrium these should also equal each other.

Now let us examine whether the cost-effective price P^C in Figure 3 could also be the equilibrium permit price in equation (9). Buyer country 2 tries to decrease the permit price by allocating more permits than O_2e^C to its trading segment and less than e^CE emissions to its non-trading segment. Let us assume that country 2 allocates O_2q_2 to its trading segment and

q_2E to its non-trading segment. Then to keep the permit price at P^C, country 1 would have to allocate $O_1\tilde{q}_1$ to its trading segment and $\tilde{q}_1E$ to its non-trading segment. This is because the distance $\tilde{q}_1e^C$ equals e^Cq_2, so that the total amount allocated to the non-trading segment (and thereby the total amount allocated to the trading segment) remains the same. However, the gap between the permit price P^C and the marginal abatement cost $MC_{i,NT}$ is now much smaller for country 1 than for country 2,[13] because the $MC_{i,NT}$ curve is strictly convex. According to equation (9), these gaps, which measure the marginal costs of the domestic distortion, should be the same for both countries. Hence, exporting country 1 will further restrict its permit allocation to the trading segment. In equilibrium, country 1 allocates O_1q_1 to its trading sector and q_1E to its non-trading sector, while country 2 allocates O_2q_2 and q_2E respectively. Total emissions in the trading segment are lower than in the cost-effective outcome, so that the permit price is now P^M, which exceeds the cost-effective price P^C. The two countries then have the same gap between the permit price P^M and the marginal abatement cost $MC_{i,NT}$, i.e., equal marginal costs of domestic distortion, as required by (9).[14]

3. Numerical Model and Benchmark Data

In order to investigate the prospects for expanding the EU ETS towards a more comprehensive coverage of sectors and regions we make use of a numerical carbon market model. The model is based on marginal abatement cost curves which reflect differences in emission reduction possibilities across sectors and regions. We can generate these cost functions in continuous form given a sufficiently large number of discrete observations for marginal abatement costs and the induced emission reductions in sectors and regions. In applied research marginal abatement costs are often provided as discrete step-functions where the data is either collected through expert assessments of abatement possibilities or generated through bottom-up models of the energy system (e.g., Criqui and Mima, 2001; Capros et al., 1998). Another wide-spread method is to derive marginal abatement costs curves from economy-wide models with a top-down representation of emission reduction possibilities in production and consumption (see, e.g., Eyckmans et al., 2001).

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[13] In Figure 3, the gaps are given by the dark thick vertical line above $\tilde{q}_1$ for country 1 and the grey plus the dark thick vertical lines above q_2 for country 2.

[14] The gap between the international permit price and marginal abatement cost in the non-trading segment is given by the dark thick vertical lines above q_1 and q_2 respectively.

As our numerical analysis requires marginal abatement cost curves for many sectors and regions, a bottom-up approach is not practical. We therefore employ an established multi-sector, multi-region computable general equilibrium (CGE) model of the world economy (see Böhringer and Rutherford, 2010, for a recent detailed model description) to obtain explicit reduced-form representations of marginal abatement cost curves. The CGE model is based on the GTAP7 dataset for 2004 which features consistent accounts of production and consumption, bilateral trade and energy (carbon emission) flows for 57 sectors and 113 regions (Badri and Walmsley, 2008) and is complemented with econometric estimates on sector-specific elasticities of substitution (Okagawa and Ban, 2008). Since our numerical simulations refer to 2020 as the central compliance year for a potential Post-Kyoto agreement, we perform a business-as-usual forward projection of the model to 2020 based on information of the International Energy Outlook (EIA, 2010). We aggregate the GTAP7 dataset towards a more compact representation with 9 sectors and 13 regions. Table 1 provides a summary of explicit sectors and regions incorporated in our numerical analysis.

Table 1: Model sectors and regions

Sectors and commodities	*Countries and regions*
Energy	*Annex B regions*
Coal (COL)	EU-27 (EUR)
Crude oil (CRU)	USA (USA)
Natural gas (GAS)	Canada (CAN)
Refined oil products (OIL)	Japan (JPN)
Electricity (ELE)	Russian Federation (RUS)
	Australia (AUS)
Non-energy	*Non-Annex B regions*
Energy-intensive industries (EIS)[a]	Mexico (MEX)
Other transport (OTP)[b]	South Korea (KOR)
Water transport (WTP)	China (CHN)
Rest of industry (ROI)	India (IND)
Final demand (C)	Brazil (BRA)
	South Africa (ZAF)
	Rest of the World (ROW)

[a] EIS composite includes chemical industry, mineral products, non-ferrous metals, iron and steel industry, paper, pulp and print, as well as air transport (i.e., the non-energy EU ETS sectors).

[b] OTP mainly includes road transport

The sectors include primary and secondary energy goods (coal, natural gas, crude oil, refined oil products, and electricity), a composite of carbon-intensive commodities covered under the existing EU ETS, and important candidates for sectoral expansion, in particular transport activities. The remaining production of commodities and services is summarized in one aggregate sector; likewise private consumption patterns with associated carbon emissions are reflected in a composite final demand activity. The regions depicted for our analysis represent key players in the climate policy debate which may be seen as potential candidates for linking up with the EU ETS.

For the sectors and regions listed in Table 1 we generate marginal abatement cost functions through a sequence of hypothetical tax scenarios where we impose sector- and region-specific CO_2 taxes starting from \$0 to \$100 per ton of CO_2 in steps of \$1 and then read off the CGE solution for the induced emission reduction. We then perform a least-square fit by a polynomial marginal abatement cost function of third degree to the set of "observations":

$$MC_{i,s}(e_{i,s}) = a1_{i,s}(e_{i,s}^0 - e_{i,s}) + a2_{i,s}(e_{i,s}^0 - e_{i,s})^2 + a3_{i,s}(e_{i,s}^0 - e_{i,s})^3 \qquad (10)$$

where

$MC_{i,s}(e_{i,s})$	denotes the marginal abatement cost of sector *s* in region *i*,
$e_{i,s}^0$	is the business-as-usual emission level of sector *s* in region *i*,
$e_{i,s}$	is the emission level of sector *s* in region *i* at a CO_2 price equal to $MC_{i,s}(e_{i,s})$, and
$a1_{i,s}$, $a2_{i,s}$, $a3_{i,s}$	are the fitted coefficients in the marginal abatement cost function of sector *s* in region *i*.

