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Fair, Optimal or Detrimental? Environmental vs. Strategic Use of Border Carbon Adjustment

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Abstract:
We carry out a detailed sensitivity analysis of border carbon adjustment (rates) by applying a global Computable General Equilibrium (CGE) GTAP7-based model. We find different incentives for the regions in the climate coalition to raise carbon-based border tax rates (BTAX) above the standard rate that mimics an equalisation of carbon prices across regions. Herein, the strategic use of BTAX (the manipulation of the terms of trade) is stronger for all coalition regions than the environmental use (the reduction of carbon emissions abroad). Higher BTAX can reduce carbon leakage but with a declining marginal effect. Furthermore, we find different incentives for regions outside the coalition to oppose high BTAX rates: Russia and the other energy exporters would oppose it, while the Low-Income Countries would not because of benefits from the trade diversion effect. Thus, BTAX encourages the former to join the coalition, while compensating transfers are necessary to encourage the other (developing) countries including China and India.

Keywords: climate policy, border tax adjustment, leakage, trade diversion, coalitions, general equilibrium model

JEL classification: F13, F18, Q5

Highlights:

- Sensitivity analysis of border carbon adjustment (BCA) rate in global CGE
- Typical ‘optimal tariff’ and ‘trade diversion’ effects of BCA
- Strategic (terms of trade) effect dominates environmental effect of BCA
- Incentive for industrial countries coalition to increase border tax (BTAX) rates above ‘fair’ rate
- Compensation payments give better incentives to join coalition than threat of BTAX

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1. Introduction

Economic theory on trade and the environment, in particular the seminal work by Markusen (1975), has derived an optimal tariff that encompasses two terms: a term (a) that influences the terms of trade in Home's favour (given monopolistic power on international markets) and a term (b) that internalises the negative environmental externality caused by Foreign's export production. In the context of climate policy, Hoel (1996) shows that a carbon tax should not be differentiated across sectors if import and export tariffs are available for all traded goods. Such tariffs, also known as border tax adjustment, have recently created a controversy regarding their feasibility for reducing negative competitiveness effects of unilateral climate policy through carbon leakage – that is the relocation of carbon intensive industries to regions without climate policies - and for reducing carbon emissions in general.

Herein, term (a) creates an incentive for policy makers to set a carbon-based tariff higher than the environmentally optimal term (b) in order to influence the terms of trade in their favour. This is especially true in a situation of uncertainty about the true carbon intensities of traded commodities (based on directly created emissions or a full life cycle analysis[4] or the practical assumption that Foreign's emission intensities are equal to Home's emission intensities). Accordingly, there are incentives for policy makers to deviate from the standard carbon tariff rate. This deviation might harm other countries and might be in conflict with WTO legislation (c.f. Bhagwati and Mavroidis, 2007). Due to the uncertainty about the true carbon intensities of products imported from different regions, this deviation can easily occur by chance. Therein, small deviations might or might not have significant effects on Home's and Foreign's welfare and global emissions. These considerations complicate the practical implementation of border tax adjustment policies. Therefore, it appears highly policy relevant to assess how important such effects are. A complex multi-region, multi-sector CGE (Computable General Equilibrium) model using real-world data and capturing relevant intersectoral and international feedback effects is an appropriate instrument to do so. In a related work with a different setting, though, in which Home aims to minimise the costs of unilaterally reaching a given emission target with sectorally differentiated carbon prices and accounting for leakage effects to Foreign, Böhringer et al. (2010b) show that the environmental term (b) is of less importance than the strategic terms of trade effect (a). From a methodological point of view they show that the strategic terms of trade effect can be switched off by compensating Foreign through lump-sum transfers such that its welfare remains at the level without climate policy in Home. Unfortunately, this approach does not carry over to the setting with border carbon

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[4] C.f. Peters et al. (2011).

adjustment where Foreign's welfare is not only affected by changes in the terms of trade, but also by the border tax Foreign has to pay. Also, in Böhringer et al. overall efficiency of abatement in Home and maximising Home's welfare go hand in hand since emission taxes apply to Home sectors only. This is different in a setting with border carbon adjustment. Overall cost efficiency is nevertheless a relevant issue also under border carbon adjustment. Against this background, our first set of research questions can be formulated as: How sensitive is regional welfare with respect to changes in carbon tariffs? How important is the strategic term (a) relative to the environmental term (b)? Are there different incentives for economies within a climate coalition to impose border tariffs that deviate from the standard rate against certain economies outside the coalition? Which countries or world regions will significantly gain or lose?

Concerning term (b) the problem is that it is difficult to assess climate damages and thus the external costs of carbon. Moreover, the value of term (b) depends on the market power of Home that imposes it: Having more market power, Home can induce higher emission reductions in Foreign; thus a higher tariff rate can be optimal from an environmental point of view. In reality, it is overall difficult to determine how high the optimal carbon-based tariff is. Theoretically, it can even be shown in a 2x2 general equilibrium trade model that term (b) can become negative if Foreign's export sector is less carbon intensive than Foreign's non-export sector (Jakob et al., 2011, based on Markusen, 1975) and that an optimal border adjustment is a net import tariff set below the standard Pigouvian rate (Yonezawa et al., 2012). The reason is that border tax adjustment might shift production from exports towards (on average) more carbon intensive non-export production. And in general, in a second best world of existing taxes, tariffs and subsidies, the additional effect of border tax adjustment on top of these is ambiguous. The standard carbon-based tariff rate sets the tariff rate such that the tax bill on imports from Foreign to Home is equal to the tax bill that exporters would have to pay in Foreign if the same carbon price as in Home existed in Foreign. Thus, the standard rate need not reduce global emissions in a (socially) optimal way and the effects of border carbon adjustment on global emissions are not clear-cut. Moreover, policy makers mainly fear that firms will relocate production to regions without a carbon price, which is the "relocation channel" of carbon leakage. Previous model simulations (e.g. Böhringer et al. 2010a), on the contrary, indicate that the reduction in global fossil fuel prices due to climate policy-induced demand reductions, i.e. the "fossil fuel price channel" is clearly the dominant channel. In this sense, our second set of research questions can be phrased as: How sensitive are regional and global emissions with respect to changes in carbon tariffs? How will carbon leakage change when the tariff rate deviates from the standard rate? Is it realistic that very high tariffs can increase carbon leakage? Is the relocation channel or the fossil fuel price channel dominant?

Furthermore, Lessmann et al. (2009) show that under certain conditions, tariffs can encourage non-coalition countries to join a climate coalition as long as the tariff rate is small relative to the Armington elasticity. They show that global welfare rises in the coalition size. In this sense, border carbon adjustment could be a feasible instrument to achieve a large climate coalition. Herein, a third leakage channel occurs, the "free-rider channel". This means a larger climate coalition increases the incentive to leave the coalition and to free-ride on the reduction efforts of the coalition. In the context of carbon-based border measures, a larger coalition can reduce emissions at a lower carbon price, which in turn reduces the carbon-based border measure rates. Thus, the "punishment" for being outside the coalition via border measures decreases and raises free-rider incentives. But again, it is an open question whether these effects are significant. A multi-region, multi-sector CGE model can help assess how this mechanism works, how strong it is and what it implies.[5] Moreover, the linkage of climate policy to trade policy will likely result in trade creation and trade diversion effects (Viner, 1961) between coalition and non-coalition countries. This leads to our third set of research questions: Do carbon-based tariffs indeed give incentives for a larger climate coalition? Is such a coalition stable or is the free-rider channel dominant? How high are the tariff rates that are necessary to induce certain countries (such as China) to join the climate coalition or to achieve a global coalition? Is it better for the coalition to use border measures or (financial) transfers to encourage non-coalition members to join? How pronounced are the trade creation and diversion effects?

To address these questions, we apply a version of the CGE model DART and focus our analysis on the year 2020. Our analysis is closely related to the literature that examines border carbon adjustment in numerical models for climate policy analysis such as Babiker and Rutherford (2005) and Böhringer et al. (2010a). This literature often finds a limited potential of border tax adjustment to reduce carbon leakage. It is furthermore related to the original theoretical literature on border tax adjustment regarding value added taxes such as Meade (1974) and Grossman (1980). They show that a uniform sales tax for all goods is non-distorting and trade-neutral under border tax adjustment of imports and exports. However, this does not hold under border carbon adjustment because tax rates differ depending on the carbon content of goods.

