Kiel
Working Papers

Kiel Institute
for the World Economy

# Can Carbon Based Import Tariffs Effectively Reduce Carbon Emissions?

by Michael Hübler

**No. 1565** | October 2009

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Düsternbrooker Weg 120, 24105 Kiel, Germany

Kiel Working Paper No. 1565 | October 2009

# Can Carbon Based Import Tariffs Effectively Reduce Carbon Emissions?*

Michael Hübler

Abstract: We estimate $CO_2$ implicitly contained in traded commodities based on the GTAP 7 data: While net carbon imports into the industrialized countries amount to 15% of their total emissions, net carbon exports of the developing countries amount to 12% of their total emissions, and net carbon exports of China amount to 24% of China's total emissions. We also analyze policies under a global per capita emissions based contraction and convergence regime with emission trading: When China joins the regime, the developing countries will benefit, while the industrialized countries will be almost unaffected. When China does not join the regime and instead a carbon content based border tax is imposed, the industrialized countries will significantly benefit, while China will be significantly worse off. The effect of the border tax adjustment on the global carbon price and on global emissions seems negligible.

Keywords: Carbon content of trade, border tax adjustment, climate policy,
contraction and convergence, China

JEL classification: F13, F18, Q54

**Michael Hübler**
Kiel Institute for the World Economy
24100 Kiel, Germany
Telephone: +49-431-8814-401
E-mail: michael.huebler@ifw-kiel.de

*I thank Sonja Peterson, Johannes Bröcker, Till Requate, Daiju Narita and Matthias Weitzel.
We thank the Leibniz Association (WGL) for supporting our work.

---

# 1 Introduction

The necessary drastic reduction in global $CO_2$ emissions critically depends on the inclusion of the developing and emerging economies, especially of China. - If China stays reluctant to join a binding post-Kyoto regime, China's emissions can possibly be reduced by imposing a border tax based on the carbon content of the traded commodities, since China is a major exporter of commodities. If such a border tax is imposed, China might react by imposing import tariffs as well. The question is how such policies affect global emissions or the global carbon price, and welfare given a certain climate policy scenario such as a contraction and convergence regime.

In this context, Paul Krugman writes in his New York Times blog under the title "The WTO is making sense" (Krugman 2009):

> "There was some question about how the WTO would handle cap-and-trade whether it would accept the need for carbon tariffs, if some countries (cough China cough) drag their feet, or whether it would adopt a purist free-trade rule. The answer seems to be in - the WTO is going to treat cap-and-trade the same way it treats VATs, with border taxes allowed if they can be seen as reducing distortions.
>
> One way to think about this is to say that the price of emissions licenses is ultimately a tax on consumers - and consumers should pay the same tax on emissions tied to imports as they do on emissions tied to domestic production. (Thats the same reason you can charge VAT on imports.)
>
> The same logic would also suggest that export subsidies are OK, but from an environmental point of view they're a bad idea; more broadly, the WTO view doesn't really take on the problem of negative externalities generated by foreigners producing for themselves.
>
> But still, a sensible judgment."

The New York Times writes under the title "Possible Plan for Tariffs on Imports From China Remains Alive in House Climate Bill" on its web site (Friedman 2009):

> "A House committee working on sweeping energy legislation seems determined to make sure that the United States will tax China and other carbon polluters, potentially disrupting an already-sensitive climate change debate in Congress. The Ways and Means Committee's proposed bill language would virtually require that the president impose an import tariff on any country that fails to clamp down on greenhouse gas emissions. ...
>
> But associations that represent importers and multinational corporations are raising red flags, warning that the language could lead to trade wars, hurt the United States' ability to export low-carbon technology and harm consumers."

Moreover, The New York Times writes under the title "Obama Opposes Trade Sanctions in Climate Bill" (Broder 2009):

> "'At a time when the economy worldwide is still deep in recession and we've seen a significant drop in global trade,' Mr. Obama said, 'I think we have to be very careful about sending any protectionist signals out there.' He added, 'I think there may be other ways of doing it than with a tariff approach.'"

From an economic point of view, the topic "carbon content of trade" is related to the issue of carbon leakage. This issue has been extensively investigated in the literature - with diverse results and conclusions.[1] Following Marschinski et al. (2009), carbon leakage can occur through three channels: "(1) free-rider leakage, i.e. lower incentives to contribute to the provision of a public good (environmental quality) as a strategic response to another actor's effort; (2) specialisation leakage, i.e. relocation of production of energy-intensive goods due to changes in relative prices; (3) supply-side leakage, where decreased demand in one region leads to drops in fossil fuel prices and therefore results in higher consumption in other parts of the world." Our CGE (computable general equilibrium) analysis will capture the second and the third channel.

Several studies have recently estimated carbon emissions implicitly embodied in traded commodities for different countries and specifically for China.[2] Shui and Harriss (2006) estimate that US $CO_2$ emissions would be 3 to 6% higher if the goods imported from China were produced in the USA, and that 7 to 14% of China's $CO_2$ emissions can be attributed to exports for US consumers.

Peters and Hertwich (2008) calculate carbon contents of trade based on the GTAP 6 data set for 2001. (Herein, net carbon exports mean implicit $CO_2$ exports via exports of commodities minus implicit $CO_2$ imports via imports of commodities.) They find net carbon imports for the Annex B region of 5.6% relative to total $CO_2$ emissions produced in this region, and relative net carbon exports of 8.1% for the non-Annex B region. In particular, according to their calculations China's net carbon exports amount to 17.8% of its total produced emissions, US net carbon imports amount to 7.3%, Japan's to 15.3%, and Germany's to 15.7%. Switzerland (122.9%) and Latvia (60.7%) are the most intensive net carbon importers among Annex B countries, while Hong Kong (182.2%), the rest of South African CU (176.4%) and Mozambique (172.4%) are the main net carbon importers among all countries. South Africa (38.2%) and the Russian Federation (21.6%) are the most intensive net carbon exporters among all countries.

Pan et al. (2008) estimate China's emissions in 2006 on a consumption basis amount-

---

[1] Compare for example IPCC (2007). Sijm et al. (2004) provide a detailed study. Marschinski et al. (2009) provide a recent review.

[2] For a "review of input-output models for the assessment of environmental impacts embodied in trade" see Wiedmann et al. (2007). For an overview of quantitative analyses of $CO_2$ embodiment in international trade see Liu and Wang (2009).

ing to 3.8Gt of $CO_2$ rather than 5.5Gt on the standard production basis. This implies that China's net carbon exports amount to 1.7Gt in 2006.

These results emphasize the relevance of consumption based emissions accounting as a policy option that takes implicit international carbon trade into account. Also, in the absence of a global carbon price as the first best solution, carbon based border tax adjustments could internalize the negative external effects of carbon emissions as a second best solution.

But a number of authors, such as Bhagwati and Mavroidis (2007), question the economic, juristic and political feasibility of carbon content based border tax adjustment (BTA).

In the CGE model based literature on border tax adjustment, possible competitiveness disadvantages for firms within the European emissions trading scheme towards non-EU firms play a central role. Alexeeva-Talebi et al. (2008a) compare border tax adjustment based on imported *quantities* multiplied by domestic carbon content factors within an integrated emissions trading scheme based on imported *emissions* created during the production of imported commodities. They conclude that border tax adjustment protects domestic competitiveness more effectively, while an integrated emissions trading scheme achieves a greater reduction in emissions abroad. Alexeeva-Talebi et al. (2008b) conclude from their simulations of the European emissions trading scheme that market based policy measures such as the Clean Development Mechanism, allowing for flexibility in the location of emissions savings, can be effective substitutes for border tax adjustments in unilateral climate policy. Manders and Veenendaal (2008) find that border tax measures under the European emissions trading scheme significantly reduce carbon leakage. Furthermore, border tax measures appear beneficial for the EU, while they may entail a welfare loss for the rest of the world.

