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Developing Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis

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Non-technical summary

The most prominent instrument of current European climate policy is the EU Emissions Trading Scheme (ETS) which is operating at the installation level in a "warm-up" phase since 2005. More recently, the EU has proposed to strengthen the European ETS by linking the scheme to emerging trading systems beyond Europe in order to more cost-efficiently achieve its climate policy objectives. At the same time, countries like Canada, Japan or Australia are considering the set up of domestic ETS with the intention of linking up to the European scheme. The EU ETS may thus form the nucleus for a gradually expanding company-based emissions trading system at the global level. Given the coexistent EU priorities with respect to competitiveness of European industries and international emissions regulation at the company level, this paper assesses the efficiency and competitiveness implications of linking the EU ETS to emerging trading schemes outside Europe.

Employing both economic theory and a large-scale computable general equilibrium model of the global economy, in this paper we (i) analytically derive the efficiency aspects of integrating emissions trading schemes from a partial market perspective, (ii) numerically analyze the aggregate welfare impacts of linking the EU ETS and (iii) explicitly assess the economy-wide and sectoral competitiveness effects of developing supra-European emissions trading schemes in the year 2020.

While a stylized partial-market analysis suggests that the integration of trading systems is always beneficial in efficiency terms, our applied general equilibrium approach shows that the aggregate welfare impacts of linking the EU ETS are rather limited. We further find that the trade-based competitiveness effects of linking the European ETS crucially depend on the linked trading system: Although EU economy-wide competitiveness varies only moderately across linking scenarios, the sectoral decomposition of these aggregate effects shows that European industries are much more sensitive to the linking constellation. Regarding the international trade impacts for non-EU countries, we find that the linking candidates have very heterogeneous incentives to join the European trading system, which range from pronounced competitiveness improvements for Canada to substantial competitiveness losses for Japan. Our sensitivity analysis assuming a stricter allowance allocation within regional trading systems suggests, however, that a more efficient design of domestic ETS can boost the overall prospects for establishing supra-European emissions trading schemes.

Developing Supra-European Emissions Trading Schemes:

An Efficiency and International Trade Analysis

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Abstract. Given the coexistent EU priorities concerning the competitiveness of European industries and international emissions regulation at the company level, this paper assesses the efficiency and competitiveness implications of linking the EU Emissions Trading Scheme (ETS) to emerging trading schemes outside Europe. Currently, countries like Canada, Japan or Australia are contemplating the set up of domestic ETS with the intention of linking up to the European scheme. While a stylized partial-market analysis suggests that the integration of trading systems is always beneficial in efficiency terms, our applied general equilibrium approach shows that the aggregate welfare impacts of linking the EU ETS are rather limited. We further find that the trade-based competitiveness effects of linking the European ETS crucially depend on the linked trading system: Although EU economy-wide competitiveness varies only moderately across linking scenarios, the sectoral decomposition of these aggregate effects shows that European industries are much more sensitive to the linking constellation. Similarly, the incentives for non-EU regions to join the European system display considerable heterogeneity. A stricter allowance allocation within domestic ETS can, however, substantially improve the overall prospects for establishing supra-European emissions trading schemes.

JEL Classification: D58, H21, H22, Q48

Keywords: Emissions Trading, EU ETS, Linking, Competitiveness, CGE model

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1 Introduction

In March 2000, the European Council agreed at the Lisbon summit to make the European Union (EU) the most competitive economy of the world (EU, 2000). At the same time, the EU pursues ambitious climate policies in order to fulfil its emissions reduction targets under the Kyoto Protocol and to limit global climate change to two degrees Celsius in the long run (UNFCCC, 1997; EU, 2007a).

The most prominent instrument of current European climate policy is the EU Emissions Trading Scheme (ETS) which is operating at the installation level in a “warm-up” phase since 2005 (EU, 2003). Thereby, the EU has established a flexible climate policy instrument at the company level independently of the Kyoto Protocol (facilitating both international emissions trading between Annex B governments and project-based emissions reductions in developing countries via the Clean Development Mechanism, CDM). More recently, the EU has proposed to strengthen the European ETS by linking the scheme to emerging trading systems beyond Europe in order to more cost-efficiently achieve its climate policy objectives (EU, 2007a). The EU ETS may thus form the nucleus for a gradually expanding company-based emissions trading system at the global level. Reflecting the coexistent EU priorities concerning the competitiveness of European industries and international emissions regulation at the company level, this paper presents an efficiency and international trade analysis of future supra-European emissions trading schemes.

At present, several non-EU countries are contemplating the set up of domestic ETS at the national and regional level with the intention of linking up to the European scheme. In the short run, the already mature emissions trading schemes of Norway and Switzerland – which are designed similarly to the EU ETS – can be expected to be linked to the European system (Sterk, 2005) until 2010. In the mid-term perspective up to 2020, several parties having ratified the Kyoto Protocol – such as Canada, Japan and the Russian Federation – may also have incentives to join the EU ETS: Canada is already promoting the Large Final Emitter System to cover energy-intensive companies accounting for almost 50 percent of total Canadian greenhouse gas emissions (CEPA Environmental Registry, 2005). Japan has started the Pilot Project of a Domestic Emissions Trading Scheme on a voluntary basis, with circa 30 private companies participating in the program (Japanese Ministry of the Environment, 2004). Moreover, initial exploratory discussions on the potential linkage of trading schemes have already been held between the EU, Canada and Japan (EU, 2005; EU-Japan Centre for Industrial Cooperation, 2006). Also Russia may have incentives to develop a domestic emissions trading system in order to be linked to the European scheme and to exploit a larger market for the sale of excess emissions permits, so-called “Hot Air”. Finally, linking the EU ETS to emerging schemes in Australia and the United States – which have so far not ratified the Kyoto-Protocol – could be considered as a first step in integrating both countries into an international climate policy regime. Indeed, Australia and United States are already promoting domestic emissions trading schemes: In the U.S., the Regional Greenhouse Gas Initiative – being pushed by nine Northeast and Mid-Atlantic states – aims at establishing a regional trading system (RGGI, 2006). In Australia, the New South Wales Greenhouse Gas Abatement Scheme is already operating at the state level (New South Wales Government, 2006) and most recently, Australian state premiers have released initial proposals for a national cap and trade system starting in 2010 (Point Carbon, 2006). To sum up, there are strong signals for emissions trading schemes to be established in non-EU countries and to be potentially linked to the European scheme by 2020.

Previous quantitative economic analyses have focused on efficiency aspects (see e.g. Böhringer et al., 2005) and competitiveness implications of the current European trading scheme (Kemfert et al., 2005; Klepper and Peterson, 2004; Peterson 2006a) in applied partial and general equilibrium frameworks. However, only Peterson (2006b) addresses the competitiveness implications of EU emissions regulation explicitly by employing a trade-based competitiveness indicator. Regarding the linkage of the European ETS to emerging schemes outside Europe, a first economic impact assessment is presented by Anger (2006) within a partial equilibrium modelling framework. Further contributions examine economic and institutional aspects of linking the EU ETS internationally in a qualitative manner only (Kruger et al., 2007; Sterk et al, 2006; Blyth and Bosi, 2004). Against this background, the contribution of this paper is threefold: Employing both economic theory and a large-scale computable general equilibrium model of the global economy, we (i) analytically derive the efficiency aspects of integrating emissions trading schemes from a partial market perspective, (ii) numerically analyze the aggregate welfare impacts of linking the EU ETS and (iii) explicitly assess the economy-wide and sectoral competitiveness effects of developing supra-European emissions trading schemes in the year 2020.

This article is structured as follows: Section 2 lays out the theoretical background of our analysis. In section 3, we present the numerical framework underlying our quantitative impact assessment. Section 4 introduces policy scenarios of linking the EU ETS internationally. Section 5 summarizes our quantitative simulation results. In section 6, we conclude.

2 Theoretical background

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

Following the stylized framework of Anger (2006), R regions are assumed ($r=1,...,R$) to commit to individual emissions targets (e.g. targets under the Kyoto Protocol), yielding an absolute emissions budget $\overline{E}_r$ for each region. Abatement costs of those sectors covered by a domestic emissions trading scheme (in the following referred to as *ETS* sectors) and the remaining non-covered sectors (in the following referred to as *NETS* sectors) in each region are denoted by $AC_r^{ETS}(e)$ and $AC_r^{NETS}(e)$, respectively. Abatement cost functions are decreasing, convex and differentiable in emissions e. Total abatement costs $AC_r(E_r)$ are the sum of the sectoral costs $AC_r^{ETS}(e_r^{ETS})$ and $AC_r^{NETS}(e_r^{NETS})$.

For all regions – with binding emissions targets (such as Annex B parties of the Kyoto Protocol) and without any commitments (such as CDM host countries) – cost minimization and profit maximization with respect to e_r^{ETS} and e_r^{NETS} yields the following first-order condition:

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

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

2.1 An international emissions trading scheme

We consider an international emissions trading scheme consisting of two regions, 1 and 2. Interregional trading of emissions permits is feasible only for a segment of each economy, i.e.

only for the *ETS* sectors covered by the trading system.[1] We denote $\overline{e_r^{ETS}}$ the regional emissions target for *ETS* sectors, i.e. an assigned emissions cap or the number of allocated permits. Figure 1 illustrates the efficiency implications from trading emissions – in the absence of the CDM – in terms of compliance costs for the fulfillment of the regional emissions targets. The figure presents the corresponding economic impacts for the *ETS* sectors of the two regions that have (for simplicity linear) marginal abatement costs $MAC_1^{ETS}(e_1^{ETS})$ and $MAC_2^{ETS}(e_2^{ETS})$ depending on regional emissions levels. We assume higher marginal abatement costs for region 1 than for region 2, equal maximum emissions for the two regions and equal regional emissions targets for the covered *ETS* sectors, amounting to 50 percent of their maximum emissions.