Table 2 details projected business-as-usual (BaU) CO_2 emissions in 2020 together with emission reduction targets from 2020 BaU levels across model regions. We have derived the post-Kyoto reduction pledges for 2020 from national communications following the Copenhagen Accord (UNFCCC, 2009), of which the 15th Conference of Parties to the United Nations Framework Convention on Climate Change "took note". The Copenhagen Accord requested Annex I countries to submit their "quantified economy-wide targets for 2020" and the non-Annex I countries to announce their "nationally appropriate mitigating actions". All major economies of the world had submitted their pledges by spring 2010. The Appendix provides a detailed explanation on how we derived emission reductions targets for our model regions based on national communications to the Copenhagen Accord.

Table 2: Business-as-usual emissions in 2020 and emission reduction pledges

	2020 BaU emissions (in Mt CO_2)	Reduction pledge (in % from 2020 BaU emissions)
EU-27 (EUR)	4450	25.4
USA (USA)	5982	17.1
Canada (CAN)	675	22.7
Japan (JPN)	1219	35.2
Russian Federation (RUS)	1945	7.7
Australia (AUS)	491	24.7
China (CHN)	9417	5.0
India (IND)	1783	5.0
Brazil (BRA)	543	17.1
Mexico (MEX)	466	17.1
South Africa (ZAF)	502	17.1
South Korea (KOR)	617	17.1
Rest of the World (ROW)	7338	5.0

4. Policy Scenarios and Results

We use the numerical model to assess the prospects for expanding international emissions trading by regions and sectors.[15] Regions thereby behave in a Cournot-Nash manner as they seek for a best-response partitioning of their domestic emission ceilings between sectors that are covered through the ETS and the remaining sectors outside the ETS.

With respect to regional ETS coverage, we begin from a core coalition comprising the EU and the USA as major climate policy players in the industrialized world (coalition C1). The first expansion includes in addition Japan, Canada and Australia – Annex 1 countries that have planned or already implemented emissions trading systems at the domestic level (coalition C2). The next coalition (C3) adds Russia and OECD regions South Korea and Mexico. Inclusion of the key non-Annex B regions Brazil, India, China, and South Africa is captured through coalition C4. Finally, full global coverage is achieved through the addition of ROW representing all other world regions (CE-World). We do not, however, consider strategic

[15] The model code and the data to reproduce all simulation results are readily available from the corresponding author upon request.

behavior by ROW, accounting for the heterogeneity and the large number of embodied countries.

With respect to sectoral ETS coverage, we first consider the extreme case that no sector is included in the ETS. This setting is equivalent to exclusively domestic abatement without international emissions trading. In the next step (*ELE*) the power generation sector, which is by far the most important source of CO_2 emissions across all countries, can trade emission allowances internationally. Variant *EIS* adds the other energy sectors and all energy-intensive industries to the ETS reflecting the current coverage of the ETS in Europe (i.e., sectors COL, CRU, GAS, OIL and EIS in Table 1). We then sequentially add CO_2-intensive transport sectors (variants *OTP* and *WTP*) to the ETS, and furthermore consider the rest of industry (*ROI*) as a segment to be added to the ETS. The final addition to the ETS is made through final demand (variant *C*) which results in full coverage of domestic emissions by the ETS. In this variant *C* there is no possibility to undertake strategic partitioning and we thus obtain the outcome of competitive emissions trading.

Table 3: Regional and sectoral coverage of international emissions trading scenarios

Regional coverage (coalitions)		Sectoral coverage[a]	
No trade	None		None
C1	EU-27 + USA	*ELE*	ELE
C2	C1 + (Japan, Canada, Australia)	*EIS*	*ELE* + COL, CRU, GAS, OIL, EIS
C3	C2 + (Russia, South Korea, Mexico)	*OTP*	*EIS* + OTP
C4	C3 + (China, India, Brazil, South Africa)	*WTP*	*OTP* + WTP
CE-World	All regions	*ROI*	*WTP* + ROI
		C	*ROI* + C

[a] The variants of sectoral coverage are written in italics (e.g., *OTP*), whereas sectors are not (e.g., OTP). For instance, variant *OTP* comprises several sectors, where the OTP sector is the additional sector included in the ETS under this variant. Sectors are defined in Table 1.

Table 3 summarizes the dimensionalities of (international) emissions trading scenarios with respect to regional and sectoral coverage. The sequence of expanding trading by sectors and regions is motivated by our view of a pragmatic climate policy course. Clearly, the numerical results for individual countries are dependent on this sequence but – as will follow from our interpretation below – the more general economic insights will still prevail.

We report the implications of regional and sectoral expansion with respect to a no-trading scenario where each region complies with its specific emission reduction pledge through a domestic economy-wide CO_2 tax or likewise a comprehensive domestic cap-and-trade system without international emissions trading (this reference scenario corresponds to the settings “none” for regional coverage and “none” for sectoral coverage in Table 3 above).[16]

Let us first consider the effects of regional expansion. Figure 4 shows how the costs of complying with the national target are reduced vis-à-vis the no-trading case when a country is part of a coalition, and how these cost reductions change as the coalition expands. Sectoral coverage is then kept constant at variant *EIS* which reflects the actual coverage of the EU ETS. We see for instance that U.S. costs are reduced by 20% when joining a coalition with the EU (C1), with the cost reduction growing to 53% when Canada, Japan and Australia are also included (C2). However, when even more countries are included, U.S. compliance costs start to increase, and in the largest coalition there are only rather modest gains vis-à-vis the autarky for the USA. The reasoning behind is that the quota price changes depending on who is part of the coalition – if the quota price then becomes close to the autarky quota price, there is little to gain from external trade.

Note that Russia, China and India see their costs turn into a net gain when they join the international emissions trading scheme since the revenues from permit exports more than offset their abatement costs. The cost reductions for these countries in Figures 4, 7 and 8 are measured along the right-hand axis (RH). For instance, the cost reduction of 1800% for Russia under coalition C3 means that the abatement costs without international emissions trading have turned into a gain that is 17 times as large as the original costs (note that the latter are rather small).

[16] For the no-trading benchmark scenario the CO_2 taxes, quota prices or likewise marginal abatement costs amount to (in USD per ton of CO_2): EUR 75.5, USA 25.9, CAN 57.4, JPN 326.8, RUS 5.9, AUS 41.3, CHN 4.2, IND 4.7, BRA 95.7, MEX 48.5, ZAF 8.5, KOR 30.4, and ROW 5.4.