Finally, Lessmann et al. (2009) examine a numerical, intertemporal optimization framework with stable coalitions. They show that carbon based import tariffs increase the emissions target coalition in an welfare improving way if the tariff rate is small relative to the Armington elasticity of imports.

Our paper contributes to the CGE model based literature on border tax adjustment by assuming a carbon based tariff on commodity trade from a region without a binding emissions target to a region with a binding emissions target. Different to the literature, our paper neglects competitiveness aspects by not assuming carbon based subsidies on exports from a region with a binding emissions target to a region without a binding emissions target.[3]

The first contribution of our paper is to calculate and illustrate implicit carbon contents of commodities traded between China, the industrialized countries and the developing countries based on the new GTAP 7 data for 2004 (section 3). The second contribution is to examine the effects of imposing a carbon content based border tax under a contraction and convergence climate regime with emissions trading on welfare and emissions in a stylized CGE model (section 4). Based on the results, the paper derives implications for post-Kyoto policies (section 5). The Appendix provides a description of the key parameters, variables and equations of the model. The paper starts with an overview of the underlying three region model (section 2).

## 2 The three region model

The underlying DART[4] model is a recursive dynamic multi-region, multi-sector CGE model of the world economy. The static part of the model is currently calibrated to the GTAP 7 database (Narayanan and Walmsley 2008) that covers global production and trade data for countries and regions, commodities and primary factors for the benchmark year 2004. Emissions data for GTAP 7 are taken from Lee (2008). The model runs under GAMS MPS/GE. For a detailed description see Klepper and Springer (2000), Springer (2002) and Klepper et al. (2003).[5]

The version of the model scrutinized here distinguishes three regions: China (CHI), industrialized countries (IND) and developing countries (DEV). The industrialized region encompasses the OECD countries plus Hong Kong, Macao, Taiwan, Singapore and South Korea, since they are important source countries of FDI to China - and potential source countries of technology transfer to China (compare Tseng and Zebregs 2002, Whalley and Xin 2006). The model distinguishes the production factors labor, capital, land, and natural resources (fossil fuels). In order to analyze climate policies, $CO_2$ emissions are linked to the use of fossil fuels in production and consumption. The current sectoral aggregation covers 30 sectors in each region.

Each commodity market is perfectly competitive. Product and factor prices are fully flexible. The model incorporates two types of agents for each region: producers

---

[3] Meade (1974) and Grossman (1980) show under which conditions an equal border tax on all imports and a corresponding subsidy on all exports leads to a readjustment of the exchange rate without real economic effects. In our current analysis these criteria are not fulfilled.

[4] Dynamic Applied Regional Trade.

[5] The description in this section follows Hübler (2009).

(one producer per production sector and region) and consumers (one private and one public consumer per region). Producer behavior is derived from cost minimization for a given output. Consumers receive all income generated by providing primary factors to production processes. Consumers save a fixed share of income and invest it into capital for production in each period. Herein, investments are produced like commodities by using production inputs. The disposable income (net of savings and taxes) is then used for utility maximization by purchasing and consuming commodities. The expenditure function is modeled as a CES (constant elasticity of substitution) composite, which combines an energy bundle with a non-energy bundle.

Factor markets are perfectly competitive with full employment of all factors. Labor is a homogenous good, being mobile across industries within regions, but being internationally immobile. While in the basic version of the DART model capital is also internationally immobile, in this version capital is internationally mobile between the industrialized region and China. The benchmark values of foreign capital located in China are taken from the China Statistical Yearbook (2006, 2007). All regions are linked by bilateral trade flows, and all commodities except the investment good are traded among regions. Domestic and foreign commodities imported from different regions are imperfect (Armington) substitutes.

The 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, total factor productivity growth, human capital growth and investment in capital. The model assumes constant, but regionally different growth rates of human capital (educational attainment) taken from Hall and Jones (1999). Population growth rates and labor participation rates are taken from the PHOENIX model (Hilderink 2000). The resulting GDP growth paths are in line with recent projections by OECD (2008).

Technological progress has an exogenous part in every region. It consists of improvements in total factor productivity and in energy biased technological progress. In the latter case, a given output quantity can ceteris paribus be produced with a smaller volume of energy inputs. In China, technological progress in a certain sector additionally increases with the import intensity of the related product, with the foreign capital intensity in this sector and with forward and backward linkages across sectors within the production chain. Technological progress decreases the closer the Chinese technology level comes to the technology frontier given by the industrialized region.[6] This results in a process of technological convergence.[7]

## 3 Carbon content of trade

We calculate the implicit carbon contents of traded commodities using the GTAP 7 data set for 2004 (Narayanan and Walmsley 2008) in combination with emissions data computed from the GTAP 7 data set (Lee 2008).[8] Such implicit carbon contents capture all emissions that occur during the production processes of commodities. Our calculation improves on Pan et al. (2008) by using the new GTAP 7 data and by distinguishing intermediate good inputs by country of origin (for detailed explanations see Ackerman et al. 2007). The latter aspect seems important for computing Chinese carbon contents of trade, since a substantial part of Chinese exports is produced by using imported intermediate goods (so that the value added is relatively low).

In the first step, we derive an input-output table, in other words a 90 × 90 Leontief technology matrix $\Lambda$, from the GTAP 7 data. In each column, it describes the production of a commodity $i$ (in a sector $i$) in region $r$. The first columns contain all commodities $i$ produced in the first region, the following columns contain all commodities produced in the second region and so on. Within each column, commodities $i$ are listed in the same order representing the intermediate good inputs that are necessary to produce one output unit of commodity $i$ in region $r$. At this point, the GTAP 7 data set does not provide *bilateral* trade flows of *intermediate* goods. It does, however, provide bilateral data on total trade flows $\mu$ (for intermediate input use plus consumption) and it does provide *bisectoral* data on total imported intermediate inputs $\iota$ of firms (without distinguishing by source country). Therefore, we use the following weighting algorithm to compute bilateral intermediate good flows $\iota^b$ from sector $ii$ in region $rr$ to sector $i$ in region $r$:

$$\iota^b(rr,r,ii,i) = \iota(r,ii,i)\frac{\mu(rr,r,i)}{\sum^{rr}\mu(rr,r,i)} \tag{1}$$

The underlying assumption is that the distribution of source countries of imports is the same for intermediate good imports as for total imports.

In the second step, we compute the Leontief inverse $\chi$ containing the volumes of all

---

[6] For further details see Hübler (2009).

[7] Full technological catching up would be far beyond the time horizon of our analysis.

[8] For this section, we only need the GTAP 7 data set, not the CGE model itself. Like Peters and Hertwich (2008), we do not distinguish intermediate inputs by source country, since the GTAP data do not provide bilateral intermediate good flows.

commodities that are necessary to satisfy the demand for one unit of each commodity, and additionally to satisfy the need for intermediate inputs throughout all production stages. Herein, $\Xi$ is a $90 \times 90$ identity matrix.

$$\chi = \Lambda \times \chi + \Xi \quad \Leftrightarrow \quad \chi = [\Xi - \Lambda]^{-1} \tag{2}$$

In the third step, we derive the direct emissions per unit of output $i$, denoted by the $1 \times 90$ vector $\varepsilon$. These direct emissions occur in each production stage via direct inputs of fossil fuels (coal, gas and oil).[9] For this purpose, we use the data on direct emissions that Lee (2008) computes from the GTAP 7 data. She takes into account that, depending on the region, a certain share of oil and gas goes into plastic products within the chemical sector. She also takes into account that the oil sector encompasses processes where oil inputs are not burned, but refined in order to gain improved oil products. In this case, she assumes that the resulting emissions are zero.

