The carbon content of trade:

Under border tariff adjustments and a global carbon regime

Matthias Weitzel[×], Sonja Peterson; Kiel Institute for the World Economy

Abstract:

In this paper we use a multi-regional, multi-sectoral CGE model of the world economy to assess the leakage effects and the changes of the carbon content of trade under different climate policy scenarios, including unilateral policies with and without border tariff adjustment (BTA) as well as stylized international policy scenarios. The paper combines input output techniques to assess the carbon content of trade over the whole production with CGE analysis to explore the impact of the different climate policies scenarios. The main results include that BTA does reduce the negative competitiveness effects of unilateral climate policy, but has only a modest effect on carbon leakage and hardly affects global carbon emissions. At the same time it is not a sufficient thread for many countries to rather join an international climate regime based on the contraction and convergence allocation of permits.

1. Introduction

Existing international climate agreements so far do not define binding carbon targets for all countries. The Kyoto Protocol that is valid until 2012 is characterized by the division into Annex-I and non-Annex-I countries, with the former facing binding carbon targets and the latter facing no targets at all. A true Post-Kyoto agreement has not yet been reached and the results of the latest climate conferences are limited to pledges by countries. Given this fragmental policy politicians worry about negative effects for their domestic industries if these face a carbon price, while competitors abroad do not. This could lead to a relocation of production to countries without stringent policy which is also a problem from an environmental point of view since this implies carbon leakage so that part of the intended emission reductions is offset. Thus, there is a discussion of possible provisions against both competitiveness losses and carbon leakage (see van Asselt and Brewer 2010 for an overview). Probably the most important of the proposed provisions are border adjustment measures in the form of taxes on the carbon content of imported goods, export refunds covering the cost of carbon for domestic producers or a combination thereof have been proposed.

[×] Corresponding author. Kiel Institute for the World Economy, Hindenburgufer 66, D-24105 Kiel; matthias.weitzel@ifw-kiel.de

Since border carbon adjustments are to be based on the so called carbon content of trade, which is the amount of carbon embodied in a good through the emissions that occurred along its production chain, the debate about border tax adjustment is also linked to the debate of consumption versus production based carbon accounting (see e.g. Davis and Caldeira 2010). Under the currently practiced production based carbon accounting only direct emissions are associated with a country. Thus, for example, the German emissions of driving a car in Germany are only those that come from burning the petrol while the emissions that occurred when producing the steel in China are not counted. Calculations (see e.g. Peters and Hartwich 2008 or Peters et al 2011) show that the carbon embodied in international trade is indeed very large and has increased to the order of 26% of global carbon emission in the past two decades. The largest net exporter of carbon is China while Europe and the US are the largest importers. Especially China argues with some justification that production based carbon accounting is not fair and that one should move to consumption based accounting since this shows the "true" amount of carbon a country consumes. From this perspective, and given that industrialized countries contributed the largest share to past emissions, an interesting question is how industrialized countries can decrease their "carbon footprint"[1] in the future.

Targeted at the carbon content of trade, border carbon adjustments are likely to affect consumption based emissions worldwide. At the same time, it is not clear whether a stringent global climate policy with a global carbon tax will not automatically also significantly reduce the carbon content of trade and thus reduce the gap between production and consumption based accounting.

This paper builds on two different strands of literature. The first is a growing number of studies that derive the carbon embodied in international trade from input-output tables of various countries. A distinction can be made into single-country models (e.g. Peters and Hertwich 2006 analyze Norway, Pan et al. 2008 and Weber et al. 2008 analyze the case of China), and multilateral models (e.g. Peters and Hertwich 2008, Peters et al. 2011).[2] For many countries, emissions from domestic consumption and emissions from domestic production differ considerably. A special focus has been put on the emission footprint of China, due to the fact that a large share of its emissions is related to exports. China being a large net exporter of emissions also plays an important role in international climate policy. Furthermore, emissions from exports contributed much to the raise in total Chinese CO_2 emissions as the share of emissions which is attributable to exports has risen over time (Weber et al. 2008). These emissions related to consumption of other countries are seen as

[1] To avoid confusion between direct emission based from production based accounting and direct plus indirect emission from consumption based accounting we will call denote the later as "carbon footprint".

[2] For a review of several single region and multi-regional models, see Wiedmann (2009).

an issue to be overcome in climate negotiations (Peters and Hertwich 2008, Wang and Watson 2008). If there was a global carbon price and given national caps, Steckel et al. (2010) show that it has no efficiency or distributive effect whether to use consumption or production allocation; for allocations based on past emissions, however, the accounting method will have distributive effects.

The second strand of literature relevant for this paper analyzes the effects of border carbon adjustments.[3] The instrument of choice for many analyses are CGE models that have the advantage to cover international trade and feed-back affects. In these models simulations changing parameters can be carried out and give qualitative insights to competitiveness impacts and carbon leakage. Existing studies focused on different coalitions and countries implementing border carbon adjustment. In Babiker and Rutherford (2005) it is the Kyoto coalition that sets border carbon adjustment, in Talebi et al. (2011) it is the EU, in Dissou and Eyland (2011) it is Canada. Furthermore, there are a number of studies in the grey literature such as Schleich and Peterson (2007), Hübler (2011). In a nutshell these studies show that in terms of leakage the border carbon adjustment can reduce the negative competitiveness effects of unilateral climate policy, though the degree to which this is possible differs across studies and in some cases other instruments (like CDM) are more effective in this respect. Concerning the effect of emissions respectively leakage, there is some effect, but it is not very large.