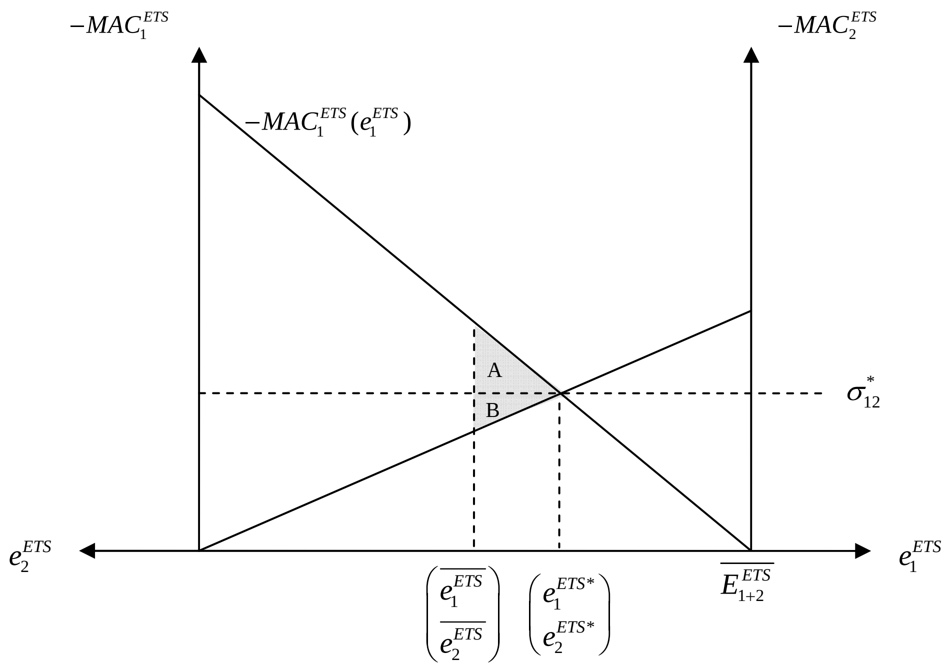

Figure 1: Sectoral efficiency gains in an international emissions trading scheme

According to Figure 1, the initial regional allocation of emissions permits $(\overline{e_1^{ETS}}, \overline{e_2^{ETS}})$ to the covered *ETS* sectors, corresponding to a total emissions ceiling of $\overline{E_{1+2}^{ETS}}$, implies economically inefficient regional emissions levels as the associated marginal abatement costs differ between

[1] Anger (2006) shows that such a sectoral restriction of international emissions trading coupled with a generous allocation of emissions permits can cause large inefficiencies.

the two regions. By means of international emissions trading, the high-cost (low-cost) region 1 (2) imports (exports) emissions permits from (to) the other region, thus increasing (reducing) its emissions. The resulting international permit price σ_{12}^{*} equalizes marginal abatement costs and yields the optimal emissions levels $\left(e_1^{ETS*}, e_2^{ETS*}\right)$. As a consequence, international trading activities generate efficiency gains both for region 1 – due to avoided abatement costs exceeding permit import costs (equal to area A) – and for region 2 – due to larger permit export revenues than associated abatement costs (equal to area B).

2.2 Linking of alternative trading schemes

We extend the bilateral perspective of Figure 1 by introducing an additional region that may be linked to the joint trading scheme of region 1 and 2 (both regions have the same characteristics as in Figure 1). Hereby, we distinguish the following two cases: linking to a high-cost region (3) with marginal abatement costs $MAC_3^{ETS}(e_3^{ETS})$ and linking to a low-cost region (4) with marginal abatement costs $MAC_4^{ETS}(e_4^{ETS})$. Both regions are assumed to exhibit the same maximum amount of emissions as the joint scheme of region 1 and 2. Analogously to the existing trading system, the linking candidates restrict emissions trading to their *ETS* sectors which face identical emissions targets $\overline{e_3^{ETS}}$ and $\overline{e_4^{ETS}}$ amounting to 50 percent of their maximum emissions. These ceilings correspond to the overall emissions target of the existing trading scheme $\overline{E_{1+2}^{ETS}}$ which features an aggregate marginal abatement cost function $MAC_{1+2}^{ETS}(E_{1+2}^{ETS})$. Figure 2 illustrates the efficiency aspects for *ETS* sectors of linking an additional region to the existing trading scheme of region 1 and 2.

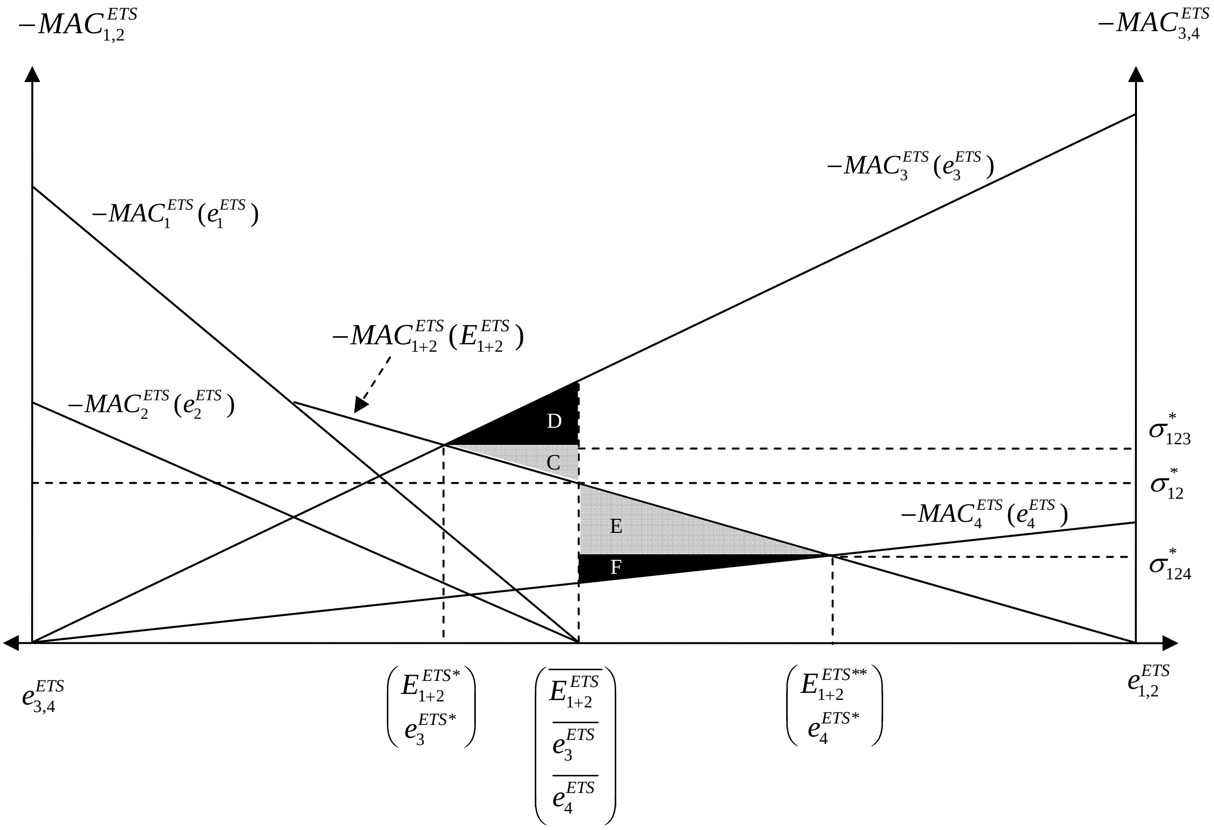

Figure 2: Additional efficiency gains from linking emissions trading schemes

In the case of linking the high-cost region 3 to the existing trading scheme, we observe that the initial allocation of emissions permits $\overline{E_{1+2}^{ETS}}$ and $\overline{e_3^{ETS}}$ to the covered *ETS* sectors again implies economically inefficient regional emissions levels. However, by means of international emissions trading the higher-cost region 3 may import permits from the lower-cost existing scheme, yielding an increased international permit price of σ_{123}^* as compared to σ_{12}^* and optimal emissions levels $(E_{1+2}^{ETS*}, e_3^{ETS*})$ with equalized marginal abatement costs. Compared to the initial allocation, in the new equilibrium region 3 increases its emissions while the existing scheme reduces pollution by the same amount. Thus, emissions trading activities induce efficiency gains for both the existing scheme (equal to area C) and region 3 (equal to area D).

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

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

3 Numerical framework

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

3.1 Modelling approach

In order to quantify the macroeconomic impacts of linking the EU ETS to emerging trading schemes outside Europe, it is crucial to account for complexities such as detailed production structures and market interactions. Computable general equilibrium (CGE) models have become the standard tool for applied economy-wide analysis of policy measures (for surveys on applications to environmental policies see Conrad 1999, 2001). The main virtue of the CGE approach is its comprehensive representation of price-dependent market interactions based on rigorous microeconomic theory. The simultaneous explanation of the origin and spending of agents' incomes makes it possible to address both economy-wide efficiency and distributional impacts of policy interference.

For our numerical analysis, we build on the *PACE* model (*Policy Assessment based on Computable Equilibrium*), a large-scale CGE model of international energy use and global trade (Böhringer and Vogt, 2003). In order to conduct an international trade analysis and assess the corresponding competitiveness effects of linking the EU Emissions Trading Scheme, we adapt the core PACE model by explicitly modelling export flows and prices.