In the fourth step, we multiply $\varepsilon$ with $\chi$. As a result, we obtain the $1 \times 90$ carbon intensity vector $\zeta$ that contains the emissions over all intermediate production stages that occur when producing one unit of each commodity $i$ in each region $r$.

$$\zeta = \varepsilon \times \chi \tag{3}$$

Figure 1 shows the results for the benchmark year 2004.[10] The figure illustrates that Chinese (CHI) products have the highest carbon ($CO_2$) intensities (except transportation trn), on average about 3.1kg/US$. Especially, the Chinese carbon content of electricity generation (egw) is extremely high due to the importance of inefficient coal power in China.[11] As expected, commodities produced in the developing countries (DEV) have the second highest carbon contents, on average about 1.6kg/US$, and commodities produced in the industrialized countries (IND) have the lowest carbon intensities, on average about 0.7kg/US$.

---

[9] Assume, steal production uses electricity and burns oil when running machines. Then, only these direct emissions from burning oil are included at this stage of the calculation.

[10] We distinguish 30 sectors: agriculture and food (agr), textiles, apparel and leather (tex), beverages and tobacco (bev), business services (bui), chemicals, rubber and plastic (crp), culture and recreation (cus), coal (col), communication (com), construction (con), crude oil (cru), electricity supply (egw), electrical equipment (elm), ferrous metals (fem), financial intermediation (fin), gas (gas), machinery (mac), metal products (met), minerals (min), non-ferrous metals (nfm), non-metallic mineral products (nmm), other manufacturing (otm), paper products and publishing (pap), petroleum and coal (oil), trade and wholesale (trd), public services (pub), real estate (ree), transport machinery (trm), transportation (trn), water supply (wat), wood (woo).

[11] The emissions intensity of gas in China was obviously an outlier. Therefore, we assumed it is equal to the emissions intensity of gas in developing countries. For further comments on accounting problems

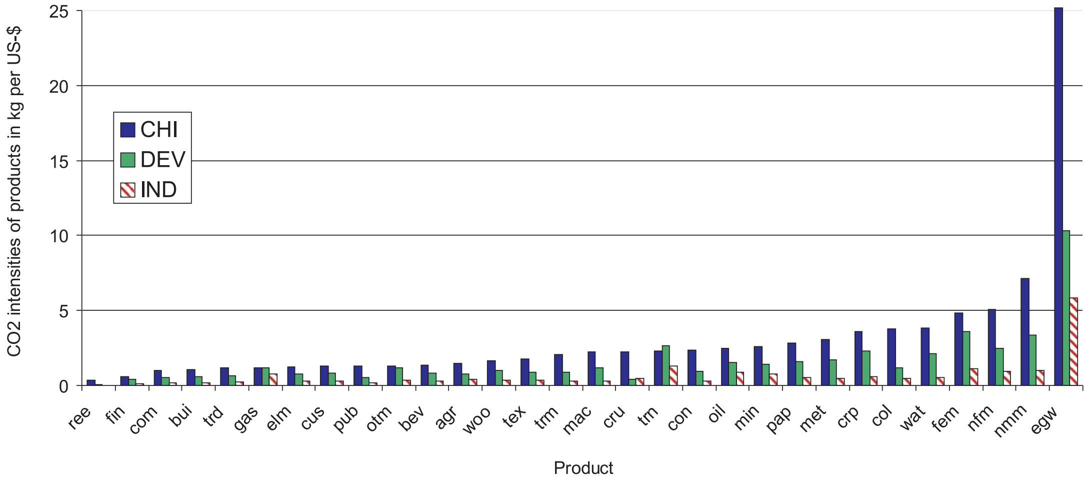

Figure 1: Carbon intensities of products

In the fifth step, *total* carbon contents of *traded* commodities per year can easily be computed by multiplying the carbon intensity factors shown in Figure 1 by the related volumes of commodity trade. (Note that implicit carbon trade within regions is not included.) Figure 2 shows the results for exports of each region. As expected, the ranking of implicit Chinese carbon export volumes is similar to the ranking of commodity export volumes. The three highest and almost equal carbon volumes are embodied in exports of textiles, apparel and leather (tex); electrical equipment (elm) and machinery (mac). Chemicals, rubber and plastic (crp) contribute the fourth highest carbon export volume which is lower than that the three highest volumes. All other products contribute lower carbon export volumes. The other developing countries obviously export substantial carbon volumes via transportation services (trn);[12] non-ferrous (nfm) and ferrous (fem) metals; via agricultural and food products (agr); via crude oil (cru); and via petroleum and coal products (oil).

Figure 3 illustrates the result of summing up over carbon contents of traded commodities per region for the benchmark year 2004. The triangle in Figure 3 visualizes the total quantities of $CO_2$ in Gt (Giga tons) that are implicitly traded between regions. While about 1.6Gt flow from the developing countries to the industrialized countries, China alone exports about 1.1Gt to the industrialized countries. $CO_2$ exports from the

---

in the GTAP data see Peters and Hertwich (2008) and their supporting information.

[12] The high volume of carbon exports via transportation services stems from the high export volume of transportation services given by the GTAP 7 data.

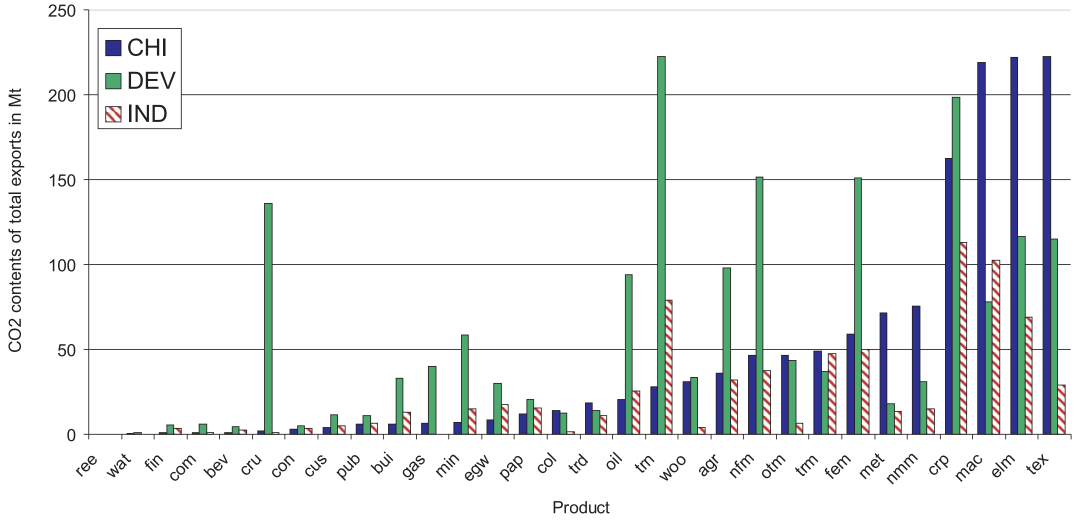

Figure 2: Implicit carbon contents of exported products

industrialized countries to the developing countries and China, as well as $CO_2$ flows from the developing countries to China and vice versa, are relatively low. Figure 3 does not show implicit carbon trade *within* regions. The implicit carbon trade within the industrialized region (between industrialized countries) is substantial; it amounts to 2.7Gt. The implicit carbon trade within the developing region amounts to 0.7Gt.