In this paper we combine features from input-output models of determining carbon embodied in trade over the whole production chain and a CGE technique, which is well suited to model impacts of policy changes. In some sense, the paper is going into the same direction as Truong (2010) who focuses on the potential impacts of the current and projected future patterns of trade and economic activities of selected Asian countries on their levels of GHG emissions, the patterns of trade and economic production, and on possibilities to achieve a better co-ordination between climate change, economic, and trade policies. In this paper the focus is on the leakage effects and the changes of the carbon content of trade under different climate policy scenarios, including unilateral policies with/without border carbon adjustment as well as stylized international policy scenarios. The focus for unilateral policy is on Europe. The paper combines input output techniques to assess the carbon content of trade over the whole production with CGE analysis to explore the impact of the different climate policies scenarios. The paper is structured as follows. In section 2 we describe the methodology and the analyzed scenarios. In section 3 we discuss the results. Section 4 concludes.

[3] There is also a broad literature on the legal validity of border carbon measures with WTO law, see e.g. Biermann and Brohm 2005, this is not further discussed here.

2. Methodology

In this section we briefly describe the DART model that is used for the simulations, the methodology to calculate the carbon content of trade and the scenarios that are analyzed with DART

2.1 Description of DART

The DART (Dynamic Applied Regional Trade) Model is a multi-region, multi-sector recursive dynamic CGE-model of the world economy. For this simulation of climate policy scenarios, it is calibrated to an aggregation of 13 regions and 12 sectors, which are shown in Table 1.

Table 1: Regions and sectors of the DART model

WEU	Western Europe	AGR	Agriculture
EEU	Eastern Europe	COL	Coal
USA	USA	CRU	Oil
CAN	Canada	GAS	Gas
JPN	Japan	OIL	Petroleum and coal products
FSU	Former Soviet Union	ELY	Electricity
ANZ	Australia and New Zealand	MOB	Transport
LAM	Latin America	ETS	Energy intensive industries (EU ETS)
CPA	China	CRP	Chemical products
IND	India	OLI	Other light industries
PAS	Pacific Asia	OHI	Other heavy industries
MEA	Middle East North Africa	SVCS	Services
AFR	Subsaharan Africa		

The economy in each region is modeled as a competitive economy with flexible prices and market clearing. There exist three types of agents: a representative consumer in each region, a representative producer in each sector, and regional governments. All regions are connected through bilateral trade flows. The DART model has a recursive-dynamic structure solving for a sequence of static one-period equilibria. The major exogenous drivers are the rate of productivity growth, the savings rate, the rate of population growth, and the change in human capital. The model horizon in this study goes until the year 2035. The model is calibrated to the GTAP7 database (Narayanan and Walmsley 2008) that represents production and trade data for 2004. The elasticities of substitution for the energy goods coal, gas, and crude oil are calibrated in such a way as to reproduce the emission projections of the IEA (International Energy Agency 2009). Trade is modeled following the Armington assumption. CO_2 emissions are calculated from the energy coefficient taken from GTAP and the carbon content of various fuels; energy use is the only source for CO_2 emissions. Autonomous energy improvements are set to 1% per year (except for the electricity sector, where the rate is set to 0.1%). For a more detailed description of the DART model, see Klepper et al. (2003).

2.2 Calculation of the carbon content of trade

The carbon content of goods used to inter alia determine the tax rate in our scenarios with border carbon adjustment (see section 2.3.) is calculated with the use of the Leontief inverse and closely follows Hübler (2011). Intermediate goods are therefore included and emissions accrued during the whole production process are taken into account. Furthermore, imported intermediate inputs are distinguished from those produced domestically. This can be of importance for countries where the share of value added to a final exported product is limited.

To calculate the carbon emissions of a good over all its production stages, input-output (IO) techniques are applied. First, a Leontief or technology matrix A is set up containing information of intermediate inputs required for each good. Its coefficients $a(i,j)$ indicate the amount of good i used as intermediate input in sector j. Total production of goods represented by vector x is hence the production needed for inputs in other sectors Ax and final consumption c:

$$Ax+c = x$$

Solving for the total output x yields

$$x= (I-A)^{-1}c$$

where we define $L:= (I-A)^{-1}$ as the Leontief inverse, which provides information on how much inputs are required for each good over the whole production process: Column i of L contains the coefficients indicating the quantity of other goods necessary for producing one unit of good i.

We define d as the vector of direct carbon intensities that collects the direct carbon intensities, i.e. emissions generated from combustion of coal, oil, and gas in the production process of each sector. Direct emissions are calculated from the energy content of fossil fuels taken from GTAP multiplied with appropriate carbon coefficients. We take into account that oil and gas inputs in the chemical sector are not entirely used for energy generation but also as an input which does not release CO_2. Oil and gas emissions of this sector are multiplied by a correction factor differentiated by region taken from Lee (2008).

Premultiplying *d'* to *L* then yields a row vector of carbon intensities e over the whole production process of the various goods:

$e = d'L$

For our analysis we construct a (12*13)x(12*13) = 156x156 Leontief matrix which includes all sectors in all countries of our analysis. With the available GTAP data, it is however not possible to construct a Leontief technology matrix *A* with international trade in intermediates. Information of domestic intermediate inputs is readily available; in the simplified 3 region, 2 good technology matrix shown in figure 1, they would represent the green block diagonal elements. For intermediate inputs traded internationally (i.e. the blue elements of the matrix), data cannot be directly taken from GTAP: First, there is information on bilateral trade flows *TRADE(i,r,rr)* of good *i* from region *r* to region *rr*, however no information is provided in which sector these goods will be used (this would be the amount of goods to be distributed over the blue cells of row in the matrix and towards final consumption). Second, there are quantities of intermediate input *QIMP(i,j,rr)* which specifies the amount of imported intermediate input *i* used in sector *j* in region *rr*, but from the GTAP data one cannot see from which country of origin (in terms of the matrix, this means the blue fields of the columns).