The model reflects the key features of the European ETS and emerging non-EU trading schemes from a single country perspective: EU Member States and countries with domestic ETS outside Europe (linking candidates) are committed to specific carbon emissions constraints $\overline{CO2}$ which are agreed upon (e.g. under the Kyoto Protocol). Each of these countries must specify a cap $\overline{E}$ and the allocation rule for free emissions allowances to energy-intensive installations in six downstream sectors that are eligible for international emissions trading (electricity, oil refineries, iron and steel, non-ferrous metals, mineral industries and paper and pulp production). Assuming that the EU and non-EU emissions trading systems cover only energy-intensive industries implies that complementary domestic abatement policies are necessary for the non-covered sectors in order to comply with the remaining national emissions budget $\left(\overline{CO2}-\overline{E}\right)$.

Figure 3 provides a diagrammatic structure of the generic open-economy model. A representative agent RA_r in each region r is endowed with three primary factors: labour $\overline{L}_r$, capital $\overline{K}_r$, and fossil-fuel resources $\overline{Q}_{ff,r}$ (used for fossil fuel production). The representative agent maximizes utility from consumption of a composite good C_r which combines demands for energy and non-energy commodities at a constant-elasticity-of-substitution (CES). Production Y_{ir} of commodities i in region r is captured by nested separable CES functions that describe the price-dependent use of capital, labour, energy and material in production. Carbon emissions are linked in fixed proportions to the emissions-relevant use of fossil fuels through carbon coefficients which are differentiated by the specific carbon content of fuels. Carbon abatement, thus, can take place by fuel switching or energy savings in production and final consumption.

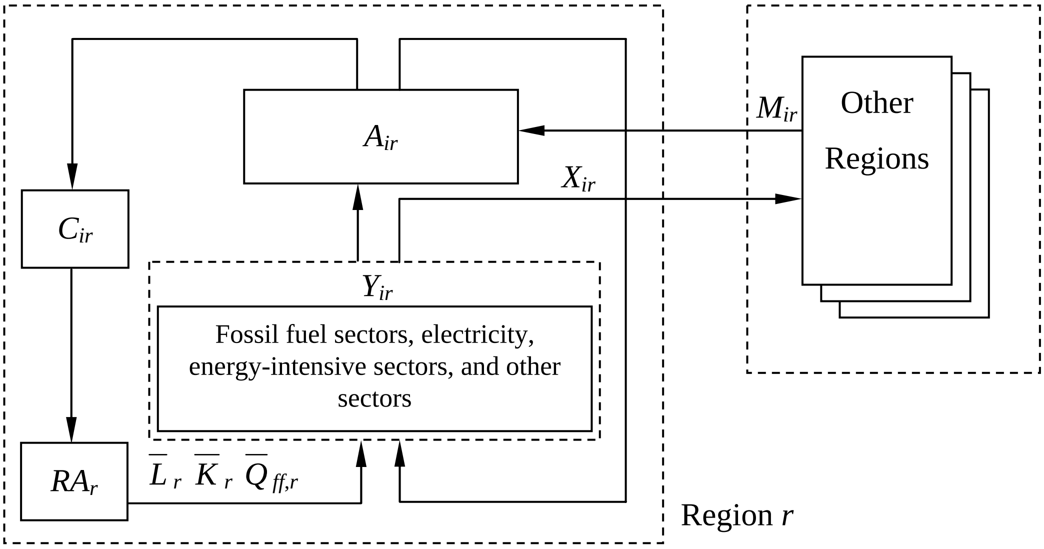

Figure 3: Diagrammatic overview of the model structure

The modelling of international trade is based on the Armington approach of product heterogeneity (Armington, 1969), so that domestic and foreign goods of the same variety are distinguished by their origin. All goods used on the domestic market in intermediate and final demand correspond to a CES composite A_{ir} that combines the domestically produced variety Y_{ir} and imports M_{ir} of the same variety from other regions. Domestic production Y_{ir} either enters the formation of the Armington good A_{ir} or is exported (X_{ir}) to other regions. Trade with other regions is represented by a set of horizontal export demand and import supply functions at exogenous world import and export prices. A balance of payment constraint, which is warranted through flexible exchange rates, incorporates the benchmark trade deficit or surplus.

The model is based on consistent accounts of national production and consumption, trade and energy flows for 2001 as provided by the GTAP 6 database (Dimaranan and McDougall, 2006). A detailed description of our benchmark data sources can be found in Appendix 8.1. The corresponding model regions and sectors of our analysis are presented in Appendix 8.2.

3.2 Prerequisites for the quantitative analysis

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

Emissions reduction targets and regional allowance allocation

In order to analyze future climate policy strategies we have to assume emissions reduction commitments of the participating regions in the year 2020: Motivated by the ambitious future European climate policy goals, the EU (having committed to an EU-wide reduction of 8 percent under the Kyoto Protocol) is assumed to commit to a 20 percent reduction target vs. 1990 levels in 2020 (EU, 2007b). To this aim the heterogeneous regional Kyoto targets for EU Member States (as manifested by the EU Burden Sharing Agreement) are decreased by 13 percent in 2020. Given the assumed leadership role of European climate policy, those non-EU linking candidates having ratified the Kyoto Protocol (Canada, Japan and Russia) are assumed to tighten their Kyoto target by only 5 percent under a future climate policy agreement. Finally, the two non-ratifiers Australia and the United States commit to conservative targets that lie 32 percent and 17 percent above their respective (non-binding) Kyoto target, thereby facing comparable effective reduction requirements in 2020. The resulting commitments for 2020 are summarized in Table 2 of Appendix 8.1.

A further central input for our policy assessment is the allocation of emissions allowances for EU Member States and linking candidates which specifies an overall cap on emissions for those installations covered by the respective trading schemes. Here, we assume that the EU continues its predominant grandfathering method (i.e. a free allocation of allowances) to the covered installations in 2020. Numerically, emissions allocation can be described by so-called allocation factors, i.e. the fraction of baseline emissions that are freely allocated as allowances. In order to derive allocation factors for EU Member States in 2020 we rely on empirical allocation data for the second trading period of the EU ETS (2008 to 2012) – as published in the National Allocation Plan of each Member State – and on recent emissions projections for 2010 (EU, 2007c). Thereby, we conservatively assume that the relative allocation does not change between the second trading period and a future trading period in 2020.[2] Due to lacking information for Finland, Sweden, Bulgaria and Romania we assume a neutral allocation factor equal to one for these countries.

Regarding the emissions allocation for the non-EU regions Japan and Canada in 2020, we start from a neutral allocation factor equal to one in 2010 which is then downscaled by 10 percent, yielding an allocation factor of 0.90 in 2020. For Russia we assume an allocation factor equal to one in 2020, implying no allocation of excess permits to installations covered

[2] We relax this assumption by presenting a sensitivity analysis of the allowance allocation in section 5.4.

by a Russian ETS.[3] Finally, for the non-ratifiers United States and Australia, we downscale a neutral allocation factor of one in 2010 by 5 percent, resulting in an allocation factor of 0.95 in 2020. Thus, all allocation factors for linking candidates in 2020 lay above the (non-weighted) average allocation factor of the European Union (0.865), indicating a less strict emissions allocation to the covered sectors as compared to the European Union. Table 5 in Appendix 8.3 presents the resulting allocation factors for the EU and all linking candidates.

CDM transaction costs and investment risk

While the CDM serves as a flexible mechanism that enables industrialized countries to import low-cost emissions reductions in order to achieve their Kyoto targets, the potential economic benefits of the CDM may be substantially reduced by transaction costs associated with abatement projects in developing countries. Such transaction costs may arise from a variety of activities associated with market exchange, e.g. search and information acquisition, bargaining over prices, as well as negotiation, monitoring and enforcement of contracts. In our quantitative model framework, constant transaction costs are represented by an absolute premium on the marginal abatement costs of CDM host countries, amounting to 1 US$/t$CO_2$.[4] Transaction costs, thereby, increase marginal abatement costs of CDM host countries by inducing an upward shift of the CDM supply curve.

As a second barrier to CDM investments we account for investment risk involved in financing carbon-abatement projects. Following Böhringer and Löschel (2002), host-country-specific investment risk for CDM projects, e.g. resulting from country and project risks, is derived by regional bond-yield spreads between long-term government bonds of the respective developing country and the United States (as a risk-free reference region). It is assumed that investors are risk-neutral and discount emissions reduction credits generated by CDM projects with the mean risk value of the respective host country. The underlying data is based on the International Monetary Fund's International Financial Statistics (IMF, 2000). In our quantitative model framework, investment risk reduces the generated CDM credit volume,

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[3] Excess emissions permits (so-called “Hot Air”) are due to lower projected baseline emissions than the target level implied by Russia’s reduction commitment in 2020. We abstract from “Hot Air” here, as a grandfathered allowance allocation of “Hot Air” would imply an indirect subsidy for Russian installations (the allocated permits could be directly exported to other ETS regions). It is not unambiguous if such an ETS design may prevail or even be linked to an EU scheme.

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

thereby lowering the revenue of CDM projects and effectively inducing a leftward rotation of the CDM supply curve.