The percentage numbers show net $CO_2$ exports (implicit $CO_2$ exports minus imports) relative to total emissions that are actually generated in each region. As expected, China is a major net carbon exporter (24% of total Chinese emissions), while the industrialized region is a net carbon importer (15% of total emissions). The developing region is a net carbon exporter as well (12% total emissions).[13]

These outcomes indicate that a climate regime in the industrialized region alone is not sufficient. It potentially increases production in the developing countries and China and imports of the produced commodities to the industrialized region as emphasized by the carbon leakage literature. Therefore, it seems straight forward to consider policies of lowering implicit carbon trade.

---

[13] Compared with Peters and Hertwich (2008) who calculate the carbon contents of trade based on GTAP 6 for the year 2001, implicit carbon carbon exports of China have risen from 0.8Gt (24.4% of total Chinese emissions) in 2001 to 1.4Gt (31.3%) in 2004. Relative carbon imports of China have risen from 0.2Gt (6.6%) to 0.3Gt (7.7%). Thus, net carbon exports of China have risen from 0.6 (17.8%) to 1.1Gt (23.6% $\approx$ 24%). According to Pan et al. (2008), China's net $CO_2$ exports amount to 1.7Gt in the year 2006.

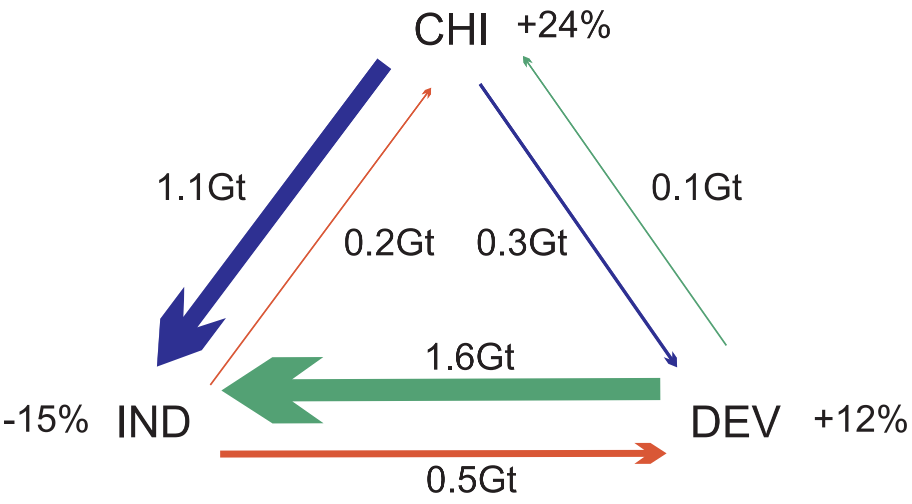

Figure 3: Interregional carbon contents of trade

## 4 Border tax adjustment

Thus, this section compares four policy scenarios: (1) A worldwide contraction and convergence scenario starting in 2012 including all regions, denoted by "+chi". Per capita emissions of the three regions converge year by year so that equal per capita emissions will be reached in the year 2050, while the model runs only until 2025 in our current analysis. In each year, regions receive emissions permits according to their current per capita based emissions goals and are allowed to trade emissions permits with the other regions. The emissions cap covers all sectors, and emissions permits can be perfectly traded across sectors and regions. (2) The same policy scenario, now excluding China, denoted by "-chi". This is our *reference scenario*; that is we measure accumulated welfare in other scenarios relative to this scenario. (3) The latter scenario excluding China, now with a carbon based border tax adjustment, denoted by "-chi-bta". The border tax revenue is received by the importing region that has a binding emissions target (IND or DEV). (4) The latter scenario with border tax adjustment, now additionally with import tariffs imposed by China as a reaction to the border tax adjustment, denoted by "-chi-contra". For this purpose, we assume an additional tariff rate of 5% on all products imported to China.

The regional emissions targets under the contraction and convergence regime follow the rule (Peterson and Klepper 2007):

$$\theta^{CO_2}(t,r) = \theta^{CO_2}(2011,r)\frac{2050-t}{38} + \theta^{CO_2}(2050)\frac{t-2012}{38}, \quad \forall t \geq 2012 \tag{4}$$

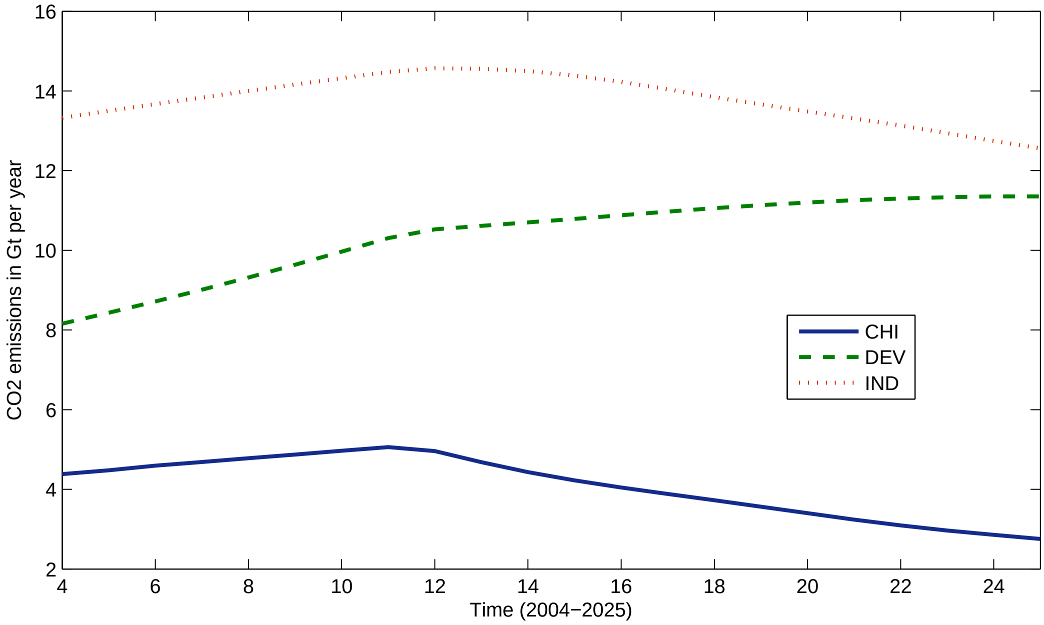

Figure 4: $CO_2$ emissions under a worldwide carbon price (scenario +chi)

Regional emissions in 2011, denoted by $\theta^{CO_2}(2011, r)$, are derived from the solution of the CGE for 2011. The global emissions level in 2050 is set exogenously to about 18.3Gt $CO_2$ which corresponds roughly to a 450ppm $CO_2$ intensity target (compare IPCC 2001).[14] As a result, per capita emissions converge step by step from their regionally different levels in 2012 to an equalized level of 2t per capita in 2050.

The carbon based ad valorem tariff rate $\tau^{BTA}(t, CHI, r, i)$ is endogenously adjusted, where $t$ denotes time (years), CHI denotes China as the exporting country, $r$ denotes importing regions, and $i$ denotes sectors or commodities. In the absence of the first best solution, a carbon price in all sectors in all regions, we aim at a second best solution by pricing imports as if they had been produced domestically. The tax rate depends on the carbon intensities of commodities that are traded from China into the industrialized or developing region, denoted by $\zeta(CHI, i)$. This implies that policy makers exactly know the real implicit carbon contents of the imported products in the benchmark year.[15]

---

[14] Without any climate policy, global emissions would be 39.2Gt $CO_2$ in 2025, and 62.7Gt $CO_2$ in 2050, according to our simulations.

[15] This is a difference to Alexeeva-Talebi et al. (2008) who assume that imported commodities are taxed as if they were produced with domestic technologies. We rather follow the scenario of integrated emissions trading, as described by Alexeeva-Talebi et al. (2008), where importers have to buy emissions permits according to the emissions that indeed occurred during the production of the imported goods. Nevertheless, we measure emissions intensities in the benchmark year and keep them constant thereafter.