Figure 4: Accumulated cost reductions by expanding the coalition (variant *EIS*)

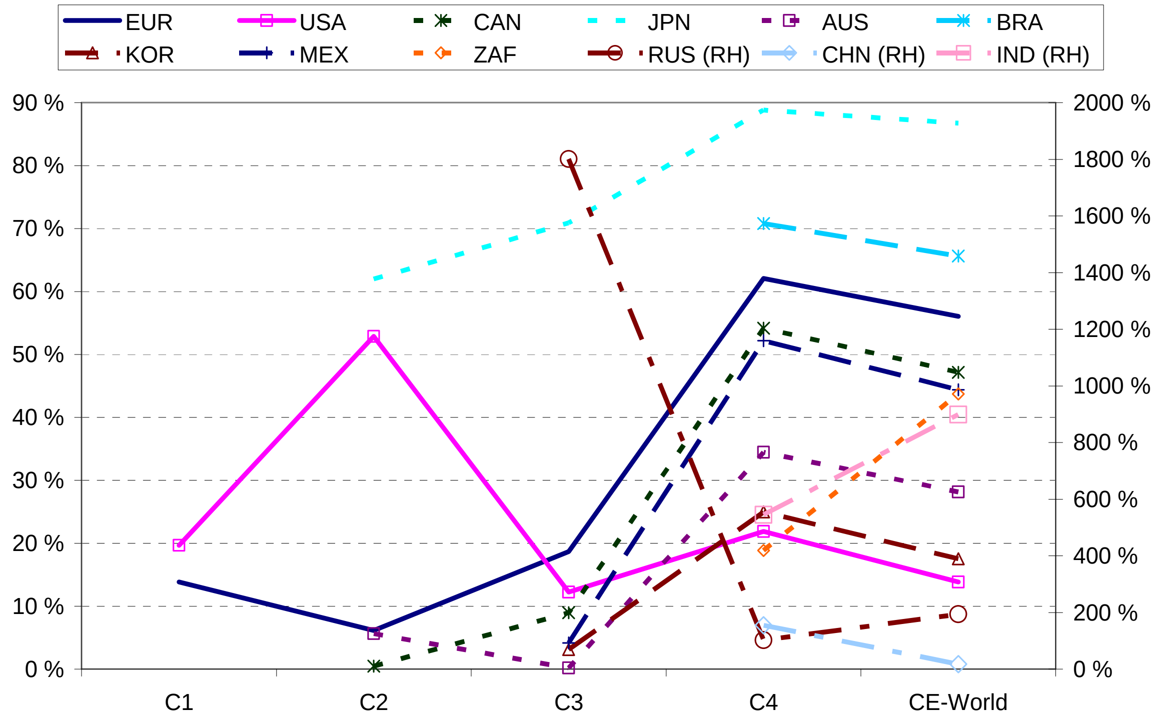


Figure 4 also illustrates that there will be opposite interests among current coalition members whether to invite new countries into the coalition or not. Again, this is related to the direction in which the quota price will change, and which countries are importers and which are exporters. For instance, the USA (exporter of quotas) will oppose new members after Canada, Japan and Australia are included, because this would drive down the quota price, whereas the other countries (importers of quotas) would like to include new members. Thus, it may be difficult to agree upon an expansion of the ETS in the direction of new coalition members.

Figures 5 through 8 show – for a given coalition – how the costs are reduced when going from no-trading to international permit trading between electricity sectors only, and then further expanding the sectoral coverage of the ETS. First, we see that the biggest cost reductions already occur when opening for permit trade through a sufficiently large emission-intensive sector such as the electricity sector (variant *ELE*). Nevertheless, there are still some cost reductions to be gained from expansion towards full coverage (*C*), indicating that there is some non-negligible strategic behavior. Aggregate costs are reduced by respectively 4%, 4%, 2% and 10% in coalitions C1, C2, C3 and C4 when going from *ELE* to full coverage. For individual countries such as Japan and Brazil, the cost reductions are even higher (16% and 19% in C4).

Although cost savings usually increase with coverage, it is possible for countries to lose from sectoral expansion of the trading scheme, as pointed out in Section 2. For instance, in coalition C2, the USA loses when the two last sectors are added to the trading scheme (variants *ROI* and *C*). In coalition C3, the USA is best off with either only the electricity sector included (*ELE*) *or* with all sectors but final demand (variant *ROI*) included in the ETS. Several countries achieve their largest cost reductions (or their highest overall gains) when *only ELE* is included in the trading scheme. These are in particular Australia in coalition C2, and Russia, China, India and South Africa in coalition C4.

The impacts of sectoral expansion are generally largest when the coalition is small (the strategic influence of a single country falls as the coalition expands). This is particularly evident from the approximately horizontal curves in Figure 7 (coalition C3) to the right of *ELE*. However, we notice some dramatic changes with the largest coalition in Figure 8, especially when we expand the ETS from *ELE* to *EIS*. In order to explain this, remember that China joins the coalition in C4. Chinese emissions are very large, with low abatement costs and only modest cutbacks (see Table 2). Thus, China is a dominant supplier of permits in C4, accounting for 77% of permit sales when all sectors are included in the ETS. Hence, the country has significant strategic incentives to cut back on the sales of permits.

Further, China's strategic power declines substantially when expanding from *ELE* to *EIS*. The reasoning behind is that the energy-intensive sector in China has both large emissions and low abatement costs which warrants significant strategic power for the case that the energy-intensive sectors remain part of the non-trading segment (cf. section 2). As an indicator of this, Chinese exports of permits under *ELE* account for 69% of permit sales (versus 75-77% with more sectors included). We notice from Figure 8 that India, Russia and South Africa – all the three being permit exporters – gain relatively more than China as they can free ride on China's export restraint which leads to relatively high permit price under *ELE* (see Figure 12 below). In absolute terms, however, China gains more than Russia and South Africa and almost as much as India.