4 Policy scenarios

In order to assess the competitiveness impacts of linking the EU ETS to emerging schemes outside Europe, we introduce alternative policy scenarios for the year 2020. Across all scenarios, the regulation stringency is represented by the underlying regional emissions reduction targets and the respective allowance allocation as presented in the previous section. Within the European and emerging non-European emissions trading schemes, the covered (*ETS*) sectors are assumed to be allocated tradable allowances, while the remaining (*NETS*) industries have to be regulated via domestic abatement measures (here: unilateral carbon taxation) in order to meet the national emissions reduction targets in 2020.[5] In our analysis, emissions trading at the installation level is, thus, approximated by sectoral trading activities. Moreover, all regions that have not (yet) set up an emissions trading scheme are assumed to comply with their emissions reduction target by cost-efficient domestic emissions regulation, imposing a uniform carbon tax on the entire economy. Table 1 presents the set of policy scenarios of our analysis, showing the corresponding constellations of linking the EU ETS internationally. As a reference case, scenario *EU* represents the current EU trading scheme, while all non-EU linking candidates fulfill their Kyoto commitment by domestic action. Scenario EU^{+} indicates the potential linkage of the current EU ETS to emerging schemes in two countries that have ratified the Kyoto Protocol, namely Japan and Canada. Scenario EU^{++} assumes that the Kyoto-ratifier Russia is joining the system of the EU-27, Canada and Japan. Finally, the most optimistic scenario EU^{+++} implies linking the EU ETS also to emerging trading schemes in the non-ratifying Annex B countries United States and Australia.

[5] Note that for the emissions trading schemes of all linking candidates we assume an identical sectoral coverage to the EU ETS, as well as the regulation of CO_2 as the only greenhouse gas.

Table 1: Policy scenarios in 2020 and CDM host countries

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

The amending directive linking the European ETS with the Kyoto Protocol's project-based mechanisms enables European companies (here: the *ETS* sectors) to generate emissions reductions in developing countries by means of the CDM and using the respective credits as a substitute for EU allowances (EU, 2004). We cover this regulation by introducing CDM access for European ETS sectors (denoting this scenario as *EU_CDM*) and adopt it for all linking candidates. By concentrating on private CDM investments only, we abstract from government CDM activities as facilitated under the Kyoto Protocol.[6] Table 1 shows that for all regional scenarios alike six central developing regions are assumed to host CDM projects, representing major suppliers on the CDM carbon market (World Bank, 2006). As described in the previous section, our CDM representation considers transaction costs and investment risk as central barriers to CDM investments. In our subsequent comparative-static analysis we measure the macroeconomic impacts of climate policy in 2020 relative to the benchmark situation – usually termed *Business-as-Usual* (BaU) – where no emissions regulation is imposed.

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

5 Simulation results

This section presents the simulation results of our model-based assessment of the macroeconomic and competitiveness impacts of linking the EU ETS internationally. The corresponding quantitative simulation results are presented in Table 6 and Table 7 of Appendix 8.5. We start our analysis by reporting the effects of linking the EU ETS on the market for emissions permits (section 5.1) and the associated macroeconomic impacts (section 5.2), before addressing the competitiveness effects of linking the European trading scheme (section 5.3). Finally, we present a sensitivity analysis with respect to the assumed allowance allocation (section 5.4).

5.1 Impacts on the emissions market

Regarding the effects of linking the EU ETS on the market for emissions permits, Figure 4 first shows that the international permit price resulting from a European emissions trading scheme in 2020 (scenario *EU*) amounts to 26.36 € per ton CO_2 assuming an empirical allowance allocation (see section 3.2). The figure further illustrates that linking the EU system to emerging schemes substantially decreases the CO_2 value in the covered sectors: Despite of the relatively high-cost abatement options of Canada and Japan, the relatively generous allowance allocation in both countries – i.e. an allocation factor equal to 0.90 – induces a lower permit price in the linked scheme (yielding scenario EU^{+}), amounting to 21.17 €.

A further integration of Russia (scenario EU^{++}) increases the where-flexibility of emissions abatement and puts more downward pressure on the allowance price, amounting to 14.27 €. Note that we assume an allocation factor equal to one for Russia, so that we abstract from the assignation of potential excess emissions permits to the covered Russian installations in our scenario setting. Hence, the lower permit price in scenario EU^{++} originates from relatively low-cost abatement options of permit-exporting Russian *ETS* sectors. Further linking of the EU ETS to the non-ratifiers Australia and the United States (scenario EU^{+++}) induces an additional permit price fall to 8.24 € per ton CO_2. Despite of the generally high-cost abatement options in Australia and the Unites States, the generously assignation of emissions (allocation factor equal to 0.95) implies that these regions exhibit relatively low marginal abatement cost *levels* as compared to the other participants. The corresponding permit supply from these countries further decreases the international permit price.

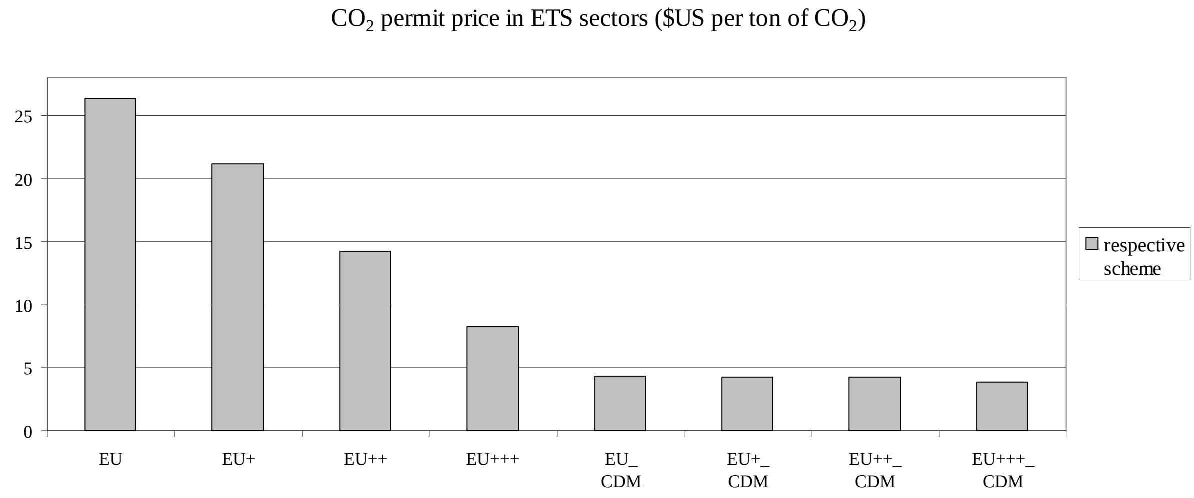

Figure 4: CO_2 permit price within linked schemes by scenario

Across all linking scenarios, allowing the covered *ETS* sectors to import low-cost emissions reductions from developing countries via the CDM substantially lowers the international CO_2 value. The maximum price in this case amounts to 4.32 € in a purely European system, while the most integrated scheme including Australia and the United States generates the lowest value of 3.87€. According to Figure 4, establishing CDM access for *ETS* sectors levels out the permit price differences between alternative linking strategies.

5.2 Macroeconomic impacts

From a general equilibrium perspective, the economic effects of climate change policies surpass the emissions market. First, carbon abatement policies may decrease domestic production levels by the associated decreased energy use due to increased domestic abatement or a policy-induced increased permit price. Second, in large open economies policy-induced carbon restrictions induce changes in exports and imports, most dominantly on fossil fuel markets, thereby affecting international prices and the regional terms of trade (Böhringer and Rutherford, 2002). In order to analyze these general equilibrium (i.e. multi-market) impacts from climate policy in greater detail, in the following we assess aggregate macroeconomic indicators such as production and social welfare.[7]

[7] Note that we pursue a cost-effectiveness analysis that quantifies adjustment costs of environmental regulation as compared to an unconstrained business-as-usual situation. The deliberate neglect of economic benefits from controlling global warming implies that the macroeconomic effects resulting from the imposition of emissions constraints on the respective economies will necessarily be negative. Welfare changes are expressed by the

Table 6 of Appendix 8.5 shows that for the EU-27, production and welfare impacts of emissions regulation in a purely European trading scheme amount to roughly three percent. While these macroeconomic impacts do not change significantly by linking the EU ETS to Canada, Japan and Russia, the maximum where-flexibility of emissions abatement in scenario EU^{+++} slightly reduces production and welfare losses. Moreover, it shows that accounting for CDM access does not change the welfare impacts across scenarios substantially: Especially in the linked scheme EU^{+++} the access to low-cost emissions abatement via the CDM for only a part of European economies (i.e. the covered sectors) cannot induce substantial efficiency improvements, as the participating regions already benefit from a high where-flexibility by linking their schemes.

For those non-EU regions which are not (yet) involved in linked emissions trading schemes we assume compliance with the national emissions reduction targets (see Table 2 of Appendix 8.1) by means of unilateral economy-wide carbon taxation. Thereby, we are able to measure the economic implications for these countries of linking to the European system against the consistent reference scenario of cost-efficient domestic action. For our policy scenarios, Table 6 shows heterogeneous macroeconomic impacts across non-EU countries. These differences originate from diverging national emissions reduction targets, permit allocation stringencies and emissions abatement options. Moreover, all regions with effective emissions reduction requirements (except of the United States) face substantially higher welfare costs when linking to the EU scheme as compared to domestic action: On pure efficiency grounds, the assumed design of emissions trading schemes is inferior to the reference case of cost-efficient domestic action. The central reason is that a generous allowance allocation to the covered *ETS* sectors implies the imposition of high emissions reduction efforts of the non-covered sectors. In the absence of the CDM, these industries – having relatively high-cost abatement options (e.g. in the household or transport sector) – have to be regulated by costly complementary domestic carbon taxation in order to achieve the national emissions reduction targets.