Our analysis is also related to the literature on optimal tariffs: Hamilton and Whalley (1983) find that existing tariffs are "some distance from optimal tariffs" and that there is a high potential for trade wars. Herein, they point out that import price elasticities are crucial parameters for such calculations. Summarising the literature, Mayer (1984) concludes that "political decisions on tariff

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[5] Finus (2008) concludes in his overview article focusing on CGE modeling that there are plenty of opportunities for studying the prospects of cooperation "but also a serious need to improve and further develop current models in order to provide policy guidance…".

rates are reflections of the selfish economic interests of voters, lobbying groups, politicians, or other decision makers in trade policy matters". Gros (1987) shows (based on Krugman, 1980) that the optimal tariff in form of a uniform ad valorem tax is an increasing function of the economy size and of product differentiation. Kennan and Riezman (1988) build on the common view that particularly large economies can manipulate the terms of trade in their favour, while retaliation would make all countries worse off. The authors show that substantially large economies can win despite retaliation. Kennan and Riezman (1990) examine custom unions[6] that are similar to climate coalitions in our context: Custom unions can improve the welfare of their members charging optimal tariffs compared with free trade. According to the authors, the move from a Nash equilibrium to free trade improves global resource allocation, while this is not necessarily the case when moving from free trade to a custom union. Yilmaz (1999) shows that results from a CGE analysis of export taxes differ from those in a partial equilibrium analysis. He finds a higher welfare improvement via Nash revenue maximising taxes than via Nash optimum taxes. Finally, Broda et al. (2008) state that "countries set import tariffs nine percentage points higher on inelastically supplied imports relative to those supplied elastically" exploiting their power on international markets. Despite the long history of theoretical work on optimal tariffs accompanied by statistical estimates, the role of optimal tariffs in an applied CGE framework appears to be not yet fully researched – in particular regarding the current climate policy debate.

Against this backdrop, our paper proceeds as follows: Section 2 describes the CGE model DART and the scenarios under scrutiny. Section 3 addresses our first set of research questions regarding welfare effects. Section 4 addresses our second set of research questions regarding global emissions and leakage. Section 5 addresses our third set of research questions regarding climate coalition formation and trade effects. Section 6 concludes.

2. Model and Scenarios

The DART (Dynamic Applied Regional Trade) model version used in this exercise is a multi-region, multi-sector recursive dynamic CGE model of the world economy.[7] DART is implemented in MPSGE (Mathematical Programming System for General Equilibrium Analysis; Rutherford, 1999), a subsystem of GAMS (General Algebraic Modeling System; Brooke et al. 2010), using PATH (Dirkse and

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[6] The theory of custom unions goes back to Viner (1961). He shows that a custom union has a trade creation (replacement of domestic production by imports) and a trade diversion effect (replacement of imports from outside by imports from inside the union).

[7] For more details see http://www.ifw-kiel.de/academy/data-bases/dart_e/a-short-description-of-dart/view?set_language=en.

Ferris 1995) for solving the MCP (mixed complementarity problem). This version of DART is calibrated to an aggregation of 9 regions:

USA - United States, RUS - Russia, EUR - EU27 and EFTA , RA1 - Other Annex I except Russia, EEX - Energy Exporting Countries except Mexico, CHN - China, IND - India, MIC - Other Middle-Income countries, LIC - Other Low-Income Countries.

It distinguishes 9 sectors:

OIL - Refined oil products, COL - Coal, GAS - Natural Gas, CRU - Crude Oil, ELE - Electricity, CRP - Chemical Products, TRN - Transport Services, EIT - Emission Intensive Trade Goods, AOG - All Other Goods.

The model distinguishes four production factors: labour, capital and land and natural resources (fossil fuels). In order to analyse climate policies, CO_2 emissions are calculated based on the carbon contents of the fossil fuels coal, gas and oil burned in final or intermediate production or consumption.

We assume perfect commodity and factor markets. In each region, there is one representative consumer who incorporates private and public consumption, and one representative producer for each sector. Producer behaviour is derived from cost minimisation for a given output. The final consumer receives all income generated by providing primary factors for production. A fixed share of income is saved, while the remaining income is used for purchasing commodities. Herein, the linear expenditure system (LES) first satisfies basic demand. The remaining consumption good is a composite of an energy aggregate and a non-energy aggregate.

Labour and capital are homogenous goods, mobile across industries within regions, but immobile across regions. All regions are linked by bidirectional trade flows of all commodities except the investment good. Domestic and foreign commodities are imperfect (Armington) substitutes distinguished by the country of origin. The trade balance of each country is kept constant relative to total (private plus government) consumption.

The DART model is recursive-dynamic. It solves for a sequence of static one-period equilibria for future time periods. The major exogenous, regionally different driving factors of the model dynamics are population growth, labour productivity growth, human capital growth and capital accumulation. Population growth rates and labour participation rates are taken from the PHOENIX model (Hilderink 2000) in line with recent OECD projections. Growth rates of human capital are taken from Hall and Jones (1999). Capital accumulation is driven by an exogenous depreciation and savings rates. The model horizon in this exercise is 2020.

The static part of the DART-Model is calibrated to the GTAP 7 database (Narayanan and Walmsley 2008) for the benchmark year 2004. For the dynamic calibration we match GDP growth and CO_2 emissions of the business as usual (BAU) scenario to the OECD Environmental Outlook (OECD 2012) by adjusting total factor productivity growth to approximately match the GDP growth and the elasticities of fossil fuel supply to match global CO_2 emissions. This leads to an average per capita growth rate between 7% in CHN and 1.5 to 1.8% in coalition countries. Global energy-related CO_2 emissions reach 34.5Gt in 2020 with 13.4Gt stemming from the coalition countries, followed by China that contributes 9.6Gt. In all regions, the output of the energy sector grows more slowly than the output of the other production sectors. Only in CHN and IND the emissions and trade-intensive sectors (EIT, CPR) grow noticeably faster than other sectors (AOG).

In the **business as usual (BAU) scenario**, no climate policy is assumed. The **reference scenario (REF)** assumes a 20% reduction below 2005 emissions in a coalition consisting of Europe, the USA and Annex 1 countries except Russia (EUR, RA1, USA). The level of global emissions in 2020 in REF (and all following scenarios that include climate policy) is fixed at BAU emissions in 2020 of the non-coalition plus 80% of the 2005 emissions of the coalition countries. Globally, this leads to a 10.3% emission reduction in 2020 relative to BAU. The reductions are reached via an endogenous uniform carbon tax in all coalition countries that ensures the targeted global emission level. Since there is carbon leakage to non-coalition countries, the coalition in general ends up reducing more than 20% in 2020. Climate policy starts in 2010 and emission reductions in the coalition countries are implemented as linear reductions until 2020.

In order to cope with the negative effects of unilateral policies, coalition members impose **border tax adjustments (BTAX)** to the emission and trade intensive sectors (OIL, CRP, EIT). We apply full border tax adjustment such that coalition exporters receive rebates for what they paid for using carbon inputs, besides levying border taxes on imports based on the carbon content of the imported goods. In the central BTAX scenario, we apply the carbon tax in the coalition countries as the standard BTAX rate reflecting the carbon content of trade based on direct emissions and emissions caused by electricity generation (for a discussion on alternative calculations see Böhringer et al., this issue). This has the aim to fully level off the carbon playing field on international markets and could thus be seen as a kind of “fair” rate. The tax revenues are in a lump-sum fashion transferred to the representative consumer of the importing country who also pays for the export rebate in a lump-sum fashion.

Since, as described above, global emissions are held constant in all climate policy scenarios, global and regional climate change damages (not represented in the model) stay constant and do not influence the welfare analysis.

[Table 1 about here.]

Table 1 presents the border measure rates for 2020 as well as pre-existing (combined ad valorem export and import) tariff rates in percent showing that there are large differences in the overall importance of the border measures and also their importance relative to pre-existing trade measures. The differences will determine the resulting welfare effects analysed in section 3. According to the table, carbon-based BTAX rates for imports from non-coalition to coalition countries in 2020 range from 0.4 to 18.5 %. For the EIT sector, tariff rates are higher than for OIL and CRP (except for Russia where CRP is highest); between 10.9% for India and 15.1% for LIC goods. EIT goods from MIC are less carbon intensive and therefore taxed lower. Export rebates are much lower than import tariff rates and amount to 0.6 to 2.5%. The reason is that the export rebates are determined based on the emission intensities of developed coalition countries inside the climate coalition which are lower than those of developing countries outside the coalition. This explains why export rebates have a small additional impact compared to import tariffs. In order to assess the overall importance of the border carbon measures, we calculate the trade-flows-weighted average tariff rate for total trade between non-coalition and coalition countries (lines "all") in 2020. This yields an average tariff rate of only 0.6% for imports to Europe, 0.7% for imports to RA1, and 0.9% for imports to USA. Exports from RUS into the coalition are subject to a considerably higher average carbon tax rate, as the share of goods subject to border measures is high. Concerning the pre-existing tariffs, Table 1 shows that these are particularly high in Russia and here especially in the oil sector (mainly export levies).

As discussed above, there are presumably incentives to deviate from the standard rate. In our model analysis, we therefore multiply the border measure rate in the time period 2010 to 2020 with a constant factor that we vary in a sensitivity analysis. Two special cases are worth mentioning: If the multiplier is zero, no border measures will be imposed as in scenario REF. If the multiplier is set to unity, the standard rate, i.e. the equalisation of carbon prices for coalition imports and coalition production, will be reached.

Furthermore, to analyse the incentives of border measures to join a global coalition, we run one additional climate policy scenario, where the same global emissions as in the other climate policy scenarios are reached via a globally uniform carbon tax.

3. Welfare Effects

This section examines the sensitivity of regional welfare with respect to changes in carbon tariffs, the importance of the strategic relative to the environmental part of the tariff and the incentives for different regions to deviate from the standard border tax rate.

[Figure 1 about here.]