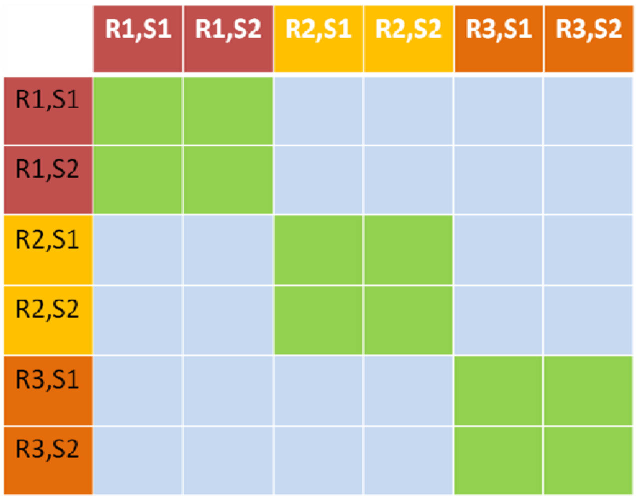

Figure 1: Simple Leontief matrix with 2 sectors and 3 regions

Hübler (2011) proposes to fill each blue cell of his 3 region, 30 sector model by taking the two pieces of information and applying the following formula to calculate the off-blockdiagonal elements *a(r,rr,i,j)* of *A* for intermediate goods from sector *i* to *j* traded from region *r* to *rr*:

$$a(r, rr, i, j) = QIMP(i, j, rr) * \frac{TRADE(i, r, rr)}{\sum_r TRADE(i, r, rr)}$$

For a first analysis, we followed this approach. Since we also want to calculate the future carbon content of trade, there is a need to update the technology matrix *A* with data taken from the DART model for years later than the base year. Therefore a Leontief technology matrix is set up from the input and output quantities of the sectors used in DART at each simulation year. In order to do so, an additional assumption has to be made about the calculation of the traded intermediates due to the fact that imported goods form an Armington aggregate with domestic goods which then enters the production process in the various domestic sectors or enters final consumption.

The following formula has been applied to calculate the off-blockdiagonal elements *a(r,rr,i,j)* of *A* for intermediate goods from sector *i* to *j* traded from region *r* to *rr*:[4]

$$a(r, rr, i, j) = Q(i, j, rr) * \frac{QIMP(i, rr)}{QDOM(i, rr) + QIMP(i, rr)} * \frac{TRADE(i, r, rr)}{\sum_r TRADE(i, r, rr)}$$

where *Q(i,j,rr)* are total intermediate inputs of good *i* into sector *j* of region *rr*, which is scaled with the share of imports in the Armington good of sector *i*. *QDOM* and *QIMP* refer to the quantity of domestic and foreign inputs into the Armington good (note that there are different Armington goods for industry intermediate inputs and final consumption). *TRADE(i,r,rr)* refers to total bilateral trade of good *i* from region *r* to *rr*. The underlying assumption is that the structure of the Armington intermediate input *i* is similar for all sectors *j*; if j_1 imports a large share of if intermediates from sector *i* while j_2 uses mostly domestic inputs from sector *i*, this will not be captured in the analysis. This feature is captured by Hübler (2011) but not when taking data from DART. In addition, this formulation does not capture a case of imports of good *i* from region r_1 being mostly for consumption and r_2 are mostly for use as intermediate input. This feature is captured neither in this approach nor by Hübler (2011). Domestic inputs are calculated in a similar way, the former of the two caveats applies here again:

$$a(r, i, j) = Q(i, j, r) * \frac{QDOM(i, r)}{QDOM(i, r) + QIMP(i, r)}$$

For intermediate inputs of energy goods, the calculation differs slightly to account for the different nesting structure but follows the same idea. To scale *A* appropriately, the input quantities of good *j* which are in row *j* have to be divided by total output of *j*, i.e. output for the domestic and the export market which is taken from DART.

Straightforward, the carbon emissions embodied in trade are calculated by multiplying the trade volume with the emission intensity of the different sectors. The results are in the order of previous studies, for example net emissions for China are well in line with the studies compared by Wang and Watson (2008).

[4] For regions in which intra-regional trade occurs, e.g. WEU, also elements on the block-diagonal are non-zero.

2.3. Definition of Scenarios

The multi-region CGE-model DART is subsequently used to assess the development of emissions embodied in trade over time and under different policy scenarios. A new input-output matrix is set up with the input and output quantities for each iteration and subsequently used to derive emissions embodied in trade, taking into account all production stages of traded goods. It is therefore possible not only to analyze the lifecycle emissions in the base year, but to also do so for the whole period of the scenarios. To our knowledge it is the first instance where the future carbon content of trade is assessed in such way. Changes in both the volume and composition of trade as well as changes in the carbon intensity of traded goods contribute to the evolvement of carbon embodied in trade.

The three policy scenarios that we analyze in this paper focus on a climate commitment in Europe with and without border carbon adjustment policy and compare the results to a global climate regime. By combining DART and IO techniques as described above, we are able to analyze how the balance of emissions embodied in trade and the carbon footprint of Europe changes in the different scenarios.

The time horizon in the policy scenarios is 2035. On the one side it will be necessary to account in more detail for alternative technologies such as renewable electricity generation or carbon capture and storage (CCS) beyond this date which would lower abatement cost. On the other side the time horizon should be long enough to account for the fact that high border adjustment measures are resulting from high carbon prices in the order to provoke a larger impact on trade flows. And to reach ambitious targets such as the 2 degree target, high carbon prices are needed eventually. In all three scenarios emission reductions start in the year 2012.

The first policy scenario (EU) is a **unilateral reduction commitment of Europe**.[5] The climate policy results in a 20% reduction of emissions in Europe in 2020 compared to 1990 which is consistent with the official current policy. In order to reach emission reductions in the order of 80-95% below 1990 in 2050, emission allowances for 2035 are set to 50% of 1990.[6] The allocation of emission allowances to the two regions under a cap (i.e. WEU and EEU) is relative to 2010 emissions. Emission trading within the two regions is possible; there is hence a uniform carbon price.