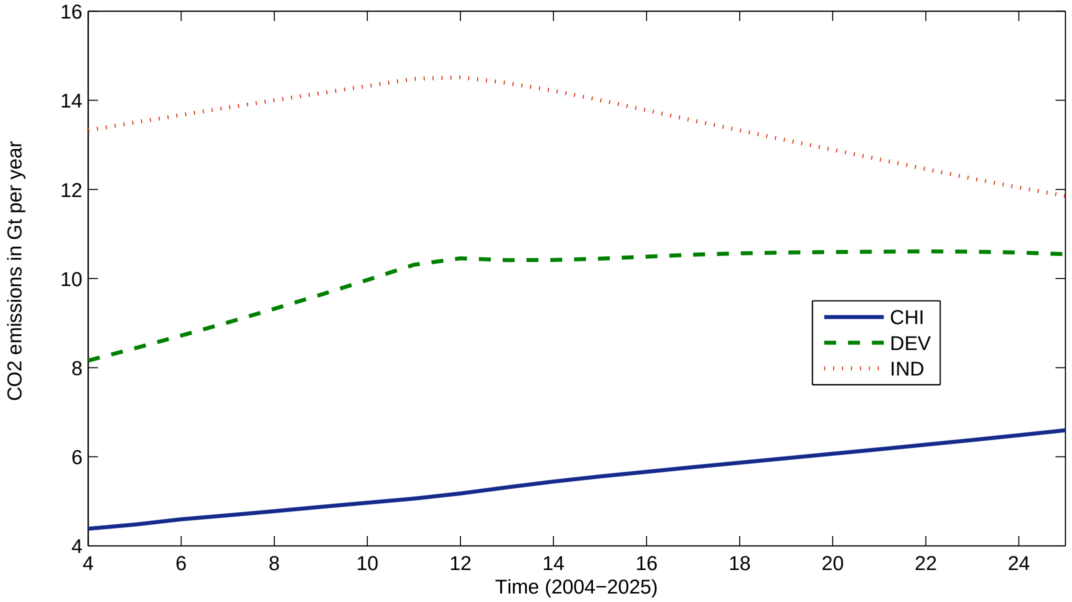

Figure 5: $CO_2$ emissions under a worldwide carbon price excluding China (scenario -chi)

Furthermore, the tariff rate depends on the current carbon price $p^{CO_2}(t)$ and on the current (Armington composite) import price of the commodity $p^M(i,t)$. The border tax adjustment is then given by the following constraint:[16]

$$\tau^{BTA}(t, CHI, r, i) = \frac{p^{CO_2}(t)}{p^M(t, r, i)} \zeta(CHI, i) \tag{5}$$

Thus, imports of commodities are due to the same carbon tax as the corresponding domestically produced commodities. As a result, across sectors, the carbon based tax rate is mainly determined by the carbon intensity. Over time, it basically follows the development of the carbon price. The carbon based tariff rate in 2012 varies between 0.06% for real estate; 0.2% for communication, public services and others; and almost 5% for gas and electricity. According to the simulation, the $CO_2$ price will rise up to 48 US-$ per ton of $CO_2$ in 2025. As a consequence, the carbon based tariff rate will rise up to 20% for paper, oil, minerals and metals; around 30% for coal, chemicals and water; around 40% for ferrous and non-ferrous metals; more than 50% for non-metallic mineral products; and 170% for electricity, given that China's energy supply will still strongly

---

[16] Rearranging the equation and multiplying by the volume of imports $M(t,r,i)$ yields: $M(t,r,i) \cdot p^M(t,r,i) \cdot \tau^{BTA}(t,CHI,r,i) = M(t,r,i) \cdot \zeta(CHI,i) \cdot p^{CO_2}(t)$. Now, the left hand side is the total tax to be paid for importing commodity $i$ into region $r$, given the ad valorem tax rate $\tau^{BTA}(t,CHI,r,i)$. The right hand side computes the carbon content of commodity $i$ and prices it at the current carbon price.

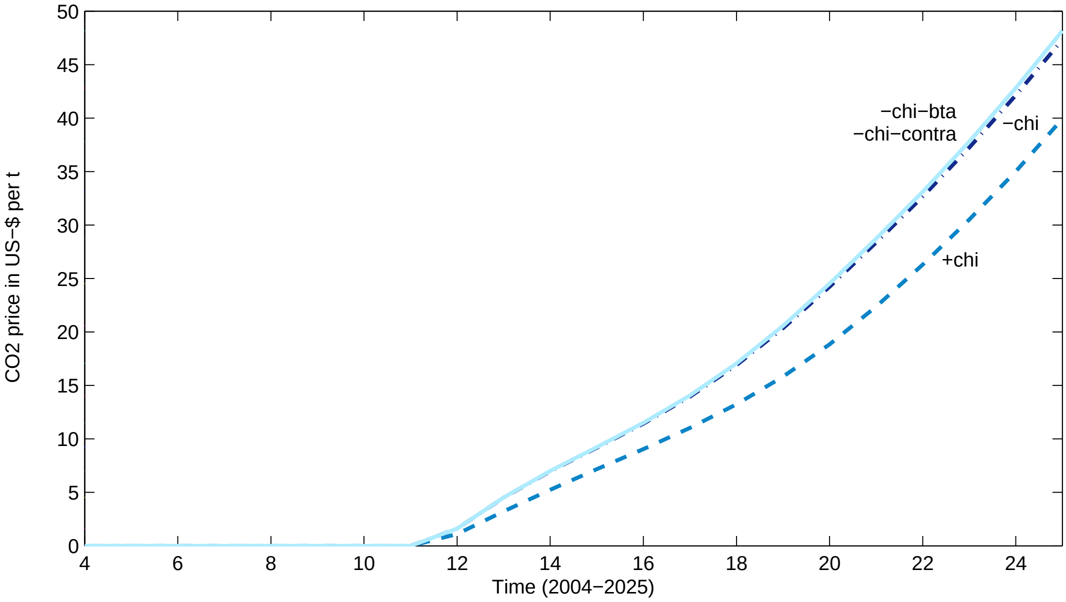

Figure 6: $CO_2$ price under different policy scenarios

rely on coal.[17]

Figure 4 illustrates the emissions paths of the three regions under a worldwide carbon price. It turns out that China will become an emissions permit seller (selling 1.5Gt of $CO_2$ in 2025), because it can save emissions at low marginal costs. The industrialized countries have to reduce emissions substantially over time while they buy emissions permits (amounting to 2.2Gt in 2025) in order to dampen the yearly emissions cuts. The developing countries are allowed to increase their total emissions due to their high populations and population growth. Therefore, they can achieve economic development without being hindered by tight emissions constraints. They are even willing to sell emissions permits to the industrialized countries (0.7Gt in 2025).

Figure 5 illustrates the emissions paths under a worldwide carbon price excluding China (-chi). Now, global emissions are in total higher (by almost 2Gt in 2025) than in the scenario including China (+chi). Both, the industrialized and the developing region must reduce emissions to a somewhat larger extent compared to scenario +chi, because China does no longer supply additional emissions permits, while the per capita based emissions targets for the other two regions remain as before.

This effect becomes obvious in Figure 6. When China joins the post-Kyoto regime

---

[17] Again, the gas sector in China appears as an outlier; the related border tax rate would almost be 250%.