Figure 1 plots first of all the change in coalition welfare in the presence of border tax adjustment at different rates relative to the business as usual (BAU). Welfare effects are measured as percentage changes in accumulated, discounted welfare effects based on the relative Hicks equivalent variation relative to the BAU scenario.[8] Obviously, a typical "optimal tariff picture" emerges for the coalition countries: Higher border measure rates improve the terms of trade (TOT)[9] of the coalition since it decreases import prices and increases export prices. E.g. when doubling the standard rate (factor 2 instead of 1) the TOT increase by 0.1% for EUR and by 0.2% for the USA and RA1. This translates into welfare changes as well, but after a certain point higher rates reduce welfare.[10] As expected, all coalition regions have an incentive to set the border measure rate above the standard rate. The extent to which regional decision makers would augment existing tariff (and export subsidy) rates differs across regions, though. Europe (EUR) has a high potential for benefitting from increased tariff rates. The maximum for EUR lies at a multiplier of 10.7. The USA's potential is somewhat lower than the average potential of the coalition with a maximum around the factor 5.6. For the other Annex I countries (without Russia) the maximum is only at a factor of about 2.9. The welfare of the entire coalition is maximised around the factor 6.2. Differences in the optimal level of border measures stem from different trade and production structures of the coalition members, differences in the level of border tariffs resulting from different carbon intensities and differences in pre-existing tariff rates. If a coalition country has for example a high share of carbon-intensive imports or a high share of OIL, CRP or EIT products from carbon-intensive countries, this will result in high tariffs, but also in high welfare costs as the consumer has to substitute imports by other goods. The carbon tariff as a value share over total imports from non-coalition countries is highest in RA1 (0.9%), lower in EUR (0.7%) and the USA (0.6%). At the same time, export rebate rates are higher in RA1 and the USA (0.3% of export value for exports to non-coalition) and lower in EUR (0.1%) when

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[8] Accumulated over the time frame 2004 to 2020 with yearly time steps and discounted at a rate of 2% per year.

[9] The terms of trade are computed in form of a Laspeyres price index for exports divided by imports.

[10] This outcome becomes intuitive when thinking of a monopolist who raises the price of his product to the optimal level above the competitive level. If he has at the same time market power on factor markets, he will reduce the price of the inputs he uses below the competitive level.

applying an equal multiplier for all regions in the coalition. Pre-existing tariff rates and trade costs are slightly lower for the USA compared to EUR and RA1. As a consequence, the same BTAX rate implies a higher relative rise in overall tariffs in the USA than in EUR and RA1 and has thus stronger effects.

We discussed the distinction between the strategic part of border measures and the environmental part in the Introduction. In our analysis, the strategic term is represented by changes in the terms of trade. In our model that does not include climate damages, the question is how to interpret and identify the environmental term. Existing approaches, as e.g. in Böhringer et al. (2010b) that was discussed in the introduction, do not carry over to our setting where in particular overall efficiency of abatement and maximisation of coalition welfare do not go hand in hand. Overall cost efficiency that is underlying the environmental term in Böhringer et al. is nevertheless a relevant issue in our analysis. It can be deduced in our case from looking at global welfare across different adjustment rates (also shown in Figure 1)[11]. The level of the adjustment factor that minimises global abatement costs and that is efficient from an environmental point of view is 1.3 which is considerably lower than the levels that maximise the welfare level of the individual coalition countries or the coalition as a whole. Under this interpretation of the environmental motive, it is thus mainly the strategic motive that drives the optimal adjustment factors to levels much higher than 1.3. Compared to BAU, climate policy without border measures reduces global welfare by 0.5%. This does not take reduced climate change damages into account. Border measures can reduce the global welfare loss to 0.4% at the best because the inefficient distribution of abatement is reduced by broadening the base for the carbon tax (see overview article, this issue).

Another way to identify the environmental motive in our setting is that the coalition suffers negative welfare effects from emission leakage that requires it to abate more to keep global emissions constant. Border carbon adjustment thus increases coalition welfare by reducing leakage and requiring lower emission reductions in the coalition countries to reach the same global target (see section 4). In order to separate the strategic effect, we run an additional scenario where we fix emission reductions of the coalition and allow global emissions to change. In such a scenario, welfare changes in the coalition countries only stem from the strategic effect while the environmental effect through reductions in carbon leakage as we explained it above is completely ignored and switched off.

[Figure 2 about here].

Figure 2 plots the welfare change of the coalition relative to climate policy without border adjustments. When determining the welfare maximising border measure as above, the coalition

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[11] Global welfare is calculated as the income weighted sum of individual regions welfare changes.

makes use of a strategic effect improving its terms of trade and an environmental effect. The latter stems from the fact that border measures reduce leakage, thus making the reduction target of the coalition less strict when global emissions are held constant. This effect will be switched off when coalition reductions are fixed to their level in REF. Figure 2 shows that for low adjustment rates the strategic effect dominates. At the standard border measure rate it accounts for 80% of the total effect. For the individual regions, the strategic effect is most important for EUR, where the 88% of the total effect are due to the strategic part. For the USA and RA1 the decomposition attributes 72% and 62% of the total effect to the strategic effect, respectively. It turns out that only at very high border measure rates the environmental effect becomes dominant. Current climate policy usually formulates fixed reduction targets, independent of leakage to non-coalition countries, which neglects the environmental effect. For such policies, the welfare maximising border measures are closer to the standard rate, albeit still higher. With the strategic effect only, coalition welfare is maximised at 4.2 times the standard rate and for the individual regions EUR, USA, and RA1 at 7.7, 3.8, and 1.9 times the standard rate, respectively.

Another indicator for the environmental benefit of border measures is the CO_2 price in the coalition. It depends on different border measure rates and drops from about 75 to about 66 2004-US-$ when raising the border measure rate from 0 (REF) to a factor of 8. This happens because the global emissions are held constant: The coalition can afford smaller emission reductions when carbon leakage to non-coalition regions decreases. If not global emissions, but the emission reductions of the coalition are held constant, the price effect reverses. Increasing the border measure multiplier from 0 to 8 leads to an increase of the CO_2 price from 75 to 80 2004-US-$.

Note that for more stringent climate targets of the coalition, Figures 1 and 2 remain similar in their shape; however, the welfare maximising BTAX multiplier would be lower. The intuition behind this is that the welfare optimising tariff is largely determined by pre-existing tariffs and the economic structure of the coalition regions which remain similar between scenarios. More stringent climate policy with a higher CO_2 price therefore leads to a lower multiplier and reduces the incentive to deviate from the “fair” rate.

[Figure 3 about here.]

Figure 3 plots the optimal adjustment factor, this means it plots only the adjustment factor given by the maximum point in Figure 1, now plotted for different years. Obviously the optimal adjustment factor declines over time for each region. This happens because the carbon price rises over time within the coalition, which results in a rising standard rate of the border measure. Therefore, the strategic part that we identified as the dominant term is reduced in order to keep the export and import prices at the optimal level for the Home region. Nevertheless, the optimal rate is still well above the standard rate in 2020 for all regions.

[Figure 4 about here.]

Figure 4 shows the change in non-coalition welfare in the presence of border measures at different rates relative to BAU (like Figure 1 for the coalition). It is obvious that the welfare change without border measures (factor 0, REF) is larger than the changes due to higher or lower border measures. The driving factor for the difference across regions is the so-called "fossil fuel price effect". Climate policy implies a reduced demand for fossil energy and thus also reduced fossil fuel prices net of carbon costs. This is in tendency welfare enhancing for major energy importing countries (like CHN, IND) and welfare reducing for major energy exporters (RUS, EEX). For different levels of border measures, the welfare effect reaches a minimum within the range of tariff rates under examination in the upper graphs (IND, CHN, MIC and LIC) wherein the welfare effects are relatively small, though. Russia (RUS), where energy exports are a major share of GDP and exports are subject to relatively high border measures (see Table 1), is hit hardest by border carbon adjustment, followed by the other Energy Exporting Countries (EEX). The Low-Income Countries (LIC) lose to a smaller extent, but they gain at high border measure rates. In these countries, exports from sectors subject to border measures only account for a quarter of imports in the same sectors, i.e. LIC benefits from export rebates but is hurt relatively little by increases in import tariffs of the coalition. Furthermore, LIC's ratio of trade with non-coalition members versus trade with coalition members is higher than in other regions. Trade within the group of non-coalition members increases, and the terms of trade improve in LIC's favour. The Middle-Income Countries (MIC) lose to a small extent at high rates. All rates appear slightly beneficial for China (CHN) and significantly beneficial for India (IND).

4. Carbon Leakage

Carbon-based border measures are supposed to reduce carbon leakage to regions without a carbon price.[12] Therefore, this section examines the sensitivity of regional and global emissions and carbon leakage with respect to changes in the carbon tariff rates. Since we keep global emissions constant in our scenarios, a reduction in leakage abroad allows for a more generous emissions target at home. In this way we capture the environmental benefit of border measures for the home region.

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[12] The leakage rate is defined as the increase in emissions in the regions without an emission cap (CHN, IND, RUS, EEX, MIC, LIC) divided by the decrease in emissions in the coalition (EUR, USA, RA1).

[Figure 5 about here.]