As for the European economies, the welfare impacts for most non-EU regions do not vary significantly across linking and CDM scenarios. However, Table 6 shows that permit-exporting Russia substantially benefits from linking to the joint scheme of the EU-27, Canada and Japan. These benefits are cancelled out again if also Australia and the United States join the international trading scheme, introducing a permit-price decreasing where-flexibility. The

Hicksian Equivalent Variation (HEV). The welfare indicator thereby summarizes both economic impacts on the emissions market as well as macroeconomic impacts.

same reasoning may be applied if CDM access for the covered *ETS* sectors facilitates the inflow of competing low-cost permits from developing countries into the trading system.

5.3 Effects on international competitiveness

In this section, we assess the national and sectoral competitiveness effects of linking EU Emissions Trading Scheme with emerging schemes outside Europe. The corresponding numerical simulation results are presented in Table 7 of Appendix 8.5.

Competitiveness effects for the EU

Focusing first on EU Member States, Figure 5 (a) reports economy-wide competitiveness effects as measured by changes in the terms of trade (ToT) – i.e. the ratio between export and import prices – across alternative policy scenarios. The figure illustrates that – consistent with our findings on welfare impacts – linking the EU ETS internationally does not substantially affect the national competitiveness for EU Member States. However, the ToT losses of EU economies in a purely domestic European scheme (scenario *EU*) are slightly increased from -3.1 to -3.3 percent by integrating Canada, Japan and Russia (yielding scenario EU^{++}), while economy-wide competitiveness can be improved to -2.9 percent by opening the European trading system to all linking candidates (yielding scenario EU^{+++}). Again these findings do not significantly change by the introduction of CDM access for the covered industries.

In order to decompose the national competitiveness impacts for EU Member States, we assess sectoral competitiveness effects using two well-known indicators: Revealed Comparative Advantage (RCA) and Relative World Trade Shares (RWS).[8] Note that the two indicators may be used complementarily in assessing the sectoral ability to compete, as they measure competitiveness implications using different reference points: The RCA indicator compares the trade performance of an *ETS* (*NETS*) sector with the performance of all sectors within the respective region. The RWS indicator relates the trade performance of an *ETS* (*NETS*) sector in a region to the performance of *ETS* (*NETS*) sectors across the world.

[8] A detailed description of the employed competitiveness indicators is given in Appendix 8.4.

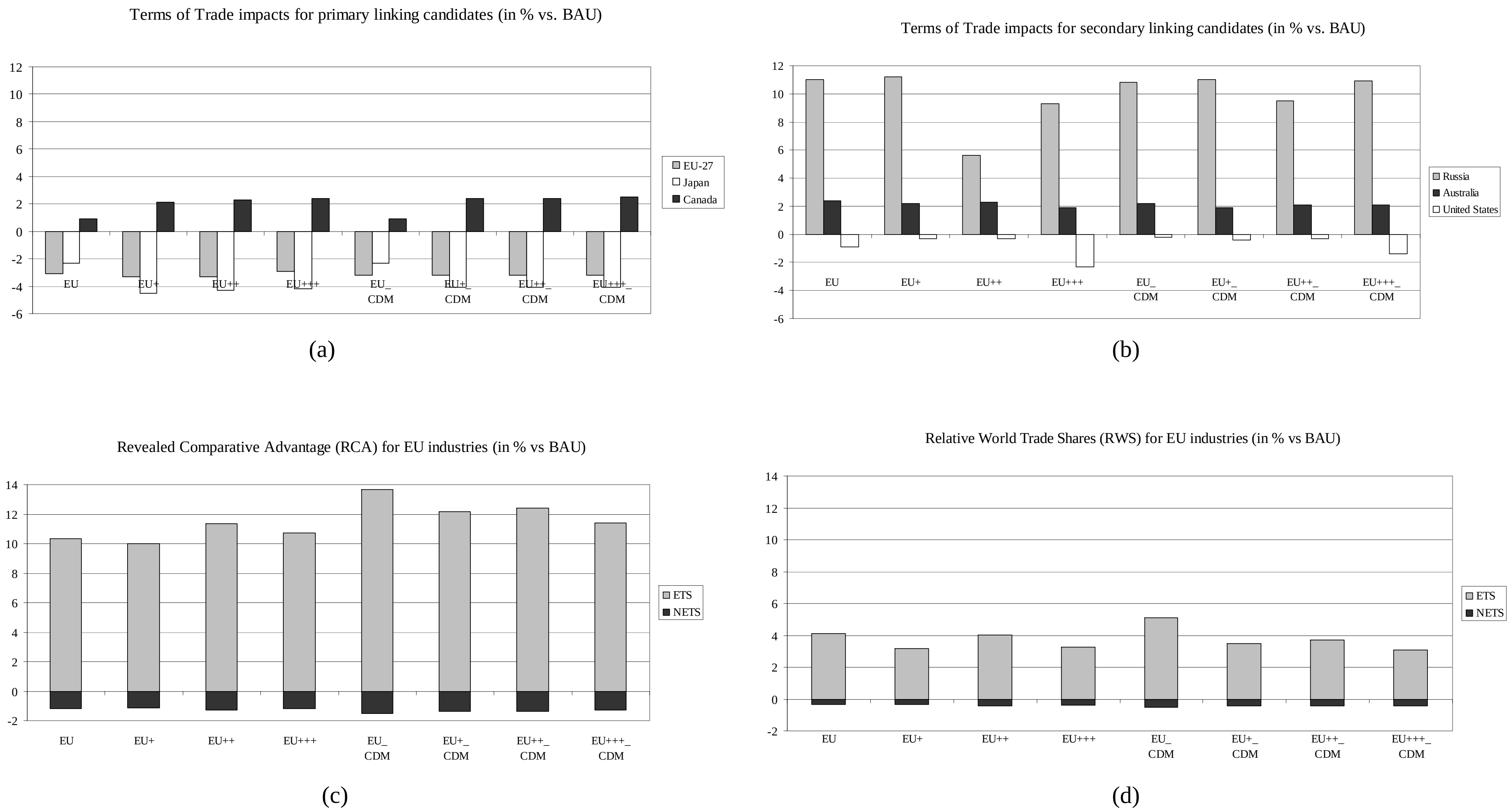

Figure 5: Economy-wide and sectoral competitiveness indicators by region, sector and scenario

While the economy-wide impacts across policy scenarios are limited, the sectoral competitiveness implications show a differentiated picture. Firstly, Figure 5 (c) and (d) illustrate that in a purely European trading scheme (scenario *EU*), the covered European *ETS* sectors exhibit large competitiveness gains vis-à-vis the remaining EU industries – the corresponding RCA indicator amounting to as much as 10.32 percent. This result is due to a relatively generous allowance allocation to these sectors and the corresponding high complementary domestic carbon taxation on *NETS* industries which have costly abatement options. Thus, the *NETS* industries account for the major economic compliance burden and face competitiveness losses vis-à-vis the *ETS* sectors. Moreover, in a purely EU trading scheme the European *ETS* sectors exhibit competitiveness gains vis-à-vis comparable sectors in non-EU regions, however at a lower level (the corresponding RWS indicator amounting to only 4.13 percent). This competitiveness improvement of the European ETS sectors is due to the fact that comparable sectors in non-EU regions are burdened by domestic emissions regulation in this policy setting.

Secondly, Figure 5 (c) and (d) suggest that the RWS varies similarly to the RCA indicator for linking scenarios of the EU ETS, only at a lower level: By linking to emerging schemes in Japan and Canada, the sectors covered by the European trading scheme may face slight decreases in their competitiveness both vis-à-vis *NETS* industries within the EU (RCA) and comparable *ETS* sectors in non-EU regions (RWS). Here, the RWS loss of European *ETS* sectors reflects the competitiveness improvement of the same sectors in Canada and Japan: The introduction of an emissions trading scheme with a generous allowance allocation implies a preferential treatment of their *ETS* sectors as compared to cost-efficient domestic action. Furthermore, the RCA loss of European *ETS* sectors vis-à-vis the European *NETS* sectors is due to general equilibrium effects on international trade: The introduction of inefficient emissions trading schemes in Canada and Japan implies an excessive burden shifting from *ETS* to *NETS* sectors in these countries. As a consequence, the (competing) European *NETS* sectors increase their international export activity and thus improve their competitiveness also vis-à-vis the European *ETS* sectors. While the European *ETS* industries face competitiveness losses through linking to Japan and Canada, we generally observe opposite (and less pronounced) effects for the non-covered European *NETS* sectors.

Further regional flexibility in emissions trading through a linkage to low-cost permit supplier Russia may, however, substantially counteract the competitiveness losses of European *ETS* sectors as compared to regional scenario EU^{+}. In particular, we observe competitiveness gains for the European *ETS* sectors as compared to regional scenarios *EU* and EU^{+}. Further integrating Australia and the United States (scenario EU^{+++}) implies a slight decrease in competitiveness for European *ETS* sectors vis-à-vis comparable industries in non-EU regions (RWS). These results can be explained analogously to our above findings for linking to Japan and Canada.

Figure 5 (c) and (d) illustrate that for each linking strategy, CDM access for *ETS* sectors serves as a flexibility instrument that improves the sectoral competitiveness effects for these industries both vis-à-vis the remaining sectors of EU economies and comparable sectors in non-EU regions. On the contrary, it shows that the non-covered *NETS* sectors are not able to improve their international competitiveness as they are excluded from the low-cost abatement options of the CDM.