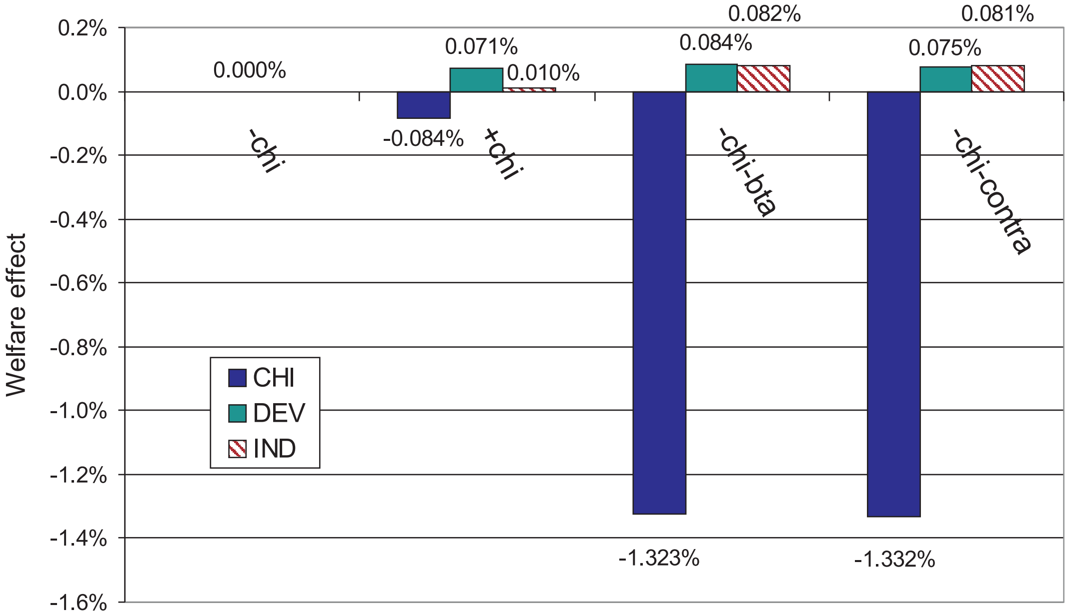

Figure 7: Accumulated, discounted welfare effects of the policy scenarios with respect to reference scenario -chi

(+chi), the time path of the carbon price is significantly lower. On the other hand, the carbon price paths almost coincide across the policy scenarios -chi, -chi-bta, and -chi-contra.

We now examine how the border tax adjustment affects emissions and exports in relation to each other. In particular, we compute the relative change in world wide emissions in scenario -chi-bta with respect to scenario -chi for each year. This relative change rises from -0.02% in 2012 to -0.72% in 2025. Additionally, we compute the relative change in Chinese exports in scenario -chi-bta with respect to scenario -chi. This relative change rises from -0.25% in 2012 to -8.64% in 2025. We then derive the following impact measure:

$$\omega(t) = \frac{EM_{-chi-bta}(t, WORLD) - EM_{-chi}(t, WORLD)}{X_{-chi-bta}(t, CHI) - X_{-chi}(t, CHI)} \tag{6}$$

This impact measure describes the change in global emissions $EM(t, WORLD)$ relative to the change in Chinese exports $X(t, CHI)$ due to the introduction of the border tax adjustment policy for each period of time $t$ in the CGE. The CGE analysis shows that $\omega(t)$ declines from about 1.5kg/US-\$ in 2012 to about 1.0kg/US-\$ in 2025. For comparison, in section 3 we found an average carbon intensity of commodities from

China of about 3.1kg/US-$ and of commodities from other developing countries of about 1.6kg/US-$. The impact measure may be lower than the average carbon intensities of commodities because of replacement of part of Chinese exports by Chinese supply to the local market and by domestic supply to the local markets in the industrialized and developing region. As a consequence, emissions decline by less than the corresponding implicit carbon content of traded commodities.

Figure 7 shows accumulated, discounted welfare effects[18] based on the relative Hicks equivalent variation for the different policy scenarios under scrutiny with respect to reference scenario -chi. Herein, the welfare effects do not include climate change damage, and they do not take capital stocks that remain in the final period into account. The figure reveals that the lower carbon price in scenario +chi compared to scenario -chi is significantly beneficial for the developing region. China is to a somewhat larger extent worse off than the developing region is better off, while the industrialized region is almost unaffected. The reason for this outcome is probably the higher price of Chinese exports due to the carbon tax. As a result, the industrialized region on the one hand benefits from a lower global carbon price, on the other hand suffers from higher prices of Chinese commodities which it imports to a large extent, while the developing region does not. However, these welfare effects are all rather small.

On the contrary, the introduction of a carbon based border tax under a post-Kyoto regime without China in scenario -chi-bta creates a relatively high welfare loss for China. The developing and the industrialized region benefit from the border tax revenues. On the other hand, the carbon price (as shown in Figure 6) and consequently emissions are to a very small extent affected by the border tax: Global $CO_2$ emissions drop by 0.1Gt in 2025, while the $CO_2$ price rises by 0.3 US-$ per ton. If China reacted by imposing an additional import tariff of 5% on all commodities, all regions would be slightly worse off compared to scenario -chi-bta, while there would be practically no change in global emissions.

Finally, one side aspect is worth mentioning. In the benchmark year 2004, per capita $CO_2$ emissions are about 3t in China, on average 2t in the developing region, and 11t in the industrialized region. Running scenario +chi forces per capita emissions targets to converge to 2t per capita for all regions in 2050. Allowing for interregional emissions permit trading, the realized emissions in 2050 are 1t per capita in China and the developing region, and 7t per capita in the industrialized region, since the latter

---

[18] Accumulated over the time frame 2004 to 2025, discounted at a rate of 2% per year.

region strongly buys emissions permits from the former regions. Running scenario -chi, per capita emissions in 2050 would be 8t in China, 1t in the developing region, and 6t in the industrialized region. This means, the industrialized region now buys more permits from the developing countries, but in total the industrialized region buys less permits since China's emissions permits are not on the market.

## 5 Conclusion

We examined implicit carbon flows through commodity trade between the industrialized countries, the developing countries, and China. The large volume of carbon that is implicitly exported from China to the industrialized countries points to a substantial carbon leakage problem: If China does not join a post-Kyoto climate regime, emissions intensive production can be shifted to China, and commodities are exported to the industrialized countries, which undermines the climate regime.

Hence, border tax adjustments based on the carbon contents of traded commodities are a straightforward policy option. They can shift demand towards less carbon intensive products and locations of production. However, our analysis indicates that such policies might have small effects on the global carbon price and on global carbon emissions. They might rather make the industrialized and the other developing countries better off and China significantly worse off due to an income transfer through tax revenues. Against this background, carbon based border tax adjustment policies appear as a good menace, also as a suitable measure for collecting tax revenues from Chinese producers, but not as an appropriate measure for reducing global emissions or for reducing the global carbon price in the presence of an emissions cap.

The inclusion of China into a global post-Kyoto regime appears to be a more effective policy option with respect to the reduction of carbon emissions. China is able to save emissions substantially and to become an emissions permits seller when joining a per capita emissions based contraction and convergence regime - however at a relatively small Chinese welfare loss due to the emissions cap. The potential reason is that according to the data and the model, China has very low marginal emissions abatement costs. The additional emissions permits supply reduces the global carbon price, which creates a welfare improvement for the developing region. The industrialized region on the other hand, seems not to benefit significantly from China's inclusion into the post-Kyoto regime. The reason is probably the fact that the introduction of a carbon price in China raises the price of Chinese commodities which the industrialized region imports at a large scale. Against this background, at first place not the industrialized countries, but the developing countries may call for an early inclusion of China into a global climate regime.

Policy makers would need to consider the following aspects. In the model, border tax adjustment is done under perfect knowledge of the implicit carbon content factors of products imported from China. In reality, true implicit carbon content factors of different products from different countries are certainly hard to estimate and to verify, which complicates the implementation of border tax adjustment policies. The opposite assumption that the carbon content factors of imported products from different countries are homogenous and equal to the carbon content factor of the corresponding domestically produced products would discriminate against exporters with low carbon intensities and benefit exporters with high carbon intensities.