Figure 5 shows the global leakage rate including all non-coalition countries at the uppermost line. The coloured parts below the upper line illustrate to what extent specific regions contribute to *global* leakage. (They do not show regional leakage rates). The global leakage rate is 19.6% without border measures, 17.9% for the standard border measure rate and 13.3% for eight times the standard rate. Accordingly, increased border measure rates have the potential to reduce total leakage by almost 8% when setting the rate to eight times the standard rate. Herein, the curve flattens at higher rates. This means, the (marginal) potential for reducing leakage declines at higher rates. The Middle-Income Countries (MIC), China (CHN) and India (IND) contribute most due to their size. The Low-Income Countries (LIC), Russia (RUS) and the Energy Exporting Countries (EEX) contribute to a small extent. We find no evidence for increased leakage due to border measures. This is in line with our finding that the environmental effect is always positive for the range of border measures we examine (see section 3). Besides the magnitude of leakage from different regions, the reaction of leakage rates to higher border measures is also important. While leakage to energy exporters (RUS, EEX) is reduced significantly with higher border measures, leakage to IND, MIC and LIC is more robust. This shows that leakage to these regions is mainly determined by the original climate policy while BTAX has only a small effect. The effect of BTAX on leakage to CHN is somewhat higher, probably because on the one hand China is a fossil fuel importer, but on the other hand higher border measures also reduce production relocation to China.

To better understand the channels of leakage we also undertake additional runs where the fossil fuel (coal, gas and crude oil) prices are held constant at their BAU levels by adjusting the endowments of the fossil fuel resources in all model regions. In these runs, the fossil fuel price channel of carbon leakage is not present. We find that although the overall leakage rate is significantly reduced (from around 20% in the case of no border carbon adjustment and flexible fuel prices to around 1%), border carbon adjustment still reduces carbon leakage compared to a scenario without border carbon adjustment. The percentage point reduction in leakage due to border measures actually remains almost the same (around two percentage points at the standard rate). This shows that the fossil fuel price channel is the dominant leakage channel of the original climate policy and that this channel can hardly be rendered ineffective via border measures.

5. Stability of the Climate Coalition

This section explores to what extent border measures can help create a larger climate policy coalition. It also explores the role of trade creation and diversion effects between coalition and non-coalition regions.

[Table 2 about here.]

We basically compare the situation of a grand coalition, this means a global climate policy coalition including all countries (regions), to the situation of the small coalition (consisting of USA, EUR and RA1) and the non-coalition (consisting of CHN, IND, MIC, LIC, EEX and RUS) that we have considered throughout the paper. In each case, the respective coalition has implemented a uniform carbon price across all regions and sectors in the coalition in order to reach the same global environmental outcome as in REF. Table 2 summarises our coalition stability analysis. The left bloc deals with the grand coalition without compensation transfers. The left column reports the regional welfare changes (accumulated and discounted year by year from 2004 to 2020) between being in the grand coalition and being in the non-coalition facing border carbon adjustment imposed by the coalition (at the standard rate). As expected, the world as a whole benefits from the formation of a grand coalition compared to the previous small coalition with border measures. This shows that super-additivity holds, i.e. total coalition welfare increases in the coalition size. Among the non-coalition regions, China (CHN), India (IND), the Middle-Income Countries (MIC), and Low-Income Countries (LIC) are worse off and would thus prefer being in the non-coalition. Energy Exporters (EEX) and Russia (RUS) would clearly prefer joining a global coalition instead of facing border measures – even without border carbon adjustments, represented by an adjustment factor of zero in the second column of Table 2. This is due to the following reasoning: The grand coalition abates a higher share of emissions from coal compared to a sub-global climate coalition. This leads to a higher share of oil in the global fuel mix in the grand coalition scenario and EEX and RUS therefore profit from higher oil prices and resource rents. This applies to the standard border measure rate. Higher border measure rates increase the cost of not joining the coalition though. However, they turn out to be only effective in incentivising CHN and MIC to join the grand coalition and only at very high BTAX rates of six to ten times the standard rate as shown in the second column.[13] LIC and IND, on the contrary, will never prefer being in the grand coalition within the scope of our feasible parameter space, even not at very high BTAX rates.

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[13] In this exercise, we raise the BTAX rate that all non-coalition countries face and find that at an adjustment factor of 6.6 MIC is indifferent between being in the grand coalition and being in the non-coalition, while at an adjustment factor of 10.0 CHN is indifferent between these situations. Herein, the non-coalition encompasses the same members as before.

Instead of threatening non-coalition countries through border measures, *compensation transfers* can create an incentive to join the grand coalition. We thus run a scenario where – everything else equal – we achieve global cost effectiveness via full international carbon trading and allocate "surplus allowances" to certain regions such that they become indifferent between being in the grand coalition and being in the non-coalition together with the other non-coalition regions and facing border carbon adjustment. This situation is shown in the middle bloc of Table 2. The fourth column of Table 2 lists the additionally allocated surplus allowances in Mt CO_2 per year.[14] Multiplying the volume of surplus allowances by the carbon price and discounting at 2% yields the monetary value of the transfer in 2010 which is shown in the sixth column of Table 2. For simplicity we assume that the volume of allowances that the original coalition regions USA, EUR and RA1 transfer is equally distributed across them. It is an endogenous model result though that the resulting welfare changes for these regions relative to the BTAX scenario with the standard rate are also equal. As can be seen from the table, EUR, USA, and RA1 are still better off in the global coalition with compensation transfers than in the small coalition with border carbon adjustment.

In addition to this exercise where compensation assures indifference between the grand coalition and the small coalition with BTAX, we examine compensation transfers that achieve indifference between being in the grand coalition and being in the non-coalition without border carbon adjustment. The latter is our scenario REF. The resulting transfers are reported in parentheses in the middle bloc of Table 2. The difference between the compensation transfers in these two cases reveals how valuable a credible threat of border carbon adjustment is for the original coalition regions: The underlying reasoning is that non-coalition members presumably have lower welfare when facing BTAX than when not facing BTAX. The welfare difference between the grand coalition and the BTAX case is thus expected to be smaller than between the grand coalition and the REF case. This results in smaller compensation transfers when border carbon adjustment exists as a credible policy instrument. And indeed, we find that the compensation transfers with respect to the BTAX scenario are substantially lower than with respect to the REF scenario (values in parentheses). The reduction in compensation payments for each coalition member due to BTAX amounts to (a discounted value of) 8.5 billion 2004-US-$. This reduction can largely be attributed to lower surplus allowances for China which receives 25% fewer surplus allowances, and for MIC which receives 20% fewer surplus allowances.

Once a grand coalition has been formed, there can still be an incentive for single regions to leave the grand coalition and free-ride as singletons (rather than being in a non-coalition together

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[14] For simplicity we keep surplus allowances in each simulation step constant over the whole reduction period 2010 to 2020.

with other regions as examined before). Hence, we also test whether the global grand coalition is stable in terms of internal stability. For this purpose, we compute the welfare change between being in the grand coalition and being the only region outside for each region except the core regions USA, EUR and RA1.[15] We assume that when a country leaves the coalition, it will face border carbon adjustment at the standard rate imposed by all regions within the coalition and will not receive any compensation payments anymore. A priori, it is not clear whether border measures are still a useful threat: On the one hand, all other regions are members of the coalition and impose border measures. On the other hand, the CO_2 price and therefore also the standard border measure rate are much lower than in a smaller coalition because the given global emission reduction can be achieved more efficiently. Indeed, our results indicate an incentive for CHN, MIC, LIC and EEX to be a single non-coalition region. For EEX this is somewhat surprising since EEX seems averse to border measures in our previous analysis (see section 3). EEX will obviously be affected differently in the case of low border measures imposed by all other regions than in the case of high border measures imposed by EUR, USA and RA1 only.

A stable grand coalition can still be achieved by granting additional allowances as a "stability premium" for *all* potentially deviating regions at the same time, paid by the core regions, EUR, USA and RA1.[16] This compensation scheme is shown in the right bloc of Table 2. The stability premium increases the costs of compensation payments by 19% compared to the previous compensation scheme.

Looking at the core coalition countries (EUR, USA and RA1) under different BTAX rates, only EUR would be better off with a small coalition and a BTAX rate of more than 4.6 the standard rate compared to a global regime with a uniform global carbon price and no border adjustments. The USA and RA1 are always better off in a global coalition. Yet, when shifting the burden sharing of compensation payments towards RA1 and USA, it is possible to reach an outcome in which all coalition countries would prefer a global coalition.

[Figure 6 about here.]

Let us now look at trade between the standard small coalition (EUR, USA and RA1) and the non-coalition. Figure 6 illustrates *trade creation and diversion* effects between the coalition and the non-coalition in 2020. Real trade flows into and out of the coalition regions are computed as the sum

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[15] It would also be beneficial for EUR, USA, and RA1 to drop out of the coalition. However, our initial policy assumption is that this small coalition has to reduce global emissions by a given amount based on the assumption that the industrialised (Annex-I) regions are the front-runners of climate policy. Allowing one of these regions to drop out would not be consistent with this assumption.