The second scenario (EU BTA) adds a **border adjustment tariff** to scenario 1 that is levied on all imports into Europe, based on the carbon content of the imports (differentiated by

[5] Europe here refers to regions WEU and EEU in the DART model representing the European Union. EU15 and EFTA members are included in WEU, new EU members to EEU. In addition, the regional aggregation of EEU includes some additional countries, mostly non-EU states from the Balkan Peninsula. These countries however have little economic weight within the aggregated region.

[6] The target for 2035 is in line with the proposed roadmap to 2050, see COM(2011)112.

sector and source region) and the carbon price of the controlled region. Compared to border carbon measures based only on direct carbon emissions or carbon content of the importing region, the tariff rates are likely to be higher as Europe generally produces in a more carbon efficient way. The emission cap for Europe in this scenario is identical to the unilateral scenario.

The border adjustment tariff rates are calculated following Hübler (2011) by taxing the carbon content of emissions over the whole production process. The tax revenue is distributed lump-sum to the representative agent on the importing regions. In contrast to Hübler (2011) however, the tax rate is adjusted to the carbon content over time by updating the Leontief matrix as described above and hence taking into account efficiency improvements and changes of the production structure over time (even in the Baseline case, the carbon intensity declines over time, this is due to the fact that capital becomes more abundant over time and fossil fuel prices rise over time). Furthermore, exporters can adjust to the levied carbon tax, i.e. there is an endogenous adjustment process in the modeling framework.[7] This is implemented by iteratively setting the carbon tax to changes in production that occur due to the changed level of the border adjustment tax; the effect from this however is small, convergence in the iteration process fast.

Finally, in the **Contraction and Convergence** (C&C, Global Commons Institute 1996) scenario, emissions are set to be globally 40% below emissions of 1990. Under a C&C regime, emission allowances in 2012 are based on current per capita emissions in different regions; per capita emissions subsequently converge to a common level in 2050. The scenario consequently puts a cap into effect in all regions, but allows for global trade in permits. Countries with lower per capital emissions are likely to have surplus emissions which they can sell on the international carbon market.

The scenario is therefore not directly comparable to the previous analysis of Europe as global carbon emissions differ substantially from the previous scenarios. The principal aim is however, to see if such a regime could be preferential for certain countries due to the fact that they are subject to low abatement costs which can be exploited under a global carbon market. A global carbon price should furthermore reduce carbon leakage and reduce the differences between carbon emissions by consumption and production. We therefore are interested in the question on how a global regime reduces the imbalances in the “carbon balance of trade” between countries in comparison with policies like border tariff adjustments.

[7] DART does not differentiate between the production of the export sector and production for domestic use. If exports are produced in a more environmentally friendly way compared to goods for the domestic market, this could overstate the carbon content of exports. Galdeano-Gómez (2010) finds evidence for a positive relationship of environmental productivity and the export status in firm level data. However, it is not possible to account for such a bias with the given GTAP data.

3. Discussion of results

In this section we discuss the results of our simulations, starting with the carbon content of trade in the baseline and then moving to the most important effects of the different policy scenarios. In particular, we present changes in global emissions and leakage, show the impacts of a border adjustment policy and discuss how the footprint of Europe changes under the different scenarios.

3.1 The carbon content of trade in the baseline

The first part of figure 2 shows the domestic emissions in Europe in the baseline scenario for the base year 2004 as well as 2020 and 2035, all three being the result of combined IO and CGE analysis. It can be seen that the European carbon footprint is substantially larger when taking emissions embodied in trade into account. The net embodied emissions of trade are rising from 1126 Mt CO_2 in 2004 to 1399 Mt in 2020 and 1385 Mt in 2035. The numbers are influenced by two counteracting forces: One the one hand, efficiency improvements lead to a reduction in emissions embodied in trade, on the other hand increased trade flows lead to larger embodied emissions in trade.[8]

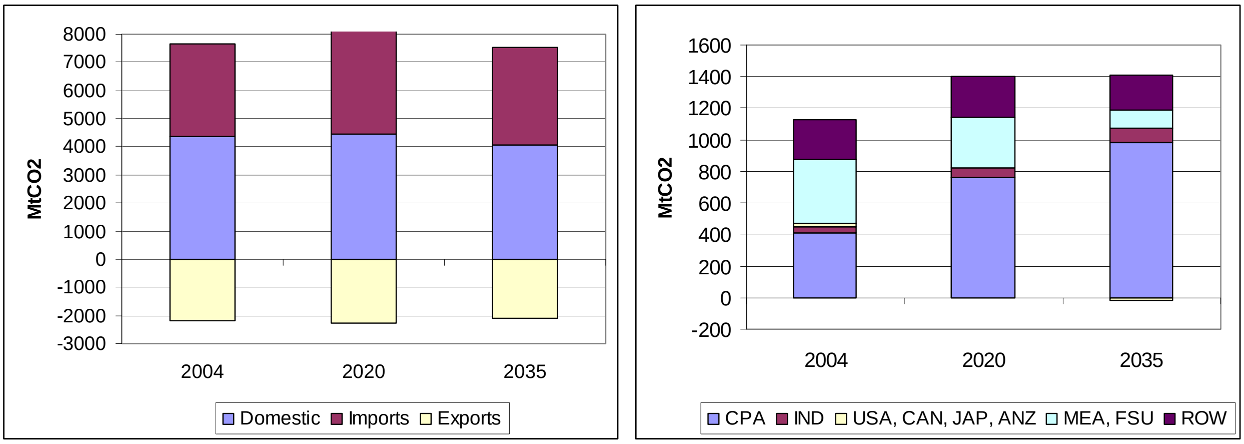

Figure 2: European Emission Footprint (under the baseline scenario, CO2 in Mt)

The second part of figure 2 splits the total net trade embodied emissions of Europe into different regional contributions. Of the different regional groups, China adds most to the total; the embodied emissions in European - Chinese trade add 413 MtCO2 to European emissions in 2004. This imbalance further widens throughout the time period until 2035.