On the other hand, in the current model, carbon content factors for different products are measured in the benchmark year 2004 and then kept constant. This eliminates any incentive for producers to reduce emissions in order to reduce the tax rates that are applied to their production. The opposite assumption would be that carbon content factors are truly endogenous, that is they are measured and adjusted simultaneously. Both assumptions appear not very appropriate with respect to Chinese exports. The former assumption, as it is implemented in the model, does not acknowledge efforts to reduce emissions. The latter assumption would require that Chinese firms regularly provide exact information on their energy inputs (or emissions outputs) to European or US policy makers. Perhaps, a reasonable policy would be in between both assumptions: Carbon intensity factors could be estimated (on a rough sectoral base) and updated after a certain period of time, for instance after five years. This would take energy intensity improvements of exporting economies like China into account without the necessity of large bureaucratic effort to measure and verify carbon emissions permanently. This would also create an incentive for the Chinese government to foster energy and emissions saving policies such as the Five Years Plan. Another option in between both assumptions would be the following: Policy makers estimate carbon intensity factors (on a rough sectoral base) and give firms the chance to improve the estimates by making their true emissions transparent. But herein again the problem of verifying the emissions of (Chinese) firms occurs.

However, our analysis involves numerous uncertainties, especially concerning future technological progress and economic growth. Moreover, the GTAP 7 data seem to incorporate inconsistencies between intermediate inputs in currency value terms and fossil fuel (emissions) inputs in physical value terms and differences in accounting emissions in few cases. Therefore, the results should be treated with caution, at least in quantitative terms. The analysis rather aims at explaining potential policy outcomes qualitatively.

A detailed long-run analysis would require adjusting the carbon content factors of products over time depending on changes in the production and trade structure. Future research may also explicitly model endogenous technological progress including the rising share of renewables and possibly CCS (carbon capture and storage) since the deployment of new technologies strongly effects future emissions paths and since coal power plays a major role in China. It might turn out that international transfer of low carbon energy technologies is a more promising option than imposing trade barriers for successfully dealing with climate change.

## 6 References

Alexeeva-Talebi, V., A. Löschel and T. Mennel (2008a). Climate Policy and the Problem of Competitiveness: Border Tax Adjustments or Integrated Emission Trading? ZEW Discussion Paper No. 08-061, 33 pp.

Alexeeva-Talebi, V., N. Anger and A. Löschel (2008b). Alleviating Adverse Implications of EU Climate Policy on Competitiveness: The Case for Border Tax Adjustments or the Clean Development Mechanism? ZEW Discussion Paper No. 08-095, 26 pp.

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.

Broder, J. M. (2009). Obama Opposes Trade Sanctions in Climate Bill. The New York Times, June, 28, 2009, online article:
*http : //www.nytimes.com/*2009/06/29/*us/politics/*29*climate.html*?$_r$ = 1.

China Statistical Yearbook (2006, 2007). National Bureau of Statistics of China, China Statistics Press, online access:
*http : //www.stats.gov.cn/english/statisticaldata/yearlydata/.*

Friedman, L. (2009). Possible Plan for Tariffs on Imports From China Remains Alive in House Climate Bill. The New York Times, June, 24, 2009, online article:
*http : //www.nytimes.com/cwire/*2009/06/24/24*climatewire − possible − plan − for − tariffs − on − imports − from − ch −* 25103*.html.*

Grossman, G. M. (1974). Border-Tax Adjustments - Do they distort trade? Journal of International Economics 10, 117-128.

Hall, R. E. and C. I. Jones (1999). Why do some countries produce so much more output than others? Quarterly Journal of Economics 114 (1), 83-116.

Hilderink, H. B. M. (2000). PHOENIX plus: the population user support system version 1.0. Online information:
*http : //www.mnp.nl/en/themasites/phoenix/index.html.*

Hübler, M. (2009). Energy Saving Technology Diffusion via FDI and Trade: A CGE Model of China. Kiel Working Paper No. 1479, 40 pp.

IPCC (2001). Synthesis Report - Summary for Policymakers. In: Climate Change 2001. Third Assessment Report of the Intergovernmental Panel on Climate Change, 34 pp.

IPCC (2007). Mitigation from a cross-sectoral perspective. In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK and New York, NY, USA, 72 pp.

Klepper, G. and K. Springer (2000). Benchmarking the Future: A Dynamic, Multi-Regional, Multi-Sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper No. 976, 72 pp.

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, 40 pp.

Krugman, P. (2009). The WTO is making sense. The New York Times, June, 26, 2009, online article:
*http : //krugman.blogs.nytimes.com/*2009/06/26/*the − wto − is − making − sense/.*

Lee, H.-L. (2008). An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP. GTAP Resource #1143, GTAP $CO_2$ emissions (for V7), online access:
*https : //www.gtap.agecon.purdue.edu/resources/res*$_d$*isplay.asp?RecordID* = 1143.

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.

Liu, X. and C. Wang (2009). Quantitative analysis of $CO_2$ embodiment in international trade: An overview of emerging literatures. Frontiers of Environmental Science and Engineering in China 3(1), 12-19.

Manders, T. and P. Veenendaal (2008). Border tax adjustments and the EU-ETS - A quantitative assessment. CPB Document No. 171, 36 pp.

Marschinski, R, M. Jakob and O. Edenhofer (2009). Analysis of Carbon Leakage in an Extended Ricardo-Viner Model. Conference paper for the 2009 EAERE conference, June 24-27, Amsterdam, Netherlands, 22 pp.

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 (eds.) (2008). Global Trade, Assistance, and

Production: The GTAP 7 Data Base. Center for Global Trade Analysis, Purdue University, online information:
*https : //www.gtap.agecon.purdue.edu/*.

OECD (2008). Environmental Outlook to 2030. Paris, France, 523 pp.

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

Peters, P. and E. G. Hertwich (2008). $CO_2$ Embodied in International Trade with Implications for Global Climate Policy. Environmental Science and Technology, 42(5), 1401-1407, online access to article and to supporting information:
*http : //pubs.acs.org/doi/suppl/*10.1021/*es*072023*k*.

Peterson, S. and G. Klepper (2007). Distribution Matters - Taxes vs. Emissions Trading in Post Kyoto Climate Regimes. Kiel Working Paper No. 1380, 26 pp.

Shui, B., and R. C. Harriss (2006). The Role of $CO_2$ Embodiment in US-China Trade. Energy Policy 34, 4063-4068.

Sijm, J. P. M., O. J. Kuik, M. Patel, V. Oikonomou, E. Worrell, P. Lako, E. Annevelink, G. J. Nabuurs and H. W. Elbersen (2004). Spillovers of Climate Policy - An assessment of the incidence of carbon leakage and induced technological change due to $CO_2$ abatement measures. Netherlands Research Programme on Climate Change Scientific Assessment and Policy Analysis, 251 pp.

Springer, K. (2002). Climate Policy in a Globalizing World. Springer, Berlin, Heidelberg, New York, 293 pp.

Tseng, W. and H. Zebregs (2002). Foreign Direct Investment in China: Some Lessons for other Countries. In: W. Tseng and M. Rodlauer (eds.), China Competing in the Global Economy, IMF, 68-104.

Whalley, John and X. Xin (2006). Chinas's FDI and Non-FDI Economies and the Sustainability of Future High Chinese Growth. NBER Working Paper No. 12249, 24 pp.

Wiedmann, T., M. Lenzen, K. Turner and J. Barrett (2007). Examining the Global Environmental Impact of Regional Consumption Activities, Part 2: Review of Input-Output Models fort the Assessment of Environmental Impacts Embodied in Trade. Ecological Economics 61, 15-26.