[16] Again, the caveat described in footnote 15 applies, as it would be beneficial for EUR, the USA and RA1 to drop out of the grand coalition.

of import into the coalition and export values, respectively. The figure illustrates the typical trade diversion effect of custom unions: Trade increases within the coalition and within the non-coalition; but trade decreases between the two groups. Compared to the situation without border measures, imports into the coalition are reduced and thus replaced by domestic production. Furthermore, since the coalition as an aggregate cannot (substantially) change its trade deficit with the non-coalition countries by assumption, a lower import value leads to a lower export value in spite of tax rebates on coalition exports. Since the average import tariff rates of the coalition are higher than the export rebate rates (see Table 1), the import changes drive the export changes in the coalition countries. Coalition exports in the sectors subject to border measures however increase with higher export rebate rates. Without border measures they drop by 6.6% relative to BAU. Introducing border measures now has two effects: First, there is a shift from exporting to supplying to the domestic market because import tariffs reduce supply from abroad. Second, the opposite shift occurs due to the export rebates. At the standard level of border measures the former outweighs the latter and exports are reduced by 8.0% below BAU or 1.5% below REF. Further increases in the border measure rate then lead to an increase in exports, however still below the BAU level when applying eight times the standard rate. Coalition imports in these sectors react more sharply to border measures. Without border measures, imports increase by 7.4% above BAU due to production relocation. At the standard rate, the import level is already reduced by 11.8% below BAU. The level is below BAU because production outside the coalition is more carbon intensive compared to production in the coalition, which leads to higher relative prices for imported goods when the carbon price is taken into account. When further increasing the border measure rate to 8 times the standard rate, coalition imports in the affected sectors will be reduced by up to 70%.

6. Conclusion

Our global CGE analysis reveals different incentives for the regions in the climate coalition – USA, Europe, and the other Annex-I countries – to raise carbon-based border tax rates above the standard rate that mimics an equalisation of carbon prices across regions. We find the strongest incentives for Europe and still a significant incentive for the USA. We also find that the strategic use of border measures (the manipulation of the terms of trade) is stronger for all coalition regions than the environmental use (the reduction of carbon emissions abroad). According to our results, there is a risk that policy makers misuse border measures for strategic reasons in the presence of market power on international markets – but there is an upper limit on increasing tariffs. With rising carbon prices over time, the welfare-optimising tariff approaches the standard rate based on the carbon content of trade. Not exploiting the environmental effect further lowers the incentive to apply higher than standard rates. However, for all coalition regions there remains an incentive to set border measures in excess of the standard rate in 2020. The WTO is justified therefore in wanting to ensure that if border measures are employed, they are limited to levels justified by the environmental benefits.

Furthermore, the sensitivity of non-coalition countries' welfare to increasing border tax rates above the standard rate appears diverse: Russia and the other energy exporters lose strongly, while China, India and the Middle- and Low-Income Countries are hardly affected. The Low-Income Countries might even slightly gain from the resulting trade diversion effect: Trade decreases between the groups of coalition and non-coalition countries, but it increases within each group. As a consequence, the Low-Income Countries can benefit from increased trade with other non-coalition countries. According to these results, some countries like Russia and other energy exporters might strongly oppose the introduction of border measures, arguing that the misuse would be harmful. Other countries like developing countries would hardly exert this argument.

Our results also confirm in accordance with the literature that carbon-based border measures have a significant but limited potential for reducing carbon leakage. Higher border tax rates are able to reduce leakage, but the marginal leakage reduction declines with higher border tax rates. Furthermore, we do not find evidence for positive leakage which is theoretically possible. Finally, we confirm that the fossil fuel price channel of leakage (through climate policy induced changes in fossil fuel prices) is far more important than the relocation channel.

Finally, carbon-based border measures can encourage certain regions like Russia and other energy exporters to join a climate coalition. Border measure rates much higher than the standard rate can make China and the Middle-Income Countries indifferent between being within the global coalition and facing border measures outside the coalition. International compensating transfers, in form of additional emission allowances, for instance, appear to be a more efficient instrument (regarding coalition welfare) to create a stable global (grand) coalition than border measures.

Overall, our paper confirms previous findings that there are incentives for countries outside global coalitions that unilaterally undertake climate policy to implement border measures. Mainly for strategic reasons this increases their welfare. Yet, border measures are not a good substitute for an efficient global carbon policy with a uniform global carbon price. They do not provide strong incentives to participate in a global climate regime for all regions either. This is especially true for India and the least developed countries.

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8. References

Babiker, M.H. and T.F. Rutherford (2005). The Economic Effects of Border Measures in Subglobal Climate Agreements. Energy Journal 26(4), 99-126.

Bhagwati, J. and P.C. Mavroidis (2007). Is action against US exports for failure to sign Kyoto Protocol WTO-legal? World Trade Review 6(2), 299-310.

Böhringer, C., C. Fischer and K.E. Rosendahl (2010a). The Global Effects of Subglobal Climate Policies. The B.E. Journal of Economic Analysis & Policy 10(2), Article 13.

Böhringer, C., A. Lange and T.F. Rutherford (2010b). Optimal Emission Pricing in the Presence of International Spillovers: Decomposing Leakage and Terms-of-Trade Motives. NBER Working Paper 15899. NBER, Cambridge.

Böhringer, C., B. Bye, T. Fæhn and K.E. Rosendahl (this issue). Alternative Designs for Tariffs on Embodied Carbon: A Global Cost-Effectiveness Analysis.

Broda, C., N. Limao and D.E. Weinstein (2008). Optimal Tariffs and Market Power: The Evidence. The American Economic Review 98(5), 2032-2065.

Brooke, A., D. Kendrick and A. Meeraus (2010). GAMS: A User's Guide. Tutorial by R. Rosenthal. GAMS Development Corporation, Washington, DC, USA, http://www.gams.com/dd/docs/bigdocs/GAMSUsersGuide.pdf (accessed 08/2011).

Dirkse, S. and M. Ferris (1995). The PATH Solver: A Non-monotone Stabilization Scheme for Mixed Complementarity Problems. Optimization Methods and Software 5, 123-156.

Finus, M. (2008). Game Theoretic Research on the Design of International Environmental Agreements: Insights, Critical Remarks, and Future Challenges. International Review of Environmental and Resource Economics 2, 29-67.

Gros, D. (1987). A note on the optimal tariff, retaliation and the welfare loss from tariff wars in a framework with intra-industry trade. Journal of International Economics 23(3-4), 357-367.

Grossman, G.M. (1980). Border-Tax Adjustments - Do they distort trade? Journal of International Economics 10, 117-128.

Hamilton, B. and J. Whalley (1983). Optimal Tariff Calculations in Alternative Trade Models and Some Possible Implications for Current World Trading Arrangements. Journal of International Economics 15, 323-348.

Hilderink, H.B.M. (2000). PHOENIX plus: the population user support system version 1.0. http://themasites.pbl.nl/phoenix.

Hall, R.E. and C.I. Jones (1999). Why Do Some Countries Produce So Much More Output Per Worker Than Others? The Quarterly Journal of Economics 114(1), 83-116.

Hoel, M. (1996). Should a carbon tax be differentiated across sectors? Journal of Public Economics 59(1), 17-32.

Jakob, M., R. Marshinski and M. Hübler (2011). Between a Rock and a Hard Place: A Trade-Theory Analysis of Leakage under Production- and Consumption-Based Policies. Potsdam Institute for Climate Impact Research, Germany. Working paper available upon request.

Kennan, J. and R. Riezman (1988). Do Big Countries Win Tariff Wars? The Canadian Journal of Economics 23(1), 70-83.

Kennan, J. and R. Riezman (1990). Optimal Tariff Equilibria with Customs Unions. International Economic Review 29(1), 81-85.

Krugman, P. (1980). Scale Economies, Product Differentiation, and the Pattern of Trade. The American Economic Review 70(5), 950-959.

Lessmann, K., R. Marschinski and O. Edenhofer (2009). The effects of tariffs on coalition formation in a dynamic global warming game. Economic Modelling 26, 641-649.

Markusen, J.R. (1975). International externalities and optimal tax structures. Journal of International Economics 5, 15-29.

Mayer, W. (1984). Endogenous Tariff Formation. The American Economic Review 74(5), 970-985.

Meade, J.E. (1974). A Note on Border-Tax Adjustment. Journal of Political Economy 82(5), 1013-1015.

Narayanan B.G., and T.L. Walmsley (2008). Global Trade, Assistance, and Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University, West Lafayette, IN, USA.

OECD (2012). OECD Environmental Outlook to 2050: OECD Environmental Outlook to 2050: The Consequences of Inaction. Organisation for Economic Co-operation and Development.

Peters, G., J. Minx, C. Weber and O. Edenhofer (2011). Growth in emission transfers via international trade from 1990 to 2008. PNAS 108(21), 8903-8908.

Rutherford, T.F. (1999). Applied General Equilibrium Modeling with MPSGE as a GAMS Subsystem: An Overview of the Modeling Framework and Syntax. Computational Economics 14, 1-46.

Viner, J. (1961). The customs union issue. Anderson Kramer Associates, Washington, DC, USA.

Yonezawa, H, E.J. Balistreri and T. Kaffine (2012). The suboptimal nature of applying Pigouvian rates as border adjustments. http://www.webmeets.com/files/papers/AERE/2012/136/leakthry11.pdf

Yilmaz, K. (1999). Optimal export taxes in a multicountry framework. Journal of Development Economics 60(2), 439-465.