Figure 5: Accumulated cost reductions by adding more sectors (coalition C1)

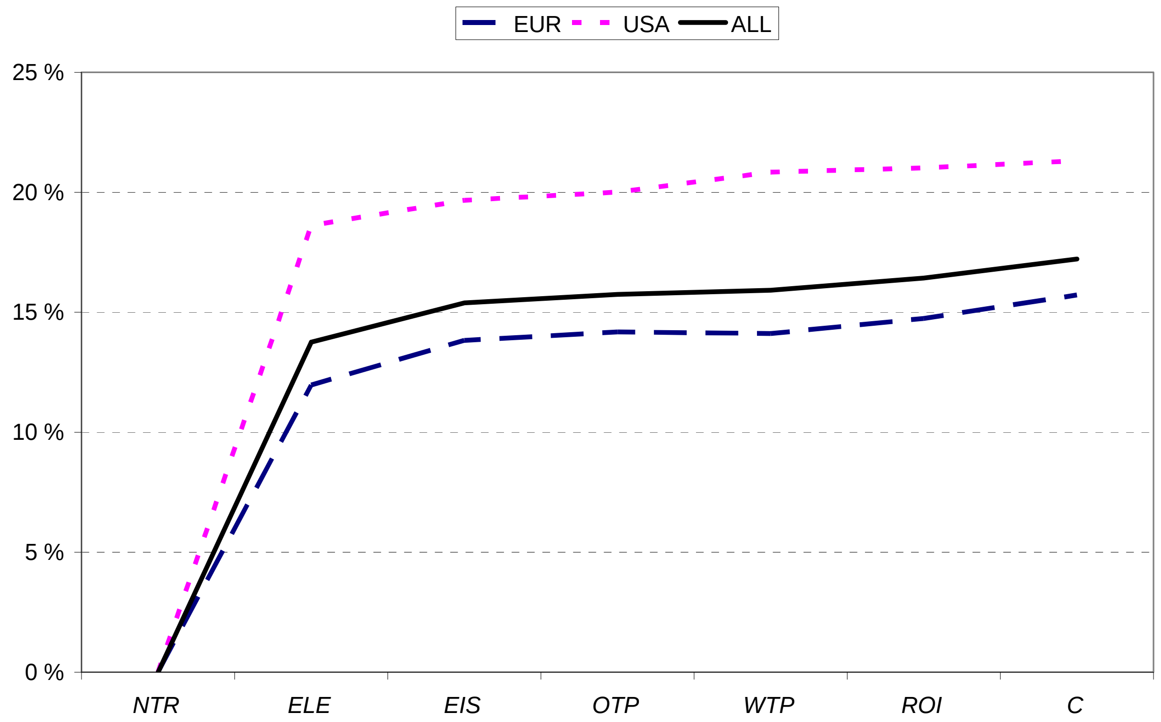


Figure 6: Accumulated cost reductions by adding more sectors (coalition C2)

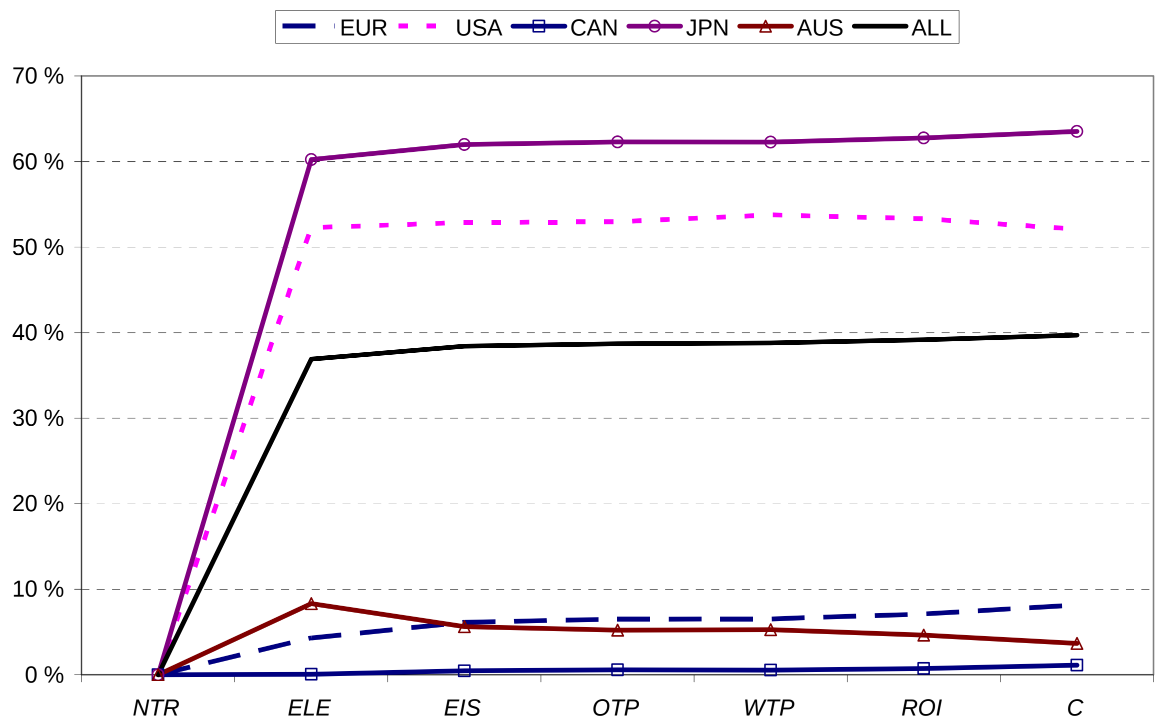


Figure 7: Accumulated cost reductions by adding more sectors (coalition C3)