# 7 Appendix

This section contains key equations of the CGE model. For further details and data sources see Klepper and Springer (2000), Springer (2002), Klepper et al. (2003) and

Hübler (2009). Tables 1 and 2 explain the meaning of the parameters and variables.[19] The equations are written in quantities, while all prices are fully endogenous.

Accumulated, discounted welfare effect excluding climate change damage is derived from the relative Hicks equivalent variation of policy scenario 1 compared with reference scenario 0:

$$W(r) = \frac{\sum_{t=2004}^{2025}\{P[p^C(2004,r),U^1(t,r)] - P[p^C(2004,r),U^0(t,r)]\}(1-\rho)^{(t-2004)}}{\sum_{t=2004}^{2025} P[p^C(2004,r),U^0(t,r)](1-\rho)^{(t-2004)}} \tag{7}$$

Households equate expenditure to income:

$$p^C C = p^K K + p^L L + p^B B + p^{CO_2} EM + R(.), \quad \forall(t,r) \tag{8}$$

Capital accumulation with a constant depreciation rate and saving rate:

$$K(t+1,r) = [1-\delta(r)]K(t,r) + \sigma(r)Y(t,r) \tag{9}$$

Interregional capital mobility :

$$K(t,IND) = cet[K(t,IND),F(t,CHI)] \tag{10}$$

Exogenous labor augmentation (via population growth and educational improvements):

$$L(t+1,r) = [1+\lambda(t,r)]L(t,r) \tag{11}$$

Basic production structure (producers minimize costs taking input and output taxes $\tau^{(\cdot)}$ into account):

$$cet(D,X) = ltf\langle N, ces\{B, cd[K,L,E]\}\rangle, \quad \forall(t,r,i), r \in \{IND, DEV\} \tag{12}$$

Basic production structure in China (producers minimize costs taking input and output taxes $\tau^{(\cdot)}$ into account):

$$cet(D,X) = ltf\langle N, ces\{B, cd[cd(K,F),L,E]\}\rangle, \quad \forall(t,CHI,i) \tag{13}$$

---

[19] The 30 production sectors are listed as a footnote in section 3.

Imported and domestically bought commodities form a consumption bundle:

$$C(t,r) = ces[D(t,r,i), M(t,r,i)] \tag{14}$$

Linking $CO_2$ emissions to fossil fuels (col, gas, oil) in an energy bundle:

$$E = cd\{cru, egw, ltf[EM(e), e]\}, \quad \forall(t,r) \tag{15}$$

Armington aggregation of imports from different regions (where export subsidies, and carbon and non-carbon based import tariffs $\tau^{(\cdot)}$ are imposed on traded commodities):

$$M(t,r,i) = ces\{ltf[X(t,rr,r,i), \Upsilon(rr,r,i)]\} \tag{16}$$

Exogenous total factor productivity improvement:

$$A(t+1,r,i) = [1+\vartheta^A(r)]A(t,r,i), \quad \forall r \in \{IND, DEV\} \tag{17}$$

Exogenous and endogenous total factor productivity improvement in China:

$$A(t+1,CHI,i) = [1+\vartheta^A(r)+T^A(t,i)]A(t,CHI,i) \tag{18}$$

Exogenous energy efficiency improvement:

$$E(t+1,r,i) = [1-\vartheta^E(r)]E(t,r,i), \quad \forall r \in \{IND, DEV\} \tag{19}$$

Exogenous and endogenous energy efficiency improvement in China:

$$E(t+1,CHI,i) = [1-\vartheta^E(CHI)-T^E(t,i)]E(t,CHI,i) \tag{20}$$

Herein, the strength of total factor productivity improvements in China increases with the intensities of foreign capital, of vertical linkages within the production chain, of imports, and with the distance to the technology frontier:

$$T^A(t,i) = f[FI(t,i), VI(t,i), MI(t,i)][Y_L(t,IND,i) - Y_L(t,CHI,i)] \tag{21}$$

The strength of energy efficiency improvements increases with the same factors:

$$T^E(t,i) = f[FI(t,i), VI(t,i), MI(t,i)][Y_E(t,IND,i) - Y_E(t,CHI,i)] \tag{22}$$

| Symbol | Explanation |
|---|---|
| $f(.)$ | General function |
| $ces(.)\quad [cet(.)]$ | Constant elasticity of substitution [transformation] function |
| $cd(.)$ | Cobb-Douglas function |
| $ltf(.)$ | Leontief function |
| $t$ | Time, year [2004; 2025] (climate policy starts in 2012) |
| $r\quad [rr]$ | Region {IND, DEV, CHI} |
| $i\quad [ii]$ | Sector, commodity (30 sectors, see footnote in section 3) |
| $e$ | Fossil fuels {col, gas, oil} (subset of i) |
| $\rho$ | Time discount rate (0.02 per year) |
| $\delta(r)$ | Capital depreciation rate |
| $\sigma(r)$ | Saving rate |
| $\lambda(t,r)$ | Population growth rate plus rate of educational improvement |
| $\vartheta^A(r)$ | Rate of exogenous general technological progress |
| $\vartheta^E(r)$ | Rate of exogenous energy biased technological progress |
| $\tau^{(.)}(.)$ | Tax rate |
| $\Upsilon(rr,r,i)$ | Transportation costs (of transporting from rr to r) |

Table 1: Parameters

| Symbol | Explanation |
|---|---|
| $W(r)$ | Accumulated, discounted welfare effect |
| $U(t,r)$ | Utility of the representative consumer |
| $P(.)$ | Expenditure |
| $C(t,r)$ | Consumption (private and public) |
| $D(t,r,i)$ | Production for domestic use |
| $X(t,r,i)\quad[X(t,rr,r,i)]$ | Exports [bilateral trade from rr to r] |
| $M(t,r,i)$ | Imports |
| $K(t,r)\quad[K(t,r,i)]$ | Capital endowment [production input] |
| $F(t,CHI)\quad[F(t,CHI,i)]$ | Endowment of CHI with capital from IND [production input] |
| $L(t,r)\quad[L(t,r,i)]$ | Labor endowment [production input] |
| $B(t,r)\quad[B(t,r,i)]$ | Land and natural resources endowment [production input] |
| $EM(t,r,e)\quad[EM(t,r,e,i)]$ | $CO_2$ Emissions permits endowment [production input] |
| $N(t,r,i)\quad[N(t,r,ii,i)]$ | Intermediate good input [flow from ii to i] |
| $R(.)$ | Total tax revenue |
| $p^{(.)}$ | Price |
| $A(t,r,i)$ | Total factor productivity |
| $E(t,r,i)$ | Energy input |
| $FI(t,i)$ | Foreign capital intensity in China $\left(\frac{F}{K}\right)$ |
| $MI(t,i)$ | Import intensity in China $\left(\frac{M}{D+X}\right)$ |
| $NI(t,ii,i)$ | Intermediate good flow intensity in China (from ii to i) $\left(\frac{N}{D+X}\right)$ |
| $VI(t,i)$ | Vertical linkage intensity in China |
| | with respect to upstream $u$ and downstream $d$ sectors |
| | $\left[\sum_{u\neq i} FI(t,r,u)NI(t,r,u,i) + \sum_{d\neq i} FI(t,r,d)NI(t,r,i,d)\right]$ |
| $Y_L(t,r,i)$ | Labor productivity $\left(\frac{D+X}{L}\right)$ |
| $Y_E(t,r,i)$ | Energy productivity $\left(\frac{D+X}{E}\right)$ |
| $T^A(t,i)$ | Rate of endog. general tech. progress in China |
| $T^E(t,i)$ | Rate of endog. energy biased tech. progress in China |

Table 2: Variables