9. Supplementary online appendix

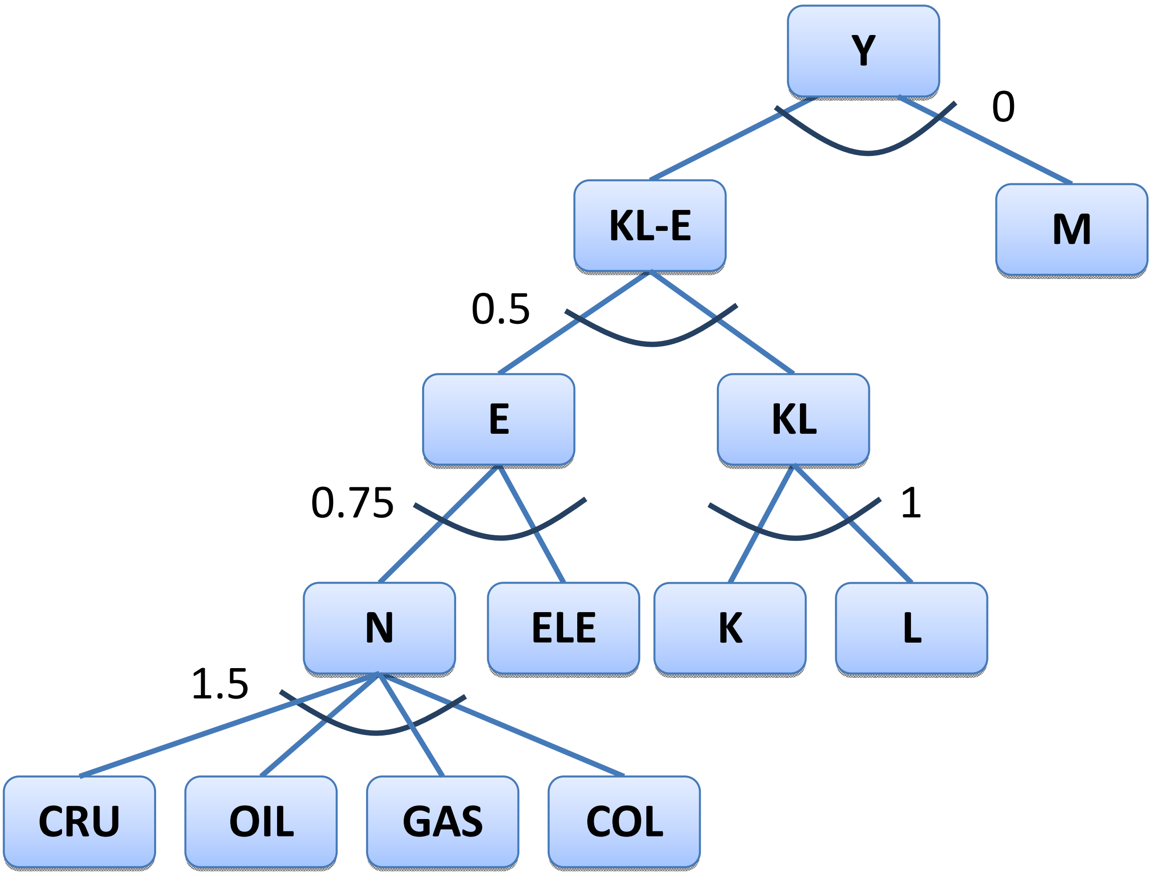

Figure A1: *The main CES production structure and substitution elasticities for each sector and region. Y = output, K = capital, L = labour, E = energy, M = intermediates, N = non-electricity. Fossil fuel inputs (crude oil, refined oil, natural gas and coal) are associated with CO_2 emissions in fixed proportions. For the production of refined oil, input of crude oil and coal are treated as intermediates M at the top nest (Leontief), no direct carbon emissions are associated with the use of this energy feedstock. The remaining fossil fuels (crude oil, natural gas and coal) use a fixed resource at the top nest. The elasticity between the fixed resource and the remainder of the production function is scaled to achieve a given global supply taken from OECD (2012).*

This section lists the *key model equations*, i.e. it describes the model in a stylised way that highlights the principal structure. The model equations are written as a *mixed complementarity problem (MCP)* for each region (*r*) and each period (*t*). An MCP consists of zero-profit and market clearance conditions and a consumer's budget condition. The model equations are implicitly programmed under GAMS/MSPGE. p denotes a price, X denotes a pecuniary quantity. i or j denote a sector described. f denotes a production factor such as capital (K) and labour (L) and in case of fossil fuel extraction also natural fossil resources. $\theta_{f,i}^{G}$ represents a set of taxes and subsidy rates on output and inputs. M indicates an Armington (intermediate) good. C is CO_2 associated with fossil fuel inputs in fixed proportion. π denotes profits, CES a constant elasticity of substitution function, and LTF a Leontief function.

I. Zero-profit conditions:

(Z1) Goods (Y) production (in sectors *i*) as shown in detail in Figure A1.

$$\pi_i^Y = p_i^Y - CES_i^Y\left(p_f^F, p_j^M, p^C \middle| \theta_{f,i}^G\right) \leq 0 \;\; \forall\, (r,t)$$

(Z2) Armington aggregation (M), combining imports from foreign regions (s), associated with a price for transportation ($p_{s,r,i}^T$) in a first step (M1) and then building an aggregate with domestic goods (M2):

$$\pi_i^M = p_i^M - CES_i^{M2}\left\{p_i^Y, CES_i^{M1}\Big|_s\left[LTF\left(p_{s,i}^Y, p_{s,r,i}^T\right)\middle|\theta_{f,i}^G\right]\right\} \leq 0 \;\; \forall\, (r,t)$$

(Z3) Utility (U) generation of the representative consumer in each region (*r*) follows the nest structure shown in Figure A1 excluding factor inputs, i.e. it combines an energy with a non-energy input bundle:

$$\pi^U = p^U - CES^U\Big|_i\left(p_i^Y,\right) \leq 0 \;\; \forall\, (r,t)$$

II. Market clearance conditions:

(M1) Goods markets (domestic inputs, Armington exports and domestic consumption):

$$\sum_j \frac{\partial \pi_j^Y}{\partial p_i^Y} X_j^Y + \sum_s \frac{\partial \pi_{s,i}^M}{\partial p_i^Y} X_{s,i}^M + \frac{\partial \pi^U}{\partial p_i^Y} X^U \leq X_i^Y \;\; \forall\, (r,t)$$

(M2) Armington goods (M) markets:

$$\sum_j \frac{\partial \pi_j^Y}{\partial p_i^M} Y_j \leq X_i^M \;\; \forall\, (r,t)$$

(M3b) Factor (F) markets (given regional factor endowments):

$$\sum_i \frac{\partial \pi_i^Y}{\partial p_f^F} Y_i \leq \bar{X}_f^F \;\; \forall\, (r,t)$$

III. Budget condition:

(B1) Consumers' purchases and investments (I) must not exceed their factor income (including natural fossil resources) plus revenues from selling CO$_2$ (C) allowances plus tax minus subsidy (Q) revenues as a function of given tax and subsidy rates, plus net financial inflows from abroad (D), less the expenditure on subsistence consumption (S) (Linear Expenditure System):

$$\sum_i p_i^Y X_i^Y + p^I X^I \leq \sum_f p_f^F \bar{X}_f^F \quad + p^C \bar{X}^C + X^G\left(\theta_{f,i}^G\right) + p^D X^D - \sum_i p_i^Y \bar{X}_i^{Y,S} \;\; \forall\, (r,t)$$

10. Figures and tables to be inserted in the text

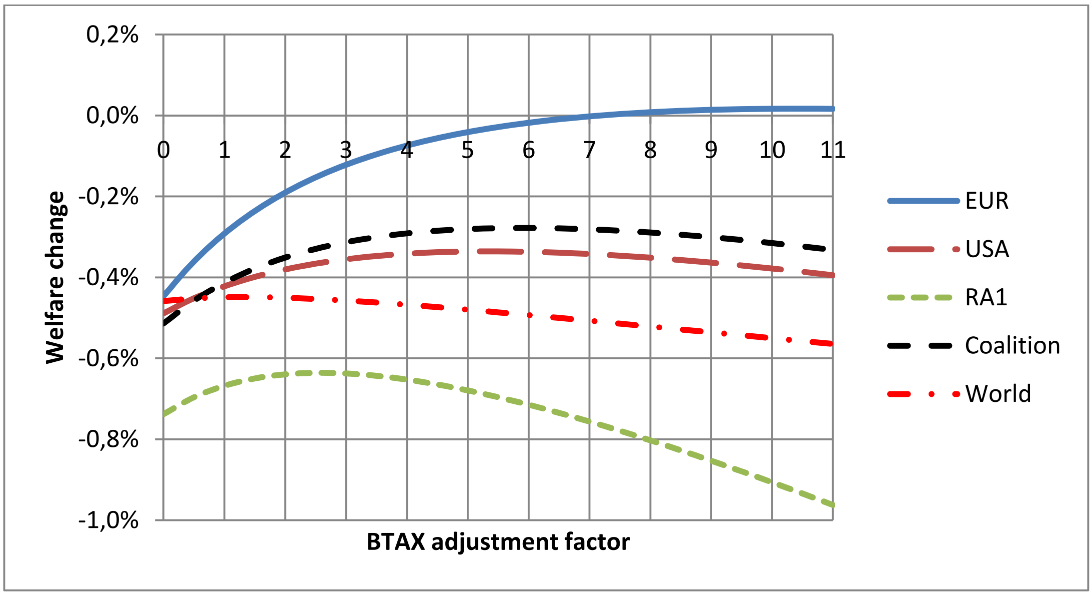

Figure 1: Change in coalition and global welfare (accumulated and discounted from 2004 to 2020) under border carbon adjustment at different rates represented by a BTAX adjustment factor (a multiplier of the standard BTAX rate) relative to BAU