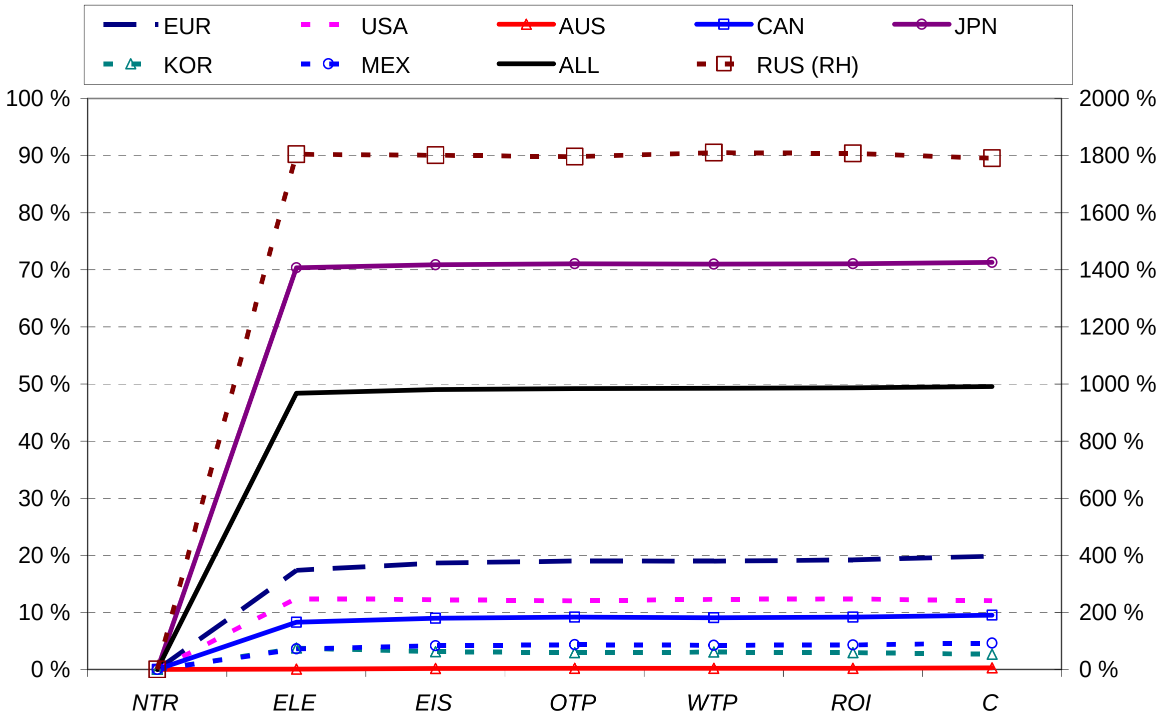
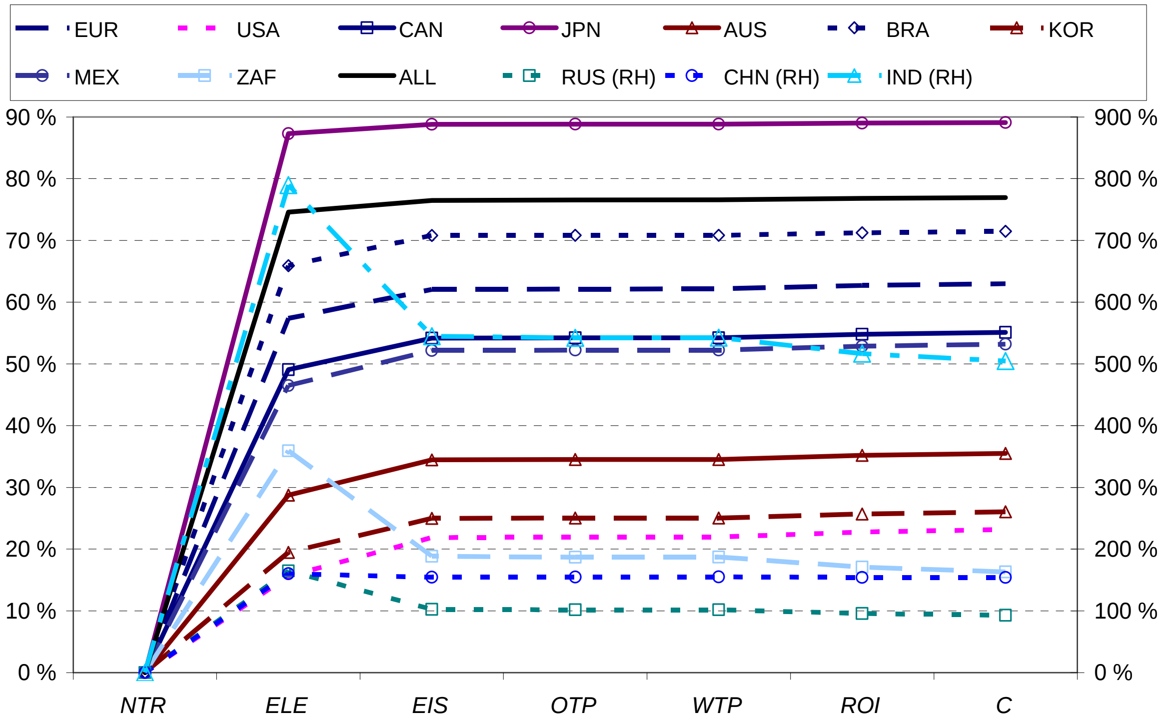


Figure 8: Accumulated cost reductions by adding more sectors (coalition C4)



Figures 9 through 12 show how the ETS-price for the trading segment and the Non-ETS price (i.e., the marginal abatement costs) for the non-trading segment develop in the different coalitions when the sectoral coverage expands. First of all, we see that the ETS price increases when going from coalition C1 to C2, and then falls as we further expand towards coalitions C3 and C4. This is consistent with the changes in U.S. costs shown in Figure 4 – the USA is an exporter of quotas and therefore prefers higher quota prices. Furthermore, we notice that there are substantial differences in Non-ETS prices across countries within a coalition, revealing significant strategic behavior in all coalitions. For instance, in coalition C2 the Non-ETS price is more than two times higher in Japan and the EU than in the USA (under *ELE*). As expected, the Non-ETS prices converge towards each other and towards the ETS price as sectoral coverage expands.

In Figure 12 we see that the Non-ETS price in Brazil is particularly high under *ELE* and then almost halved when expanding to *EIS*. The explanation for this is that Brazil has adopted quite ambitious emission reduction pledges *and* that its electricity sector has rather low emissions (compared to other countries). Hence, Brazil would prefer to allocate a negative number of permits to its ETS sector in order to reduce the marginal abatement costs in the non-trading segment. As we do not allow for negative allocation in our simulations, the Non-ETS price for Brazil becomes particularly high under *ELE*.

Finally, we observe that in all four coalitions with incomplete regional coverage (C1-C4) the ETS price falls when sectoral coverage expands. The exporters are thus more able to play strategically in order to raise the quota price compared to the cost-effective solution (i.e., under *C* when all sectors are included). This result echoes our theoretical prediction from Section 2, stating that exporters in general will tend to have stronger strategic power than importers. In addition, exporters tend to be bigger emitters than importers in our simulations (e.g., USA in C2, USA and RUS in C3 and CHN in C4).