[8] Efficiency improvements ceteris paribus also reduce the imbalances of Europe since other countries are catching up in terms of energy efficiency. In the DART model, autonomous energy improvement rates are equal for all countries. More inefficient countries (like China) therefore have a larger energy improvement in their products compared to Europe which is already more efficient at the start of the simulation. On the other hand, increasing trade flows ceteris paribus increase the gap; given a certain difference in carbon efficiency, an increase in trade will lead to a widening of the balance of embodied emissions.

Similarly, the fast growing economy of India will also contribute to the widening of the gap, albeit India starts with an almost balanced carbon exchange with Europe. On the other hand, the difference of emissions embodied in trade with oil exporting regions (FSU and MEA) declines over time, embodied carbon flows to other regions play a minor role in the overall change.

3.2 Carbon prices and tariff rates

Within the trading system that covers the EU in scenarios EU and EU-BTA and the entire world in Scenario C&C the carbon prices rise from around 4.5 to 5 US$/t$CO_2$ in 2012 to around 213 to 246 US$/t$CO_2$ in 2035. Compared to the scenario EU without BTA where the price reaches 213 US$/t$CO_2$ the price is higher in EU BTA where it reaches 241 US$/t$CO_2$. The reason is that is now harder to substitute to carbon intensives imports as a strategy for (domestic) mitigation. The carbon price for the C&C scenario is in the same order as in the other scenario but it cannot be directly compared to the other scenarios, since it is based on global targets.

In addition to putting a price on domestic carbon emissions, Europe puts a border carbon adjustment tariff into effect in the second policy scenario. It now becomes more costly to import carbon intensive goods, relocation of production is reduced, also because carbon intensity of source countries is often higher than of Europe, production in Europe is c.p. cheaper when accounting for the carbon tax that has to be paid by the producer.

Efficiency improvements cause the carbon tariff to decline over time, this is outweighed by the increase in the carbon price which rises to 241$/t$CO_2$ in 2035 under the BTA scenario. Therefore tax rates grow over time, but levels vary between sectors and originating countries. In 2035, the sector with the most tariff revenue is generated in the OHI sector with imports from China, with a tariff rate of 16.5%. The trade weighted tariff rate starts at 0.5% in 2012 and reaches 11.1% in 2035. This causes substantial changes in trade flows not in the near future, but in the longer run.

3.3 Global carbon emissions and leakage

Despite the 50% reduction goal of Europe in 2035, the emission reduction in Europe alone is small seen on a global scale (table 2). Under the unilateral scenario, global emissions are reduced only by 1.4% in 2020 and 2.7% in 2035, respectively. With a border carbon adjustment, some of the leakage is reduced, slightly increasing the global emission reductions. The difference to a more stringent regime aiming at a 450 ppm target is striking and shows the stark variation between a partial and a global regime.

Table 2: Global emission reductions under different scenarios relative to the baseline emissions in the respective year

	EU	EU BTA	C&C
2020	-1.4%	-1.5%	-23.0%
2035	-2.7%	-3.0%	-47.6%

Part of the European reduction is compromised by increased emissions outside the region under a cap. We calculate two measures to determine the effect of the relocation of carbon emissions under the different scenarios.

The first is the classical measure for leakage, i.e. changes in emissions in the regions without a carbon policy over the emission change in the capped regions. Leakage rates are shown in table 3 and are in the order of 42%[9] throughout the EU scenario and change relatively little over time. Most of the relocation is driven by the fact that the emission reduction in Europe leads to lower fossil fuel prices globally which are then translated into higher fossil fuel use and hence increased carbon emissions in other regions (price effect). Another effect is that production is relocated to regions outside Europe and final or intermediate goods of relocated production are subsequently imported into Europe (relocation effect). This effect can be estimated from the change in carbon emissions of total emissions and the change in net embodied emissions of total embodied emissions. Under the EU BTA scenario, the leakage rate is reduced, but still quite high at about 36%. This shows the large impact of the price effect.

Secondly, we calculate a measure representing how much of the emission reduction in the caped region is lost by importing from another location. This is expressed by the ratio of additional carbon (net) imports embodied in trade to the emission reductions with a carbon policy. In contrast to the traditional measure for leakage which is dominated by the price effect, this measure is showing how much of the responsibility Europe has in a more direct way by substituting to importing carbon intensive goods. The results are summarized in table 3. In the EU only scenario, the effect is little above 20%, i.e. 20% of domestic emission reductions in Europe are lost because of additional imports to Europe. It is therefore also an indicator for production relocation. With a rising carbon tax over time, the share of additional imports also increases. Under EU BTA the measure is negative, i.e. there are less carbon emissions embodied in imports compared to the baseline. Because other regions often

[9] Compared to other studies, the leakage rate is rather on the high end, which is partly driven by the Armington elasticities of 4 between domestic and foreign goods, and 8 between foreign goods of different origin also being at the high end.

produce more carbon intensively, the border adjustment tariff is higher than paying the carbon tax for a domestic good.

The relocation of production with the aim to subsequently import goods to Europe can thus be decreased with a BTA, and the emissions of additional imports can be eliminated by imposing a carbon tariff. There is however remaining leakage through the price effect channel of lower fossil fuel prices that makes production more energy intensive in the uncontrolled regions compared to the base case.