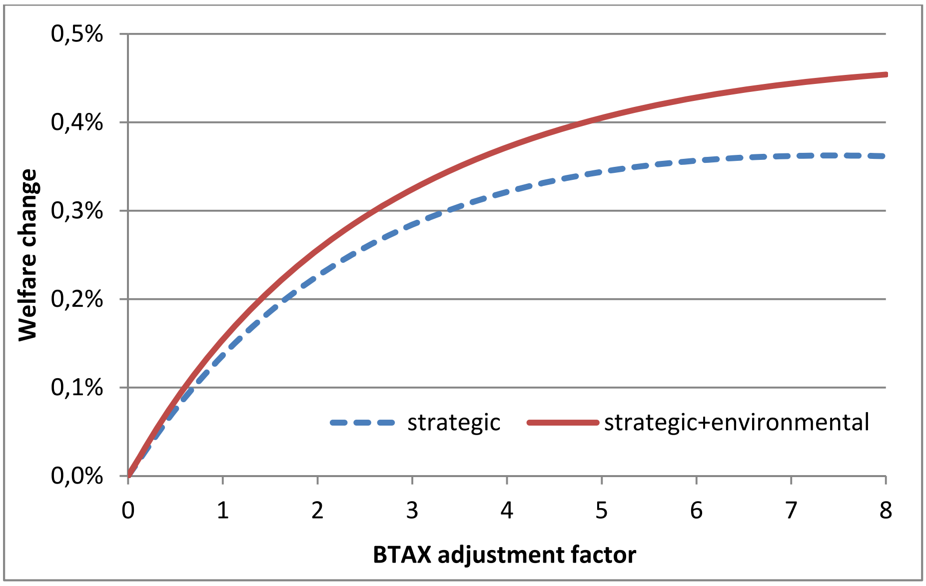

Figure 2: Change in coalition welfare between the scenario allowing global emissions to change (strategic effect) and the scenario keeping global emissions constant (strategic + environmental effect)

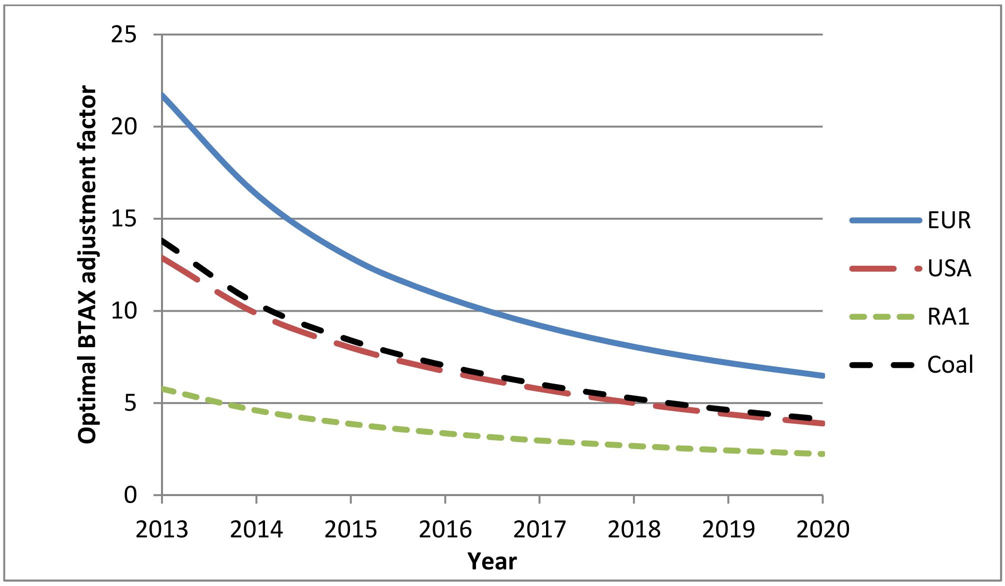

Figure 3: The BTAX adjustment factor measured relative to the standard BTAX rate that maximises Home's welfare in the respective years

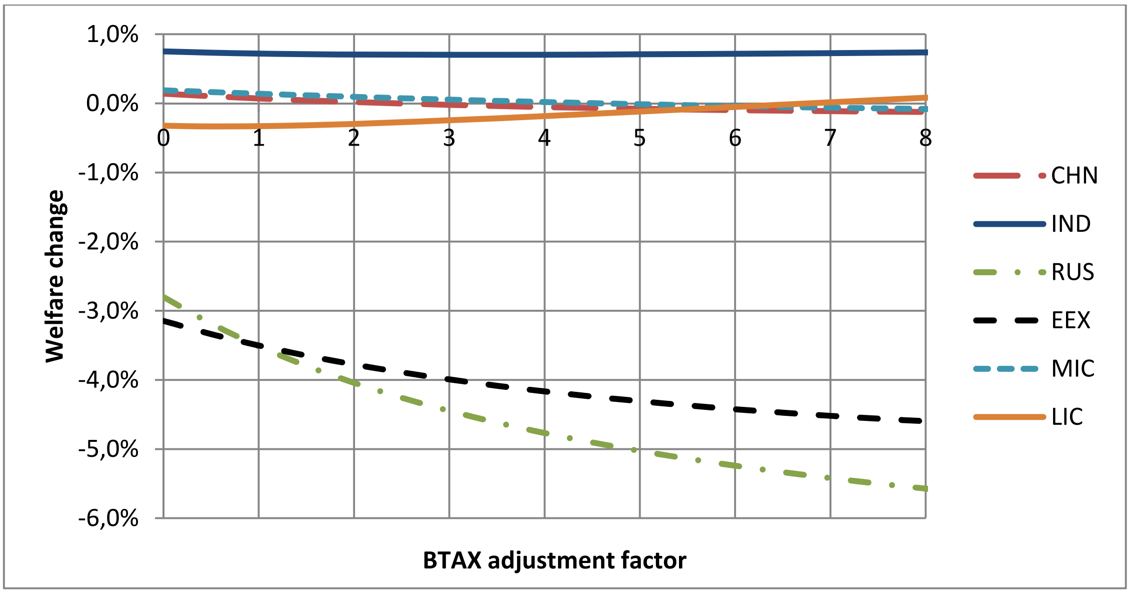

Figure 4: Change in non-coalition welfare (accumulated and discounted from 2004 to 2020) between a scenario with border carbon adjustment at different BTAX adjustment factors and BAU

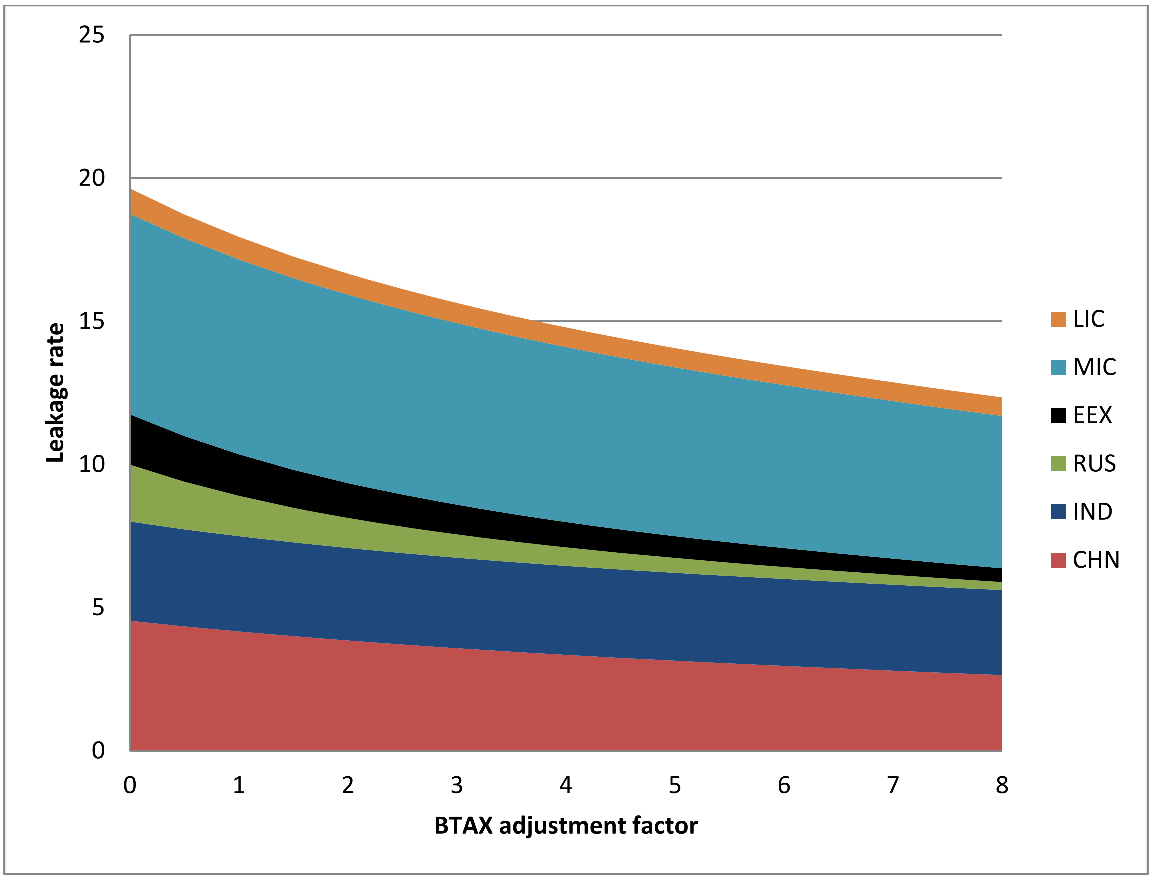

Figure 5: Regional carbon leakage rates depending on the strength of border carbon adjustment represented by different BTAX adjustment factors