Competitiveness effects for linking candidates

Figure 5 (a) and (b) summarize the prospects for the non-EU linking candidates of joining the European trading system in terms of national competitiveness impacts.[9] While linking the EU ETS to Japan and Canada (yielding scenario EU^{+}) induces a further increase of the initial economy-wide competitiveness for Canada in scenario *EU*, Japan is facing a further decrease in its ToT. These heterogeneous results can be explained as follows: A linkage to Japan and Canada implies the introduction of an inefficient domestic emissions regulation in both countries. As mentioned above, these inefficiencies are due to the relatively generous allowance allocation and the associated abatement-burden shifting to the non-covered *NETS* sectors of these regions. Such a policy design implies competitiveness gains for *ETS* sectors and competitiveness losses for *NETS* sectors in both countries. However, the induced burden-shifting from covered to non-covered sectors is more pronounced in Japan than in Canada. As a consequence, in Japan overall export (import) values are decreasing (increasing) and the ToT further deteriorate through linking to the European ETS. In contrast, Canada is able to increase (decrease) its overall export (import) values and can thus benefit from linking to the EU in terms of overall competitiveness. Here, the reason is a strong competitiveness improvement in the energy-intensive sectors covered by the Canadian trading system. These industries are benefiting to a large extent from linking to the low-priced European system, as they faced a relatively high domestic carbon tax before linking to the EU.

[9] Note that all numerical sectoral competitiveness impacts for non-EU regions can be found in Table 7 of Appendix 8.5.

A further linkage to permit-exporting Russia (yielding scenario EU^{++}) slightly improves the ToT situation of the permit importers Canada and Japan, but substantially decreases the competitiveness gains of Russia itself. Here, the newly linked Russia has an incentive to reduce emissions at relatively low marginal cost in order to export permits to the emissions-trading partners. These adjustments in the Russian economy induce negative feed-back effects in terms of a decreased international fossil-fuel demand and price, subsequently deteriorating the ToT of energy-exporting Russia. Finally, a further integration of Australia and the United States (yielding scenario EU^{+++}) decreases the national-wide competitiveness of both linking candidates due to the introduction of an inefficient domestic emissions regulation also in these countries. However, the Russian ToT are increasing again in this policy scenario. In general, allowing for CDM imports to the covered *ETS* sectors leaves these qualitative findings unchanged.

Summarizing our findings from an incentive perspective, in the absence of the CDM both the European Union and Canada improve their economy-wide competitiveness by linking their emissions trading schemes to all linking candidates (yielding scenario EU^{+++}). On the other hand, both Russia and United States benefit most from a joint trading scheme between the EU-27, Canada and Japan (scenario EU^{+}). For their part, Japan and Australia loose competitiveness – compared to cost-efficient domestic action – by establishing and linking their emissions trading systems internationally. However, from the set of alternative trading schemes, Australia prefers a joint system between the EU-27, Japan, Canada and Russia (scenario EU^{++}), while Japan would opt for linking up to all candidates. In summary, we observe a large regional heterogeneity regarding the incentives for establishing alternative supra-European emissions trading schemes.

5.4 Sensitivity analysis: Proportional allowance allocation

While the allocation of emissions permits to the covered sectors in future trading schemes is crucial for our simulation results, it clearly underlies a considerable uncertainty. In the following we therefore present a sensitivity analysis with respect to the stringency of allowance allocation. In contrast to the empirically motivated allocation factors (see sections 3.2 and 5.3) we now assume that the covered sectors of a domestic trading system have to reduce their emissions proportionally to the national effective emissions reduction target. In contrast to the preferential treatment of *ETS* sectors under the original allowance allocation, in this case the covered industries equitably contribute to the national abatement efforts. For example, a region with an effective emissions reduction target of 40 percent versus BaU in

2020 would allocate an amount of emissions allowances to the covered sectors which corresponds to an allocation factor of 0.6. This rule implies a stricter allocation to the covered sectors as compared to the empirically based allocation factors.

The simulation results of our sensitivity analysis are presented in Table 8 and Table 9 of Appendix 8.5. It shows that the stricter allowance allocation induces a higher permit price within the EU ETS, amounting to 31.73 € per ton of CO_2. In contrast to our previous findings, the proportional permit allocation induces a slightly increased permit price (to 33.68 €) by linking the European scheme to Canada and Japan. This price increase is, however, substantially counteracted by linking to the permit exporter Russia, which decreases the CO_2 value to 20.54 €, and further to 15.27 € by integrating Australia and the United States.

We find that the overall level of welfare losses due to emissions regulation and the associated economy-wide competitiveness effects are far less pronounced in the case of a stricter allowance allocation, improving efficiency within the trading schemes for all linking scenarios. In particular, the former negative welfare impacts for non-EU linking candidates from establishing an inefficient domestic trading scheme are substantially diminished, thereby increasing the attractiveness of the linking process for these countries. While our economy-wide competitiveness results do not differ significantly from our findings in the previous section, we conclude that the competitiveness impacts for the European ETS sectors of linking the EU system are amplified in the case of proportional allowance allocation: While linking to Canada and Japan is even more disadvantageous, the partly positive previous competitiveness effects of integrating Russia, Australia and the United States are improved substantially both vis-à-vis the remaining EU sectors and comparable industries in non-EU regions.

6 Conclusions

Given the coexistent EU priorities concerning the competitiveness of European industries and ambitious international emissions regulation at the company level, this paper presents an efficiency and international trade analysis of developing supra-European emissions trading schemes. In order to achieve its climate policy objectives more cost-efficiently, the EU currently proposes to strengthen the EU Emissions Trading Scheme (ETS) by linking to emerging domestic trading systems outside Europe, e.g. in Canada, Japan and Australia. The EU ETS may thus form the nucleus for a gradually expanding global carbon market that enables international emissions trading at the company level.

Employing both economic theory and numerical model simulations, we first discuss the efficiency aspects of integrating emissions trading schemes within a partial analytical framework. Our stylized analysis suggests that – independently of the marginal abatement costs of a region to be linked with an existing scheme – the integration of trading systems yields economic efficiency gains for all participating regions. This result is due to the increased where-flexibility of regional emissions abatement. We subsequently analyze the macroeconomic and trade-based competitiveness impacts of linking the EU ETS employing a large-scale computable general equilibrium model of the global economy.

Based on empirical allowance allocation of the EU ETS, we find that while linking the EU system internationally may substantially decrease the international permit price, the associated aggregate welfare impacts for the EU are rather limited. As the efficiency gains from an international linkage exclusively apply to those sectors which are covered by the linked trading schemes, the remaining sectors will not benefit from an increased where-flexibility. For non-EU countries, establishing an inefficient trading system may induce substantial welfare losses – due to a too generous allowance allocation to the covered sectors – which may be compensated only partially through linking to the EU trading scheme. Accounting for permit imports from outside the linked schemes via the Clean Development Mechanism (CDM) does not alter these welfare impacts substantially: The access to low-cost emissions abatement in developing countries for only a part of the economy (i.e. the covered sectors) cannot induce substantial aggregate efficiency improvements – especially in the case of linking all candidates, as the participating regions already benefit from a high where-flexibility.

We find that – consistent with the insights from our welfare analysis – linking the EU ETS internationally does not substantially affect economy-wide EU competitiveness as measured by the terms of trade. However, the trade-based competitiveness effects crucially depend on the linked trading system: Although EU economy-wide competitiveness varies only moderately across linking scenarios, the sectoral decomposition of these aggregate effects shows that European industries are much more sensitive to the linking constellation. By integrating emerging schemes in Japan and Canada, those sectors covered by the European trading scheme may face competitiveness losses both vis-à-vis the non-covered industries within the EU and comparable sectors in non-EU regions. These effects are due to the introduction of inefficient emissions trading schemes in Canada and Japan. Further regional flexibility in emissions trading through a linkage to low-cost permit supplier Russia may, however, substantially counteract the negative sectoral competitiveness impacts on the covered European industries. Finally, a future integration of Australia and the United States into a joint trading system of all linking candidates keeps the competitiveness losses for European ETS sectors at a moderate level.

Regarding the international trade impacts for non-EU countries, we find that the linking candidates have very heterogeneous incentives to join the European trading system, which range from pronounced competitiveness improvements for Canada to substantial competitiveness losses for Japan. Our sensitivity analysis assuming a stricter allowance allocation within regional trading systems suggests, however, that a more efficient design of domestic ETS can boost the overall prospects for establishing supra-European emissions trading schemes.

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8 Appendix

8.1 Benchmark data sources

The main data source underlying our model assessment is the GTAP version 6 database that represents global production and trade data for 87 regions and 57 sectors in the baseyear 2001 (Dimaranan and McDougall, 2006). For this application, the data set has been aggregated to 36 regions and 10 sectors in order to reduce the dimensionality of the computational problem, but at the same time keep sufficient detail for the carbon-relevant regions and sectors (see Table 3 and Table 4 in Appendix 8.2). Reconciliation of these data sources yields the benchmark data of our model.

In a second step, we perform a forward calibration of the 2001 economies to the target year 2020. For this purpose we employ baseline estimates for GDP growth, energy demand and future energy prices as well as carbon emissions, relying on energy trends for EU Member States (EU, 2003) and on international energy projections for non-European economies (US Department of Energy, 2005). The magnitude and distribution of costs associated with the implementation of future emissions constraints depend on the baseline projections for GDP, fuel prices, energy efficiency improvements etc. In our comparative-static framework, we measure the costs of abatement relative to a baseline, i.e. relative to the benchmark situation – usually termed *Business-as-Usual* (BaU), where no emissions regulation is imposed. As an overview on the emissions data underlying our analysis, Table 2 shows baseline emissions and reduction requirements of Annex-B countries in 2010 and 2020. For the year 2010 we present the targets under the Kyoto Protocol, while for 2020 we assume the future commitments as laid out in section 3.2. Contrasting regional baseline carbon emissions in the respective year to the regional emissions reduction target vs. 1990 emissions yields the effective emissions reduction requirement of a region.