Table 3: Leakage under non-global scenarios

		EU	EU BTA
Leakage	2020	42.1%	36.9%
	2035	41.2%	35.1%
Add. Imports rel. to reduction	2020	20.3%	-5.2%
	2035	23.8%	-10.0%

3.4 The Carbon footprint of Europe

Figure 3 presents the European carbon footprint and separates the direct effect from domestic emissions and the effect from emissions embodied in trade.

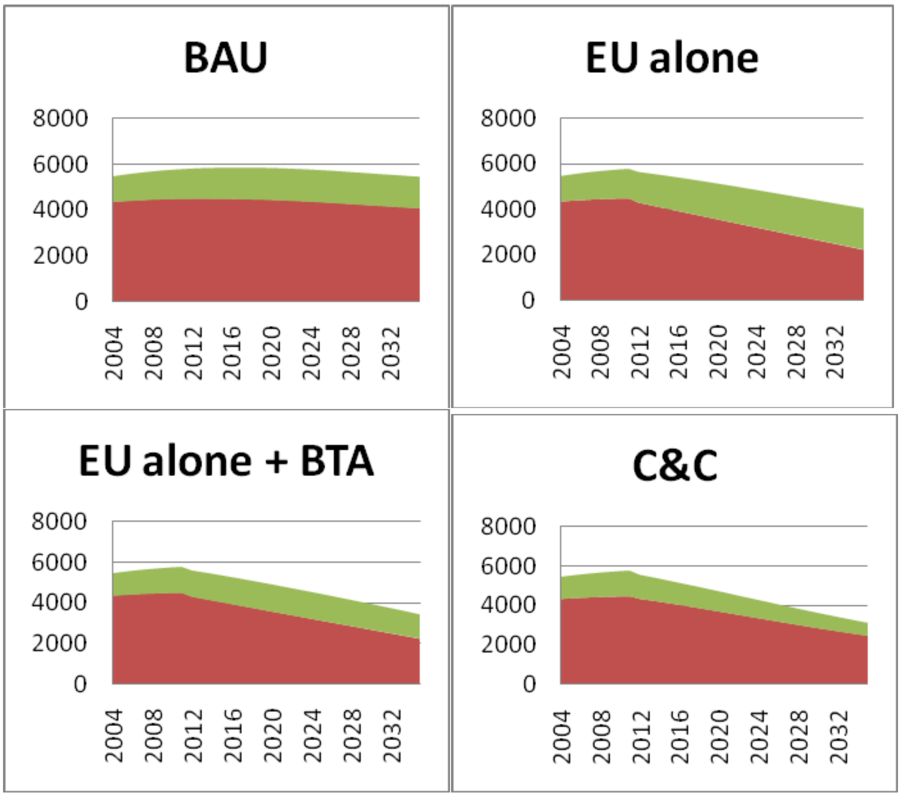

Figure 3: Direct emissions (red) and emissions embodied in trade (green) in Europe in different policy scenarios.

It can be seen that emissions embodies in trade have a noticeable share in the total footprint. With the climate policy in Europe only, domestic emissions are reduced, however, imported emissions are increased. As described above, this leads to the total reduction of the footprint being lower than the reduction in domestic emissions. By imposing a border tariff adjustment (BTA), net embodied emissions in trade can be held relatively constant, domestic emissions per construction are equal to the EU scenario. Under the C&C scenario, decarbonization of net imports is largest because the incentive in other countries is much larger compared to a BTA. The C&C puts a carbon prize on every production step regardless of the country and the sector instead of only having a partial effect for producers that export to Europe. In the C&C scenario, domestic emissions in Europe are slightly higher than in the other scenarios, despite a higher carbon price. This is caused by reversed leakage vie the fossil fuel price channel, because with global cab, the effect of lower fossil fuel prices is more pronounced and since global emissions are capped, there is leakage to Europe.

3.5 Regional contribution to emissions embodied in European trade

Figure 4 shows regional contributions to the changes in net embodied emissions in trade under the different scenarios. The baseline column repeats part of figure 2 and again gives evidence of the important role of trade with China.