Figure 9: Non-ETS prices and ETS price (coalition C1)

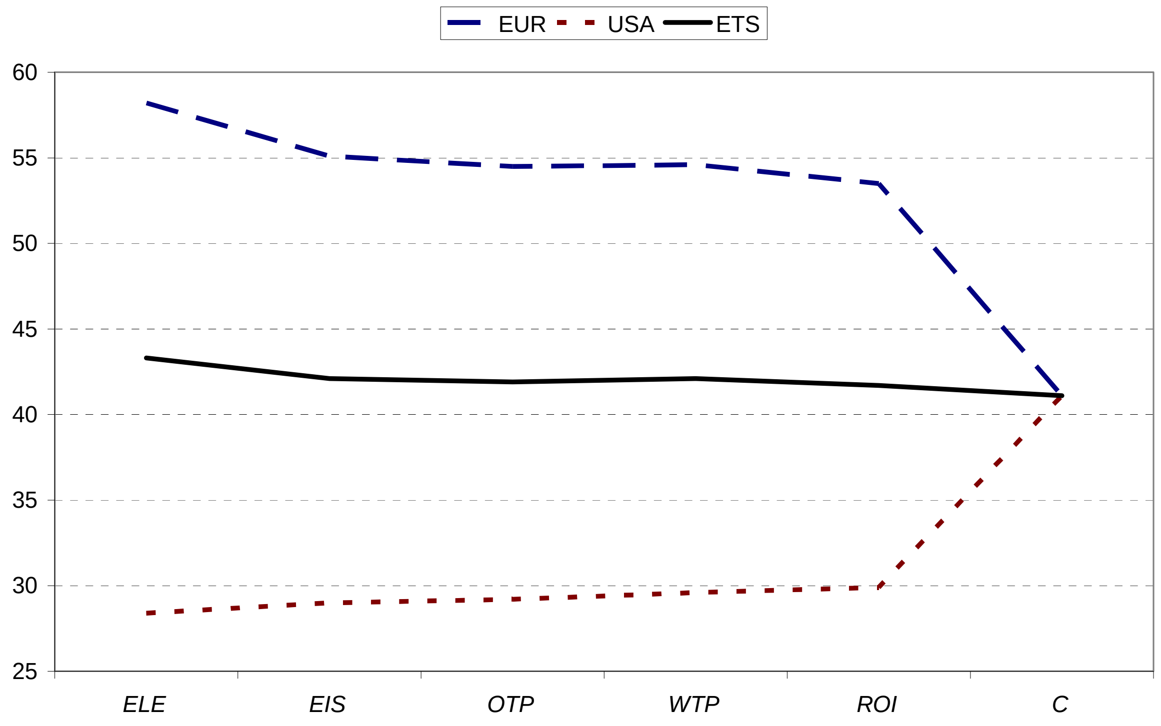


Figure 10: Non-ETS prices and ETS price (coalition C2)

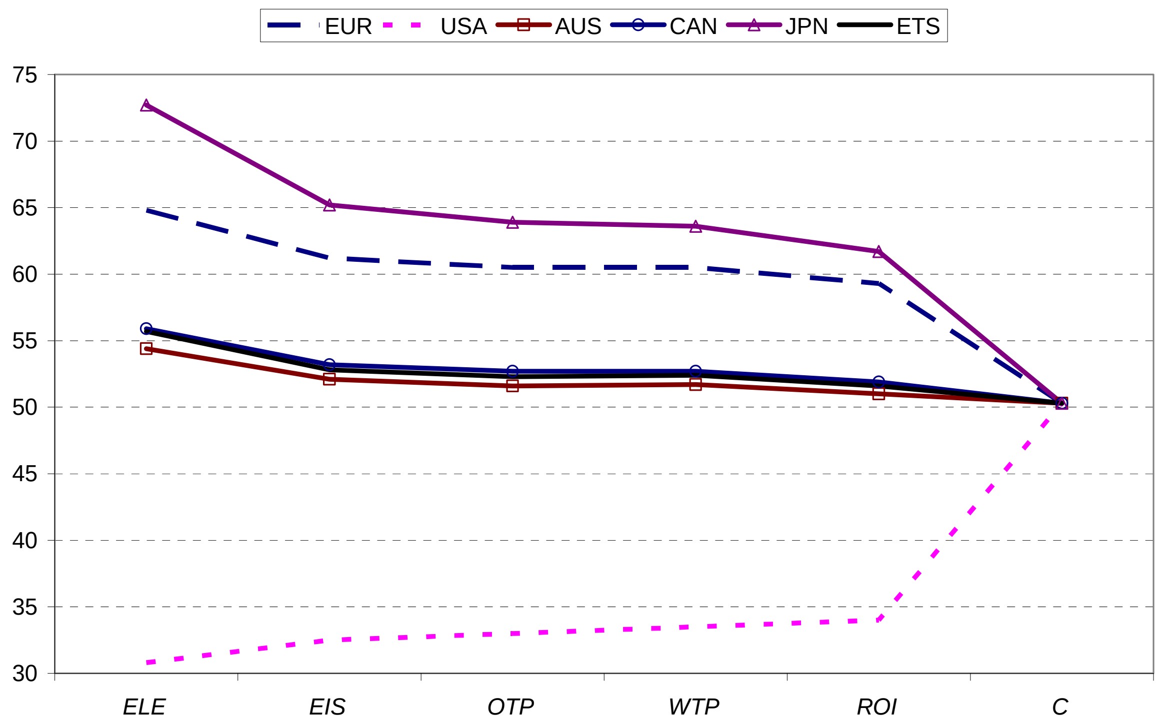


Figure 11: Non-ETS prices and ETS price (coalition C3)