Table 2: Baseline emissions and reduction requirements of ratifying Annex-B countries

	Baseline CO_2 Emissions (Mt of CO_2)			Emissions reduction target (% vs. 1990)		Effective reduction requirement (% vs. baseline)	
Year	**1990**	**2010**	**2020**	**2010**	**2020**	**2010**	**2020**
Austria	55.1	60.7	66.7	13.0	24.3	21.0	37.5
Belgium	106.3	112.2	120.1	7.5	19.5	12.4	28.8
Denmark	52.8	46.6	45.0	21.0	31.3	10.5	19.4
Finland	53.2	51.4	55.7	0.0	13.0	-3.5	16.9
France	354.1	406.4	447.9	0.0	13.0	12.9	31.2
Germany	943.0	823.6	869.8	21.0	31.3	9.5	25.5
United Kingdom	569.1	519.4	559.0	12.5	23.9	4.1	22.5
Greece	71.1	105.6	112.2	-25.0	-8.8	15.8	31.1
Ireland	29.7	46.5	48.7	-13.0	1.7	27.8	40.0
Italy	390.8	422.2	437.4	6.5	18.7	13.5	27.3
Netherlands	152.9	174.0	184.4	6.0	18.2	17.4	32.2
Portugal	39.0	67.9	80.4	-27.0	-10.5	27.1	46.4
Spain	203.8	302.6	335.7	-15.0	0.0	22.5	39.3
Sweden	50.6	54.0	68.3	-4.0	9.5	2.5	33.0
Luxemburg	10.6	11.6	12.6	28.0	37.4	34.2	47.3
Hungary	68.5	62.2	68.9	6.0	18.2	-3.5	18.7
Poland	340.1	286.2	325.1	6.0	18.2	-11.7	14.4
Cyprus	4.5	8.1	8.9	8.0	20.0	48.9	59.5
Czech Republic	158.8	103.1	100.5	8.0	20.0	-41.7	-26.5
Malta	2.5	3.3	4.2	8.0	20.0	30.3	52.4
Slovakia	51.4	41.6	46.2	8.0	20.0	-13.7	11.0
Slovenia	10.9	14.0	15.4	8.0	20.0	28.4	43.3
Estonia	36.6	14.2	11.8	8.0	20.0	-137.1	-148.3
Latvia	16.9	8.3	9.9	8.0	20.0	-87.3	-36.6
Lithuania	32.2	17.2	22.0	8.0	20.0	-72.2	-17.1
Bulgaria	73.6	42.9	43.0	8.0	20.0	-57.8	-37.0
Romania	168.6	90.3	100.6	8.0	20.0	-71.8	-34.1
Canada	473.0	681.0	757.0	6.0	11.0	34.7	44.4
Japan	990.0	1211.0	1240.0	6.0	11.0	23.2	28.9
Russia	2347.0	1732.0	1971.0	0.0	5.0	-35.5	-13.1
Australia	294.0	520.0	582.0	-8.0	-40.0	38.9	29.3
United States	4989.0	6561.0	7461.0	7.0	-10.0	29.3	26.4

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

8.2 Model regions and sectors

Table 3: PACE model regions

EU-15	EU-12	Non-EU regions
Austria	Hungary	Japan
Belgium	Poland	Canada
Germany	Czech Republic	Russian Federation
Denmark	Slovakia	Rest of Former Soviet Union
Finland	Bulgaria	Australia
France	Romania	New Zealand
United Kingdom	Baltic States (Estonia, Latvia, Lithuania)	United States
Greece		China including Hong Kong
Ireland	Rest of EU (Slovenia, Luxembourg, Malta, Cyprus)	India
Italy		Rest of East South Asia
Netherlands		Brazil
Portugal		Central and South America
Spain		South Africa
Sweden		Rest of World

Table 4: PACE model sectors

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

8.3 Regional allowance allocation

Table 5: Allocation factor by region in 2020

Region	Allocation factor
Austria	0.813
Belgium	0.943
Germany	0.876
Denmark	0.752
Spain	0.693
France	0.907
Finland	1.000
Greece	0.807
Ireland	0.750
Italy	0.849
Netherlands	0.893
Portugal	0.839
Sweden	1.000
United Kingdom	0.900
Czech Republic	0.825
Estonia	0.644
Hungary	0.887
Lithuania	0.953
Latvia	0.736
Luxembourg	0.839
Poland	0.833
Slovenia	0.777
Slovakia	0.929
Cyprus	0.881
Malta	0.997
Bulgaria	1.000
Romania	1.000
Japan	0.900
Canada	0.900
Russian Federation	1.000
United States	0.950
Australia	0.950

Source: EU (2007b), own calculations

8.4 Competitiveness indicators

We implement the following indicators into the PACE model in order to account for sectoral and economy-wide competitiveness effects:

- *Terms of Trade (ToT):*

$$ToT_i = \frac{P_{X_i}}{P_{M_i}}$$

where P_{X_i} denotes the price of exports and P_{M_i} denotes the price of imports, for a particular region *i* the ToT index expresses the price of its exports in terms of its imports. The Terms of Trade improve (deteriorate) as the index increases (decreases).

- *Revealed Comparative Advantage (RCA)*

For a particular region and sector, this index compares the ratio of exports by a specific sector over its imports with the ratio of exports over imports across all sectors of the region. Letting *X* denote exports, *M* imports, *i* the region and *j* the sector, the index for revealed comparative advantage (RCA) for region *i* in sector *j* can be presented as follows:

$$RCA_{ij} = \frac{X_{ij} / M_{ij}}{\sum_j X_{ij} / \sum_j M_{ij}}$$

If the sectoral export-import ratio is identical to the economy-wide ratio, the RCA index takes the neutral value of one ($RCA_{ij} = 1$). Thus, a region *i* is said to have a revealed comparative advantage in sector *j* if the RCA index exceeds unity ($1 < RCA \leq \infty$). By contrast, a region *i* has a revealed comparative disadvantage in sector *j* if the RCA index takes the values between zero and one ($0 \leq RCA < 1$).

- *Relative World Trade Shares (RWS)*

This index compares the ratio of country's exports in a certain sector over the world's exports in this sector with the ratio of country's overall exports over the world's exports in all sectors:

$$RWS_{ij} = \frac{X_{ij} / \sum_i X_{ij}}{\sum_j X_{ij} / \sum_i \sum_j X_{ij}}.$$

The RWS indicator lies in the same value range as the RCA indicator ($0 \leq RWS_{ij} \leq \infty$) and may thus be interpreted analogously.

8.5 Numerical simulation results

Table 6: Core allowance allocation – Environmental and macroeconomic indicators in 2020

Scenario / Region	*EU*	*EU^{+}*	*EU^{++}*	*EU^{+++}*	*EU_CDM*	*EU^{+}_CDM*	*EU^{++}_CDM*	*EU^{+++}_CDM*
	Carbon emissions reduction (in % vs. BaU)							
EU-27	-27.30	-25.70	-23.00	-20.50	-16.70	-17.00	-16.80	-17.50
Canada	-36.40	-38.70	-36.50	-34.90	-36.40	-33.30	-33.20	-33.50
Japan	-23.60	-28.70	-26.70	-24.60	-23.60	-21.90	-21.80	-22.40
Russia	2.80	2.50	-8.10	-5.30	2.50	2.30	-2.00	-2.60
Australia	-21.90	-21.90	-21.90	-22.70	-21.90	-21.90	-21.90	-17.40
United States	-14.10	-14.10	-14.10	-16.80	-14.10	-14.10	-14.10	-13.90
	CO2 value in ETS sectors (in $US per ton of CO_2)							
EU-27	26.36	21.17	14.27	8.24	4.32	4.27	4.23	3.87
Canada	104.31	21.17	14.27	8.24	103.90	4.27	4.23	3.87
Japan	94.90	21.17	14.27	8.24	94.96	4.27	4.23	3.87
Russia	0.00	0.00	14.27	8.24	0.00	0.00	4.23	3.87
Australia	23.40	22.94	23.03	8.24	23.24	22.66	22.77	3.87
United States	20.10	19.77	19.79	8.24	19.90	19.55	19.62	3.87
	Production impact (in % vs. BaU)							
EU-27	-3.46	-3.5	-3.49	-3.36	-3.48	-3.45	-3.46	-3.44
Canada	-0.48	-2.49	-2.52	-2.47	-0.45	-2.56	-2.57	-2.46
Japan	-0.35	-1.25	-1.24	-1.22	-0.34	-1.22	-1.22	-1.21
Russia	1.04	1.10	0.75	1.04	1.09	1.14	1.02	1.16
Australia	0.38	0.41	0.41	-2.76	0.37	0.41	0.41	-2.8
United States	-0.09	-0.06	-0.06	-0.28	-0.09	-0.05	-0.05	-0.26
	Welfare impact (in % of HEV)							
EU-27	-2.98	-2.98	-2.98	-2.96	-2.95	-2.95	-2.95	-2.95
Canada	-0.91	-2.14	-2.16	-2.18	-0.92	-2.17	-2.17	-2.20
Japan	-0.03	-0.51	-0.52	-0.52	-0.03	-0.53	-0.53	-0.53
Russia	-1.82	-1.93	-1.53	-1.98	-1.83	-1.94	-1.87	-2.12
Australia	-0.46	-0.45	-0.45	-3.08	-0.45	-0.43	-0.44	-3.07
United States	0.10	0.02	0.02	0.05	0.01	0.02	0.02	-0.05