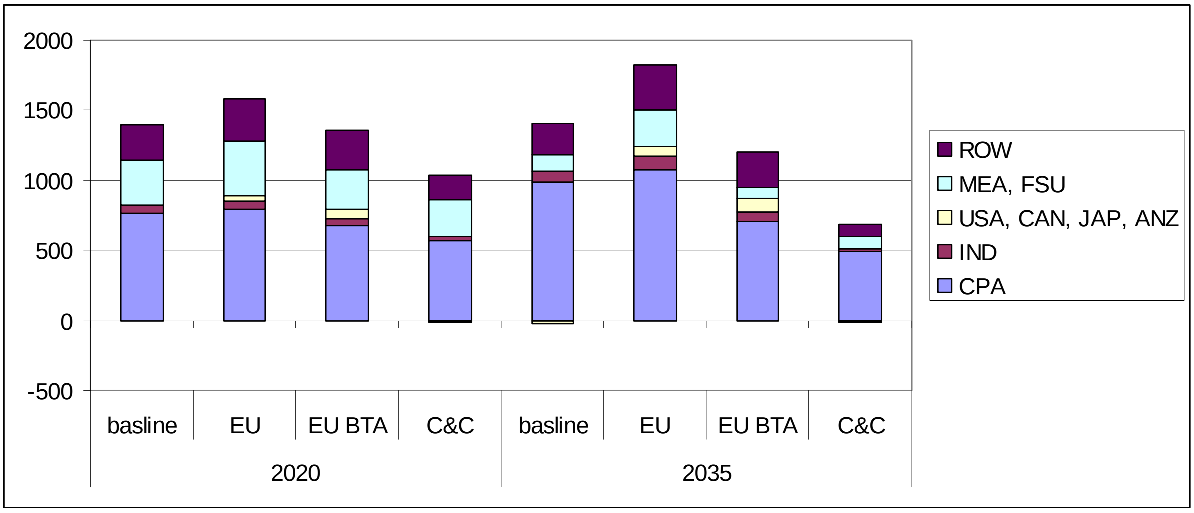

Figure 4: Regional contribution to European net trade emissions

Under the EU scenario, the values of net embodied emissions in trade increase for all source regions. Under EU BTA the emissions embodied in net imports for China are much lower. However, for other regions such as the USA, CAN, JAP and ANZ group, the opposite holds and emissions rise compared to the EU scenario. This can partly be interpreted as a trade diversion effect. Instead of importing from China where carbon intensity and hence the carbon tax is high, Europe imports more from developed regions where a lower carbon tariff is levied. This is the same principle as described in Böhringer and Rosendahl (2009): those regions with the highest carbon intensity are hit most, while those with the lowest profit.[10] As described above, global decarbonization of production leads to lower net imports on embodied emissions in the C&C scenario. The largest change can be observed in China, where production is much less carbon intensive with a price on CO_2.

3.6 Effects on the global carbon content of trade

Figure 5 shows the global carbon content of trade in 2004 and in 2035 across the different scenarios. This is also interesting because it shows the wedge between consumption and production based accounting of emissions.

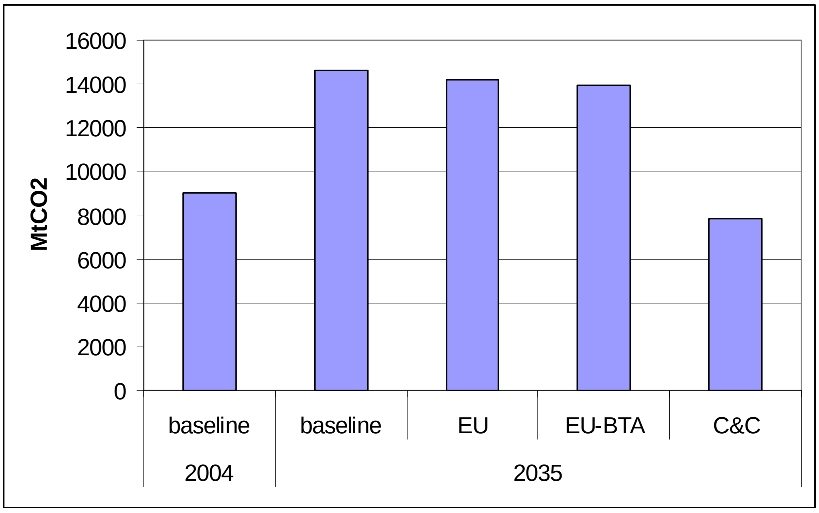

Figure 5: The global carbon content of trade

The first observation is that in the baseline not only trade but also the carbon content of trade intensifies significantly over time. While in 2004 the global carbon content of trade amounts to around 8 GtCO2, it increases to over 14 GtCO2 in 2035. Emission reductions in Europe alone – with our without border tariff adjustment have little effect on this development. Figure 3 shows that for Europe the emissions embodied in trade reduce drastically in scenarios EU and EU BTA. Yet, in EU emissions in trade not from or to Europe increase in scenario EU (on average by around 2%) and decrease by only 0.3% in scenario EU BTA so that the effect on global emissions embodied in trade is negligible. The picture for the scenario C&C is very

[10] Böhringer and Rosendahl (2009) describe how the dirtiest industry profits most under a relaxation of the carbon cap. Here, this would be the switch from baseline to EU. The opposite then holds for the switch from EU to EU BTA.

different. Here, global emissions as well as global emissions embodied in trade are reduced below the value in 2004. While global carbon emissions are reduced by 13% in 2035 relative to 2004, the amount of emissions embodied in trade is reduced by 22%. Thus, an efficient global climate regime also reduces the wedge between production and consumption based carbon accounting.

3.7 Welfare

Welfare is measured as the sum of discounted Hicksian equivalent variation until the year 2035. Changes in welfare relative to the baseline are shown in figure 4. In general, it can be seen that the worst off countries are fossil fuel exporters (FSU and MEA) that suffer under reduced fossil fuel prices and lower revenue from their exports. The lower global emissions and therefore the lower the demand for fossil fuels, the higher is the welfare loss they encounter.

Figure 6: Welfare changes relative to the baseline for different regions and scenarios

Under a climate policy in Europe alone, there are some welfare losses in Europe, which can be partly compensated by the revenues from border carbon tariffs. Other countries profit from the unilateral European commitment as long as there is no border adjustment in place. Importers of fossil fuel enjoy lower import prices, and there is an increased demand from Europe for carbon intensive goods. China, India and Pacific Asia all experience welfare gains, however, in EU BTA these are reduced or even turn negative because the import demand of Europe for goods from countries which produce in a carbon intensive manner is lowered. Japan on the other hand also profits from an EU BTA scenario; because of its carbon efficient production, it gains from trade relocation. The effects of a global C&C regime are much larger; again the largest losses are faced by fossil fuel exporters. But also countries with an allocation below their production have to cope with welfare losses because carbon permits have to be bought on the international carbon market. India and Africa which are sellers of permits on the other hand can gain from additional revenue.

What is certainly not the case is that the thread of BTA adjustments provides incentives for most developing and emerging countries rather to sign a stringent international climate regime. At least under the assumptions made in the scenarios here, the welfare losses under BTA are much less severe than under a Contraction & Convergence regime.

4. Conclusions

In this paper we have analyzed the effects of three different climate policy scenarios on the emissions embodied in trade and thus on competitiveness and carbon leakage. In the first two policy scenarios only Europe is facing emission restrictions and is trying to avoid negative competitiveness effects and carbon leakage by border tariff adjustment (BTA). The third scenario assumes a global climate regime with a global carbon price.