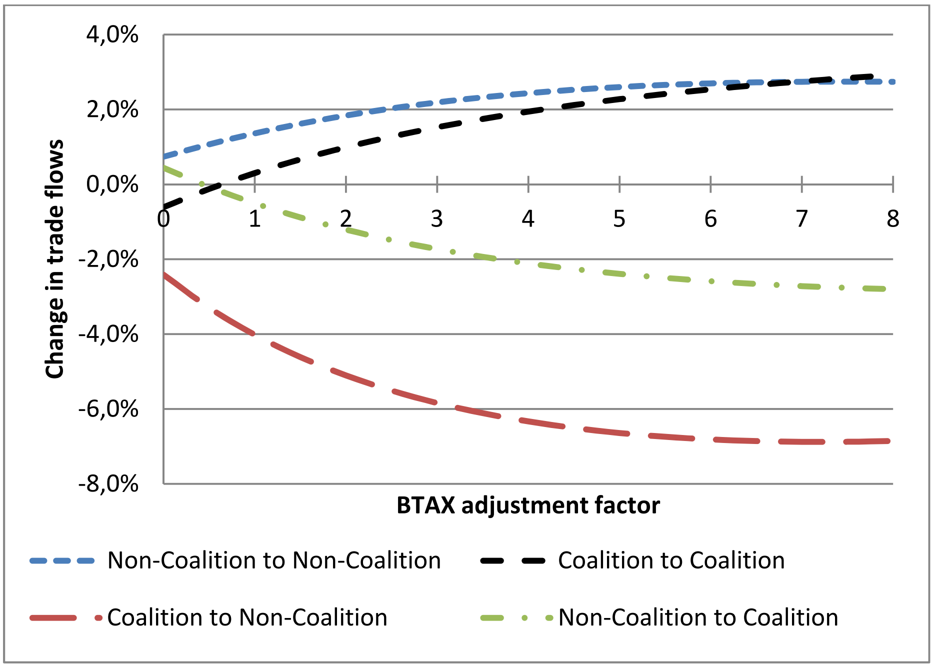

Figure 6: Real trade flows in 2020 relative to BAU

Non-coalit. region	**Sector**	**Pre-existing import/export tariffs for imports into**			**Standard BTAX rate for imports into**			**Carbon export rebate for exports from**		
		USA	*EUR*	*RA1*	*USA*	*EUR*	*RA1*	*USA*	*EUR*	*RA1*
CHN	OIL	0.5	0.0	1.3	3.0	3.0	3.0	1.6	0.6	0.8
IND	OIL	1.3	0.0	2.7	0.4	0.4	0.4	1.6	0.6	0.8
RUS	OIL	20.5	22.0	20.4	2.4	2.4	2.4	1.6	0.6	0.8
EEX	OIL	1.2	0.4	2.4	5.4	5.4	5.4	1.6	0.6	0.8
MIC	OIL	1.5	1.8	2.4	1.0	1.0	1.0	1.6	0.6	0.8
LIC	OIL	1.9	11.1	7.0	1.7	1.7	1.7	1.6	0.6	0.8
All	OIL	2.3	7.5	1.8	3.1	3.4	3.7	1.6	0.6	0.8
CHN	CRP	3.0	3.5	1.3	5.5	5.5	5.5	1.5	0.6	1.1
IND	CRP	1.8	0.7	2.1	8.0	8.0	8.0	1.5	0.6	1.1
RUS	CRP	5.1	6.7	7.7	18.5	18.5	18.5	1.5	0.6	1.1
EEX	CRP	1.4	1.1	1.6	7.7	7.7	7.7	1.5	0.6	1.1
MIC	CRP	1.4	1.5	2.0	3.2	3.2	3.2	1.5	0.6	1.1
LIC	CRP	1.6	1.7	5.9	13.3	13.3	13.3	1.5	0.6	1.1
All	CRP	0.1	0.3	0.3	5.2	5.8	5.6	1.5	0.6	1.1
CHN	EIT	3.4	2.7	0.9	10.9	10.9	10.9	2.5	1.4	1.7
IND	EIT	0.3	0.4	1.7	14.8	14.8	14.8	2.5	1.4	1.7
RUS	EIT	6.5	7.0	9.5	12.5	12.5	12.5	2.5	1.4	1.7
EEX	EIT	1.5	1.0	1.2	11.5	11.5	11.5	2.5	1.4	1.7
MIC	EIT	0.6	0.7	1.0	5.6	5.6	5.6	2.5	1.4	1.7
LIC	EIT	1.8	0.8	2.3	15.1	15.1	15.1	2.5	1.4	1.7
All	EIT	0.7	1.4	1.0	8.4	9.5	9.4	2.5	1.4	1.7
CHN	all[a]	6.8	4.6	4.1	0.6	0.5	0.7	0.3	0.1	0.3
IND	all[a]	5.5	2.8	3.3	1.4	0.9	1.2	0.3	0.2	0.6
RUS	all[a]	9.9	24.5	24.3	5.9	3.0	3.7	0.1	0.1	0.3
EEX	all[a]	1.2	2.1	1.1	0.6	0.8	1.0	0.2	0.1	0.3
MIC	all[a]	1.4	3.8	2.8	0.5	0.5	0.7	0.4	0.2	0.3
LIC	all[a]	6.4	2.7	3.4	0.2	0.7	0.6	0.2	0.1	0.3
all	all[a]	4.2	5.0	4.2	0.6	0.7	0.9	0.3	0.1	0.3

[a] Trade-flow-weighted average tax rate for the total trade between non-coalition and coalition countries.

Table 1: Pre-existing tariff rates, carbon tariff rates, and export rebate rates for 2020 in percent

Region	Grand coalition		Grand coalition with compensation via emissions allowances							
	Comparison to small coalition + non-coalition facing BTAX		Grand coalition members equally off as in non-coalition facing BTAX (not facing BTAX under REF)						Grand coalition member equally off as singleton facing BTAX	
	Welf. change rel. to BTAX in %	*BTAX factor making region join*	*Welf. change rel. to BTAX in %*	*Surplus allowances*[a] *in Mt CO_2 p.a.*		*Cumulative value*[b] *in bill. US-$*		*Incent. to become singleton*	*Addit. allowances Mt CO_2 p.a.*	*Addit. cumul. value in bill. US-$*
CHN	-0.2	10.0	0.0	810	(1076)	48.0	(63.7)	yes	172	10.2
IND	-0.8	/[c]	0.0	770	(798)	45.6	(47.3)	no	0	0.0
MIC	-0.2	6.6	0.0	482	(603)	28.5	(35.7)	yes	38	2.3
LIC	-0.2	/[c]	0.0	77	(79)	4.6	(4.7)	yes	36	2.1
EEX	1.9	1.0	1.9	0	(0)	0.0	(0.0)	yes	165	9.8
RUS	2.3	1.0	2.3	0	(0)	0.0	(0.0)	no	0	0.0
USA	0.4	-	0.3	-713	(-852)	-42.0	(50.5)	-	-137	-8.1
EUR	0.4	-	0.3	-713	(-852)	-42.0	(50.5)	-	-137	-8.1
RA1	0.6	-	0.3	-713	(-852)	-42.0	(50.5)	-	-137	-8.1
World	0.3	-	0.3	0	(0)	0.0	(0.0)	-	0	0.0

[a] Calculated as the difference between the allowance allocated to this region under the emission trading scenario and the emissions in the uniform tax scenario.

[b] Value of the transfer in 2010 calculated by multiplying the surplus allowances in $MtCO_2$ by the carbon price and discounting at 2%.

[c] Within the range of feasible BTAX rates under scrutiny, we find no BTAX rates that make IND and LIC being equally off in the coalition and in the non-coalition facing BTAX.

Table 2: Incentives to join the climate coalition: The left bloc compares the grand climate coalition consisting of all regions to the small coalition that consists per assumption of USA, EUR and RA1, while the other regions form the non-coalition. Therein, higher BTAX rates (expressed by a higher adjustment factor) make single regions indifferent between being in the grand coalition and being in the non-coalition. The middle bloc shows the situation where the grand coalition entrants are equally off as being in the non-coalition due to compensation transfers. The right bloc shows the situation where regions' incentives to free-ride as singletons (rather than jointly being in the non-coalition) are compensated additionally to the previous compensation.