Table 7: Core allowance allocation – Economy-wide and sectoral competitiveness indicators in 2020

Scenario / Region	EU		EU+		EU++		EU+++		EU_CDM		EU+_CDM		EU++_CDM		EU+++_CDM	
	Terms of Trade impact (in % vs. BaU)															
EU-27	-3.10		-3.30		-3.30		-2.90		-3.20		-3.20		-3.20		-3.20	
Canada	0.90		2.10		2.30		2.40		0.90		2.40		2.40		2.50	
Japan	-2.30		-4.50		-4.30		-4.20		-2.30		-4.10		-4.10		-4.10	
Russia	11.00		11.20		5.60		9.30		10.80		11.0		9.50		10.90	
Australia	2.40		2.20		2.30		1.90		2.20		1.90		2.10		2.10	
United States	-0.90		-0.30		-0.30		-2.30		-0.20		-0.40		-0.30		-1.40	
	Revealed Comparative Advantage – RCA (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	10.32	-1.16	9.99	-1.12	11.33	-1.26	10.70	-1.19	13.66	-1.50	12.19	-1.35	12.39	-1.37	11.38	-1.26
Canada	-22.02	3.63	9.92	-1.15	12.93	-1.55	12.27	-1.41	-22.68	3.75	16.11	-1.94	16.31	-1.97	12.83	-1.46
Japan	-11.73	1.02	9.10	-0.56	11.09	-0.70	9.81	-0.61	-12.04	1.05	12.19	-0.77	12.55	-0.80	10.14	-0.63
Russia	-4.58	1.82	-6.72	2.84	-23.1	9.88	-18.49	7.81	-6.37	2.45	-8.31	3.46	-13.49	5.59	-14.26	5.98
Australia	-23.88	5.51	-25.75	5.99	-25.54	5.93	9.13	-0.47	-24.26	5.61	-26.26	6.13	-26.1	6.08	15.47	-1.64
United States	-4.98	0.39	-11.04	0.93	-11.33	0.96	-7.13	0.53	-5.88	0.47	-12.44	1.06	-12.33	1.05	-6.54	0.47
	Relative World Trade Shares – RWS (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	4.13	-0.34	3.19	-0.32	4.04	-0.41	3.25	-0.38	5.08	-0.51	3.49	-0.42	3.72	-0.44	3.08	-0.41
Canada	28.68	2.20	52.54	-0.78	55.34	-1.10	53.99	-0.99	27.71	2.25	56.72	-1.37	57.06	-1.40	53.59	-1.01
Japan	37.21	0.43	45.43	-0.13	47.06	-0.22	46.00	-0.23	36.56	0.43	46.94	-0.27	47.31	-0.29	45.74	-0.25
Russia	45.95	1.26	43.43	2.12	31.23	7.76	34.92	6.07	44.51	1.72	41.87	2.60	38.18	4.33	37.68	4.60
Australia	23.46	4.24	20.69	4.60	21.30	4.52	45.45	0.24	22.70	4.30	19.61	4.70	19.96	4.66	50.82	-0.80
United States	43.51	0.01	38.15	0.20	38.12	0.20	38.39	0.12	42.42	0.02	36.62	0.23	36.80	0.23	38.11	0.10

Table 8: Proportional allowance allocation – Environmental and macroeconomic indicators in 2020

Scenario / Region	***EU***	***EU^{+}***	***EU^{++}***	***EU^{+++}***	***EU_CDM***	***EU^{+}_CDM***	***EU^{++}_CDM***	***EU^{+++}_CDM***
	Carbon emissions reduction (in % vs. BaU)							
EU-27	-26.50	-26.90	-23.60	-21.90	-15.60	-16.00	-15.90	-16.60
Canada	-36.40	-33.00	-29.90	-28.50	-36.40	-24.30	-24.30	-24.70
Japan	-23.60	-23.80	-21.00	-19.50	-23.60	-14.20	-14.10	-14.90
Russia	3.00	2.90	-10.20	-8.30	2.70	2.50	-2.00	-2.80
Australia	-21.90	-21.90	-21.90	-22.00	-21.90	-21.90	-21.90	-12.40
United States	-14.10	-14.10	-14.10	-16.00	-14.10	-14.10	-14.10	-10.30
	CO2 value in ETS sectors (in $US per ton of CO_2)							
EU-27	31.73	33.68	20.54	15.27	4.45	4.66	4.61	4.85
Canada	105.03	33.68	20.54	15.27	104.55	4.66	4.61	4.85
Japan	93.46	33.68	20.54	15.27	93.38	4.66	4.61	4.85
Russia	0	0	20.54	15.27	0	0	4.61	4.85
Australia	23.70	23.48	23.57	15.27	23.51	23.04	23.14	4.85
United States	19.85	19.72	19.72	15.27	19.72	19.37	19.44	4.85
	Production impact (in % vs. BaU)							
EU-27	-1.73	-1.72	-1.70	-1.67	-1.66	-1.65	-1.65	-1.65
Canada	-1.73	-1.72	-1.70	-1.67	-1.66	-1.65	-1.65	-1.65
Japan	-0.58	-1.14	-1.20	-1.19	-0.55	-1.25	-1.25	-1.17
Russia	-0.37	-0.62	-0.59	-0.58	-0.37	-0.55	-0.55	-0.55
Australia	0.82	0.84	0.38	0.56	0.86	0.88	0.76	0.81
United States	0.30	0.32	0.32	-0.15	0.30	0.32	0.32	-0.26
	-0.12	-0.11	-0.10	-0.18	-0.12	-0.09	-0.09	-0.14
	Welfare impact (in % of HEV)							
EU-27	-0.85	-0.84	-0.84	-0.84	-0.81	-0.81	-0.81	-0.81
Canada	-0.89	-1.02	-1.00	-0.99	-0.89	-0.92	-0.92	-0.94
Japan	-0.04	-0.13	-0.13	-0.12	-0.04	-0.12	-0.12	-0.12
Russia	-1.45	-1.51	-0.84	-1.17	-1.45	-1.50	-1.43	-1.54
Australia	-0.45	-0.45	-0.45	-0.58	-0.44	-0.42	-0.43	-0.51
United States	-0.01	0	0	0	0	0.01	0.01	0.01

Table 9: Proportional allowance allocation – Economy-wide and sectoral competitiveness indicators in 2020

Region / **Scenario**	***EU***		***EU^{+}***		***EU^{++}***		***EU^{+++}***		***EU_CDM***		***EU^{+}_CDM***		***EU^{++}_CDM***		***EU^{+++}_CDM***	
	Terms of Trade impact (in % vs. BaU)															
EU-27	-2.80		-2.80		-2.60		-2.60		-2.50		-2.60		-2.60		-2.60	
Canada	0.80		1.50		1.70		1.80		0.80		1.70		1.70		1.80	
Japan	-2.30		-3.10		-2.90		-2.90		-2.30		-2.70		-2.70		-2.70	
Russia	10.10		10.30		2.20		4.80		9.70		9.60		8.00		8.40	
Australia	2.20		2.20		2.30		1.80		2.10		1.80		1.90		1.90	
United States	-0.30		-0.30		-0.30		-1.00		-0.30		-0.40		-0.40		-0.60	
	Revealed Comparative Advantage – RCA (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	3.72	-0.43	2.86	-0.33	4.96	-0.57	5.10	-0.58	7.33	-0.83	6.28	-0.71	6.49	-0.73	5.89	-0.67
Canada	-19.53	3.17	-1.95	0.35	2.66	-0.33	3.38	-0.41	-20.26	3.30	7.67	-1.00	7.87	-1.03	5.21	-0.63
Japan	-8.60	0.74	2.21	-0.12	4.94	-0.33	4.64	-0.30	-9.11	0.79	6.29	-0.42	6.64	-0.45	5.23	-0.34
Russia	0.66	-0.48	-0.18	-0.06	-23.58	9.69	-19.60	7.88	-1.74	0.38	-3.21	1.13	-8.97	3.37	-9.95	3.84
Australia	-21.74	5.03	-22.7	5.27	-22.56	5.22	-13.09	3.22	-22.27	5.16	-23.75	5.54	-23.57	5.49	-1.45	0.68
United States	-1.57	0.12	-4.88	0.40	-5.64	0.46	-4.64	0.36	-2.62	0.20	-7.62	0.64	-7.50	0.63	-2.85	0.20
	Relative World Trade Shares – RWS (in % vs. BaU)															
	ETS	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*	*ETS*	*NETS*
EU-27	0.63	0.16	-0.25	0.22	1.07	0.07	0.84	0.06	1.81	-0.05	0.51	0.04	0.76	0.02	0.25	0.04
Canada	32.35	1.87	47.05	0.05	51.35	-0.45	51.49	-0.50	31.19	1.93	53.87	-0.90	54.22	-0.93	51.31	-0.62
Japan	40.97	0.27	46.30	-0.08	48.61	-0.22	48.15	-0.22	39.96	0.27	48.28	-0.28	48.69	-0.29	47.59	-0.27
Russia	51.40	-0.77	50.14	-0.38	33.01	7.44	36.03	6.01	49.35	-0.09	47.12	0.59	43.18	2.43	42.27	2.79
Australia	26.09	3.93	24.55	4.13	25.14	4.05	32.83	2.67	25.05	4.01	22.55	4.33	22.93	4.28	44.16	0.52
United States	47.88	-0.16	45.06	-0.05	44.64	-0.04	44.15	-0.04	46.47	-0.14	42.15	0.02	42.34	0.02	43.89	-0.10