For Europe, the analysis shows that BTA is indeed able to reduce negative competitiveness and welfare effects of unilateral climate policy. Yet, a global regime would still be preferable for Europe. If one measures the success of BTA from an environmental perspective, it is able to reduce the simple substitution to imports as a mitigation strategy, but there is still substantial leakage caused by reduced fossil fuel prices. Hence, global CO_2 emissions change little with BTA and such a regime does not move the world much closer to reaching e.g. the 2 degree target.

The question is then, whether BTA can be a credible thread for other regions to join a global climate regime. The picture in this respect is mixed. BTA has clearly negative welfare effects for basically all regions outside Europe. For the US, Canada, the Former Soviet Union, Australia/New Zealand, Latin America, China and the Middle East the negative effects of a contraction and convergence (C&C) global climate regime would be much larger though. For Japan, India, Pacific Asia and Africa the C&C regime that has a very favorable permit allocation especially for Japan and India would actually bring welfare gains. A partially dominating effect of the C&C scenario though is that the reduced fossil energy use and thus reduced energy prices are favorable for energy importing regions (such as e.g. Japan) and imply large losses for major energy exporting regions (Former Soviet Union, Middle East). Since the regimes are highly stylized though, it could be possible to search for alternative policies which would increase welfare compared to EU BTA for those countries that are worse off with stringent climate policy. It could also be the case that for some countries is pays to accept a BTA as long as the tariff rate is low and join a cap and trade regime once the trade effects become too costly.

Finally, the analysis shows that a global carbon regime will over proportionally reduce the emissions embodied in trade and close the gap between consumptions and production based carbon accounting.

5. References

Babiker, M.H. and T.R. Rutherford (2005). The economic effect of border measures in subglobal climate agreements. *Energy Journal,* 26(4): 99-126.

Biermann, F. and R. Brohm (2005). Implementing the Kyoto Protocol without the USA: the strategic role of energy tax adjustments at the border. *Climate Policy*,4(3): 289-302.

Böhringer, C. and K. E. Rosendahl (2009). Green Serves the Dirtiest. On the Interaction between Black and Green Quotas, Discussion Papers 581, Research Department of Statistics Norway.

Davis, S.J., and K. Calderia (2010). Consumption-based accounting of CO2 emissions, PNAS 107(12): 5687–5692.

Dissou, Y. and T. Eyland (2011). Carbon control policies, competitiveness, and border tax adjustments. *Energy Economics,* 33(1): 556-564.

Galdeano-Gómez, E. (2010). Exporting and Environmental Performance: A Firm-level Productivity Analysis, *The World Economy*, 33(1): 60-88.

Global Commons Institute (1996). Contraction and Convergence: A Global Solution to a Global Problem. http://www.gci.org.uk/contconv/cc.html.

Hübler, M. (2011). Can Carbon Based Tariffs Effectively Reduce Emissions? A Numerical Analysis with Focus on China. Working Paper. http://www.gtap.agecon.purdue.edu/resources/download/5189.pdf

International Energy Agency (2009). *World Energy Outlook 2009*. Paris: OECD/IEA.

Klepper, G., S. Peterson and K. Springer (2003). DART97: A Description of the Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper No. 1149.

Lee, H.-L. (2008). An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP. GTAP Resource #1143, GTAP CO2 emissions (for V7)

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

Pan, J., J. Phillips and Y. Chen (2008). China's balance of emissions embodied in trade: approaches to measurement and allocating international responsibility, *Oxf Rev Econ Policy* 24(2): 354-376.

Peters, G. P. and E. G. Hertwich (2006). Pollution embodied in trade: The Norwegian case, *Global Environmental Change* 16(4): 379-387.

Peters, G. P. and E. G. Hertwich (2008). CO_2 Embodied in International Trade with Implications for Global Climate Policy, *Environ. Sci. Technol.*, 42 (5): 1401–1407.

Peters, G. P., J. C. Minx, C. L. Weber, and O. Edenhofer, O. (2011). Growth in emission transfers via international trade from 1990 to 2008, *PNAS*.

Schleich, J. and E. Peterson (2007). Economic and environmental effects of border tax adjustment. Working paper sustainability and innovation S2/2007. Fraunhofer Institute for Systems and Innovation Research, Karlsruhe.

Steckel, J., M. Kalkuhl and R. Marschinski (2010). Should carbon-exporting countries strive for consumption-based accounting in a global cap-and-trade regime? *Climatic Change* 100(3): 779-786.

Talebi, V. A., N. Anger and A. Löschl (2011). Alleviating adverse implications of EU climate policy on competitiveness: the case for border tax adjustment or the clean development mechanism? In: V. Ghosal (Ed.) Reforming rules and regulations: laws, institutions, and implementation, p 105 – 127.

Truong P. T. (2010). A Comparative Study of Selected Asian Countries on Carbon Emissions with Respect to Different Trade and Climate Changes Mitigation Policy Scenarios, ARTNeT Working Paper Series, No. 86, http://www.unescap.org/tid/artnet/pub/wp8610.pdf.

van Asselt, H. and T. Brewer (2010). Addressing competitiveness and leakage concerns in climate policy: An analysis of border adjustment measures in the US and the EU, *Energy Policy*, 38(1): 42-51.

Wang, T. and J. Watson (2008). China's carbon emissions and international trade: implications for post-2012 policy. *Climate Policy* 8(6): 577-587.

Weber, C. L., G. P. Peters, D. Guan and K Hubacek (2008). The contribution of Chinese exports to climate change, *Energy Policy* 36(9):3572-3577.

Wiedmann, T. (2009), A review of recent multi-region input-output models used for consumption-based emission and resource accounting, *Ecological Economics*, 69(2): 211-222.