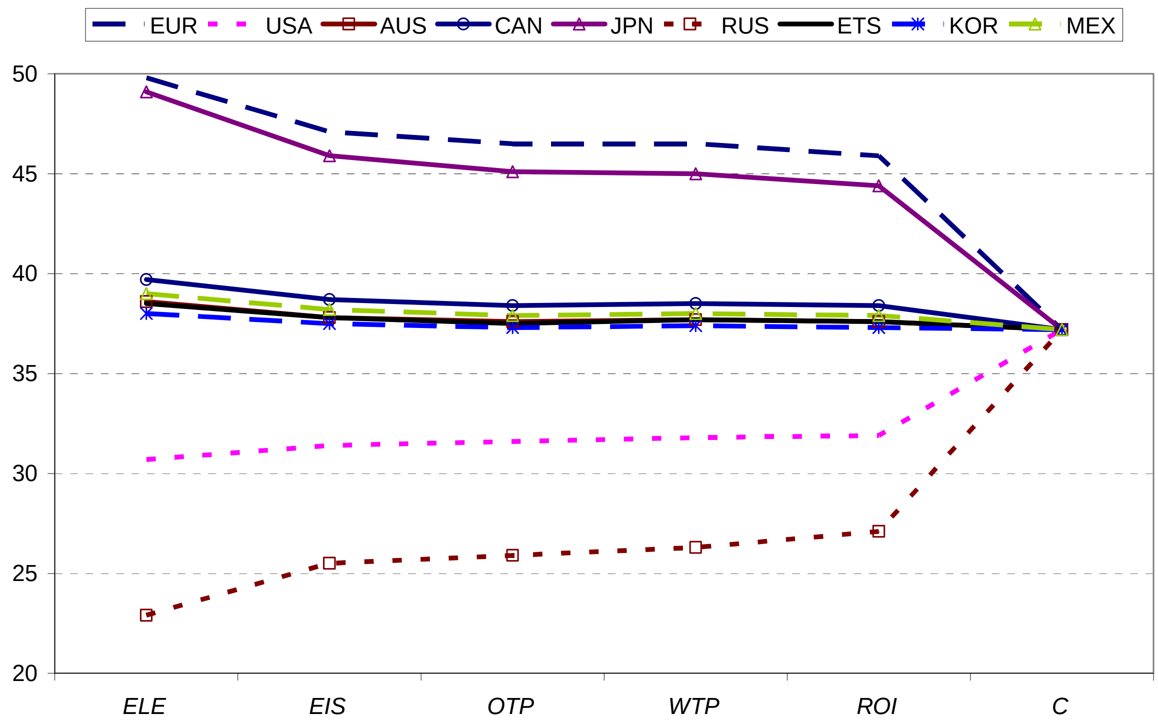


Figure 12: Non-ETS prices and ETS price (C4)

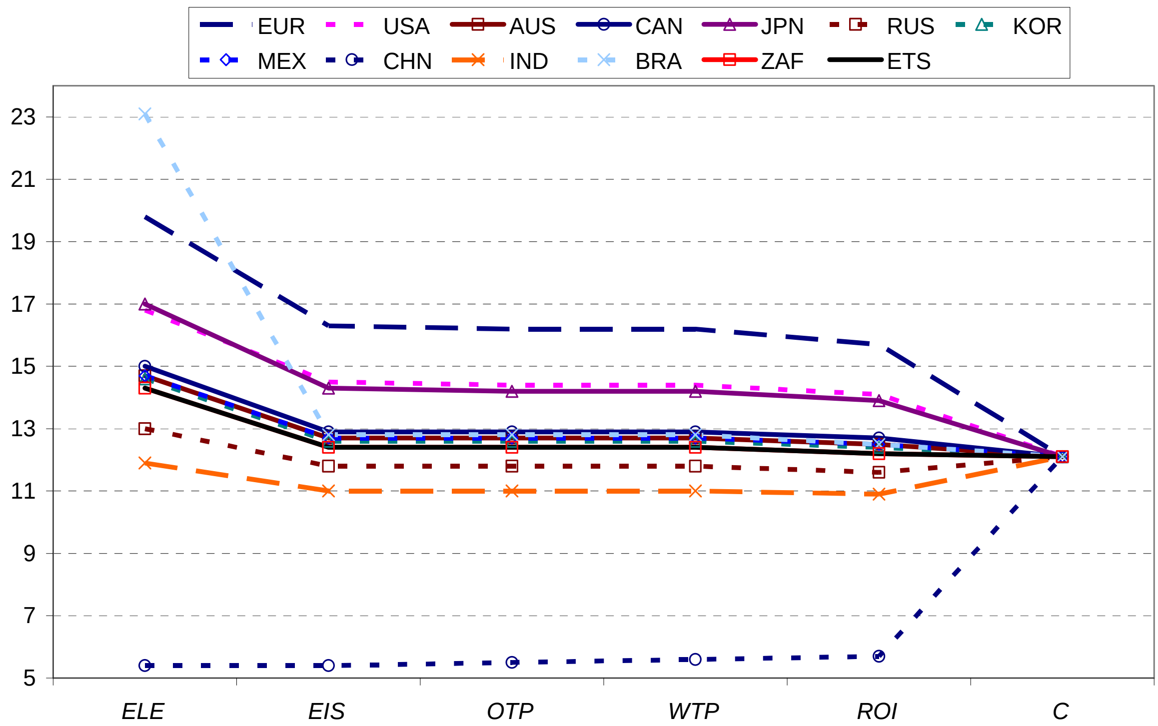
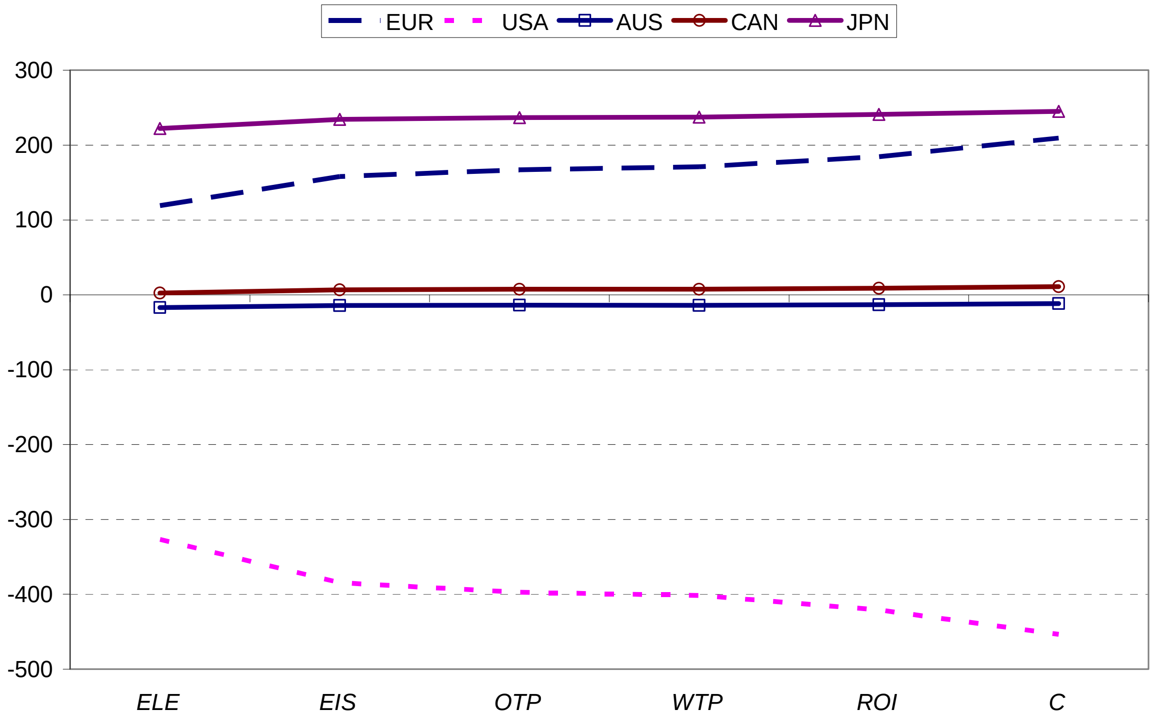


Figure 13 shows how trade in allowances evolves under coalition C2 when sectoral coverage expands.

Figure 13: Trade in allowances (coalition C2)



We notice that gross trade increases, or in other words: With only some sectors included, exporters have incentives to export fewer allowances in order to raise the price, whereas importers have incentives to import fewer allowances. This is especially true for big players, and we see that the USA changes trade volumes most, consistent with the change in ETS price discussed above.

5. Conclusion

Where-flexibility of emission abatement through international emissions trading is perceived as a crucial element of climate policy to reduce overall costs (and thereby increase political feasibility) of effective climate protection. In this vein, already the Kyoto Protocol dating back to 1997 calls for the use of flexible instruments.[17] So far, however, cap-and-trade systems are regionally separated with the EU ETS being the only scheme where international

[17] With regard to where-flexibility the Kyoto Protocol allows for the use of three flexible instruments: (i) international emissions trading (IET) between Annex B countries; (ii) joint implementation (JI) between Annex B countries; and (iii) the Clean Development Mechanism (CDM) between Annex B countries and non-Annex B countries.

emissions trading takes place across multiple jurisdictions. Apart from limited regional coverage, trading schemes are in general also restricted to energy-intensive industries in terms of sectoral coverage. As a prime example the EU ETS covers only around 40% of overall EU greenhouse gas emissions.

Given the limitations in regional and sectoral coverage of actual trading schemes there is broad consensus among climate policy makers to push for increased coverage in order to exploit the cost savings potentials of comprehensive where-flexibility. Yet, the feasibility of overall cost savings might be seriously hampered through opposed incentives from the perspective of individual countries.

In this paper we have investigated the economic implications of regional and sectoral expansion of international emissions trading in a policy setting where individual countries are bound to emission reduction pledges under the Copenhagen Accords but incomplete sectoral coverage provides scope for strategic behavior to manipulate the international emission price.

With our integrated theoretical and applied analysis we shed some light on the economic incentives at stake when climate policy makers contemplate the regional linkage and sectoral expansion of emission trading regimes.

As to regional expansion our results illustrate that the interests of quota exporters and importers are usually opposed when including more countries into the trading scheme. The exporters would like to let in more potential importers, which would raise the quota price, while the importers would like to let in more potential exporters to depress the quota price.

When expanding sectoral coverage for a given trading coalition of countries, the highest cost reductions generally come from the first step: going from “No trade” to a trading scheme that includes one sector with a sufficiently large emission share (in our case: the electricity sector). When sectoral coverage is expanded, a country usually gains, however we identify several cases in our numerical simulations where countries lose. This happens because sectoral expansion makes the marginal abatement costs in the remaining non-trading segment of these countries less elastic, so that they are less able to manipulate the quota price in their preferred direction. The USA and Russia are the countries that most frequently experience a loss from sectoral expansion of the trading scheme.

The economic impacts of sectoral expansion are more substantial when the coalition is small, because an individual country has more market power in a smaller coalition. However, including China into the coalition means that a particularly large player joins the carbon market, implying significant strategic effects if the trading scheme only covers the electricity sector. Sectoral expansion reduces the quota price in all our simulations, consistent with our theoretical prediction. This implies that – as a group – exporters have more market power than importers, but their influence decreases when more sectors are added to the scheme.

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Appendix: Specification of emission reduction targets

In this appendix, we explain how we have transformed the Copenhagen pledges for 2020 to effective reductions in emissions from their 2020 business-as-usual (BaU) levels (cf. Table 2).

As shown in Table A1, most of our model regions have stated their pledges in terms of an absolute reduction in greenhouse gas emissions. Only China and India have adopted pledges in relative terms, promising to reduce their emissions per unit of GDP. The base year from which the reduction should be measured varies from 1990 to 2020 (business-as-usual).

Six regions have provided a range of emission reduction targets. As a general rule, we choose the lower bound of the range. For Russia, China and India, however, the lower bound does not require any emission reduction in 2020. We therefore use the upper bound of the range instead. For China and India, even the higher bound of their Copenhagen pledge would not require any emission reduction compared to BaU in 2020. Here we take the view that these countries would come under pressure from other countries to at least undertake some effective emission reduction, which we set at 5% below BaU emission levels. We also assume that the countries that we do not model individually (the rest of the world) would reduce emissions by on average 5%.

In contrast to China and India, the other developing countries that we model have made very ambitious pledges committing them to larger emission reductions than most OECD countries. We argue that these pledges are not particularly credible. Thus, we replace them by the percentage reduction of the OECD country with the weakest target (in percentage terms compared to 2020 BaU emissions) –the USA with a reduction target of 17.1%.

Note that Table A1 shows the calculated emission reductions according to the Copenhagen pledges, i.e., before our adjustments. Our adjusted emission reduction pledges that we use in the model simulations are shown in Table 2 in the main text. In our numerical simulations we only capture CO_2 emissions, thereby assuming that the CO_2 emission reductions will be proportional to the overall greenhouse gas emission reductions.

Table A1: Calculation of emission reduction targets based on Copenhagen pledges

Region	Reduction pledge	Variable	Base year	Base year value	2020 BaU value	2020 reduction
EUR[l]	20 – 30%	GHG	1990	4149	4450	1131
USA	17%	GHG	2005	5975	5982	1023
CAN	17%	GHG	2005	629	675	153
JPN	25%	GHG	1990	1054	1219	429
RUS[u]	15 – 25%	GHG	1990	2393	1945	150
AUS[l]	5 – 25%	GHG	2000	359	464	123
CHN[u]	40 – 45%	GHG/GDP	2005	2.428	1.323	0
IND[u]	20 – 25%	GHG/GDP	2005	1.480	0.827	0
BRA[l]	36.1–38.9%	GHG	BaU	543	543	196
MEX	30%	GHG	BaU	466	466	140
ZAF	34%	GHG	BaU	502	502	171
KOR	30%	GHG	BaU	617	617	185

Sources: EIA (2009), UNFCCC (2010a,b)

Notations:

l: Lower bound of the reduction pledge range;

u: Upper bound of the reduction pledge range

Variable: GHG = Greenhouse gas emissions; GHG/GDP = Greenhouse gas emissions per unit of GDP

Base year: BaU = 2020 business-as-usual

Base year value, 2020 BaU value: Mt CO_2/GDP in billion 2005 USD for CHN, IND; Mt CO_2 for all other regions

2020 reduction: Mt CO_2

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