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Environmental Effects of Trade between Middle- and High-Income Countries

Empirical Magnitude and Political Abatement Strategies

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Anton Hartl

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Betreuer:	Univ.-Prof. Alejandro Cuñat, PhD

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List of Abbreviations

BRICs	A group of middle-income countries comprised of Brazil, the Russian Federation, India and China
CH_4	Methane
CO_2	Carbon Dioxide
GTAP	Global Trade Analysis Project
HICs	High-income countries
HFCs	Hydrofluorocarbons
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISIC Rev.2	International Standard Industrial Classification of all economic activities, Revision 2
MITPs	A country's 10 Most Important Trading Partners
MRS	Marginal Rate of Substitution
MRT	Marginal Rate of Transformation
N_2O	Nitrous Oxide
nec	Not elsewhere classified
OECD	Organization for Economic Co-operation and Development
PFCs	Perfluorocarbons
SF_6	Sulphur Hexafluoride
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
WIOD	World Input-Output Database
WTO	World Trade Organization

1 Introduction

Today's world economy is marked by ever-increasing trade flows on an ever-increasing geographic scale. The question of who is benefitting from this development and who might be losing is one of the most fiercely debated in discussions on economic development perspectives. The mainstream views among economists and also the dominant forces in international politics see an increase in trade as *the* chance for developing countries to start what is called a "catch-up-process". But this is by no means an uncontroversial issue. Many social movements, politicians and scientists warn developing countries of opening up their markets and participating too heavily in the process of globalization, which is held responsible for the large inequalities among world regions and social misery in many world regions. The argument goes that poor countries are exploited by the rich world via extraction of cheap labour, ressources and migration of skilled workers.

Rather recently, a new facet was added to this debate on trade and development, a facet dealing with the environmental consequences of increasing trade. Not only, say the critics, are developing countries exploited in the aforementioned ways, the rich world also uses them for potentially or actually environmentally damaging economic activities that the rich countries do not want to have performed at home. One might find these accusations too harsh or one-dimensional but are they unjustified altogether or just an exaggeration? Or might they be true at last? What this thesis intends to deliver is not a discussion of isolated cases of environmental harm caused by possibly reckless or criminal behavior of firms or individuals in developing countries but rather a look at the aggregate level: Concentrating on emissions of an important greenhouse gas, CO_2, I am investigating how the emission burden is shifted between middle- and high-income countries via international trade and how policy instruments could be used to make the distribution of the environmental burden fairer.

1.1 Motivation and Aims

From an economic research perspective, it seems straightforward to first see what economic theory tells us about the environmental consequences of trade and to confront these theoretical implications in a second step with what happens empirically. But life for empirical researchers is rarely so easy. Usually reality presents us with a large set of complications that make it difficult to verify or falsify a theory easily in the social sciences. As economic theory in general works with a remarkable amount of simplifications and we can not observe this kind of a stripped-down economy in reality, it becomes empirically difficult to distinguish cause and effect which is indispensible for a solid proof. Moreover, many empirical results are objected to the critique of leaving out some important economic mechanisms, it is said they suffer from the so-called "omitted-variable-bias". To give an example that will be of some importance later in my thesis, it is often assumed that environmental conscience depends on income. If higher income increases consumers' preferences for a clean environment this could explain why a city like Beijing suffers from smog to an extent that the World Health Organization considers 40 times above a level that is safe for humans[1], while a city like London, heavily plagued by smog in the 19th century, enjoys a much cleaner air today. There are, however, not few people who heavily doubt that it is really income that is *causing* environmental conscience to grow. These people present alternative suggestions like education or culture as explanatory variables. To distinguish between these different explanatory variables becomes especially important if economists enter the world of political advices. Obviously it makes a big difference to suggest giving money to a heavily polluting country in order to raise incomes or to suggest methods of strengthening this country's educational performance. A way of handling the abovementioned problems with empirical proofs in the social sciences is to use a step-by-step procedure. If we accept that it will rarely be possible to deliver a fully fletched empirical proof of some economic theory we are left with the possibility of investigating parts that can be more easily handled. This is what my study intends to do for the relationship between trade and the environment.

The empirical part of my thesis deals with emissions of CO_2, a topic that has gained considerable weight in the last twenty years as the consequences of the anthropogenic climate change became increasingly clear. Climate change is highly affected by the concentration of greenhouse gases in the atmosphere. CO_2 is the most important greenhouse gas originating from human activity, as is depicted in Figure 1.1 with data for the so-called Annex I countries[2]. Its concentration is measured in parts per million (ppm)[3]. The concentration of CO_2 in the atmosphere has risen from 280 ppm in pre-industrial times to 379 ppm in 2005 and its growth rate has been particularly high in the last decades. Although the concentration of greenhouse gases in the atmosphere has been subject to natural fluctuations over the course of history, its range over the past 650.000 years lay between 180 and 300 ppm (IPCC, 2007, p.2). There are a number of simulations showing the effect of a further increasing concentration on global temperatures. If CO_2 concentration would stay below 450 ppm this would mean a 60% chance that the global mean temperature rise would not exceed 2°C, which is a declared target of EU policy (den Elzen and Meinshausen, 2006, p.560). For politicians and society as a whole

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[1] *The Economist*, 10 Aug 2013, "The East is grey", p.17

[2] The UNFCCC refers to countries that committed themselves to binding greenhouse gas emission reduction targets as Annex I countries. These countries include among others all high-income countries dealt with in my thesis as well as the Russian Federation. Not included in this group are Brazil, China and India.

[3] 1 ppm means 1 molecule of CO_2 per million molecules of dry air (IPCC, 2007, p.2).

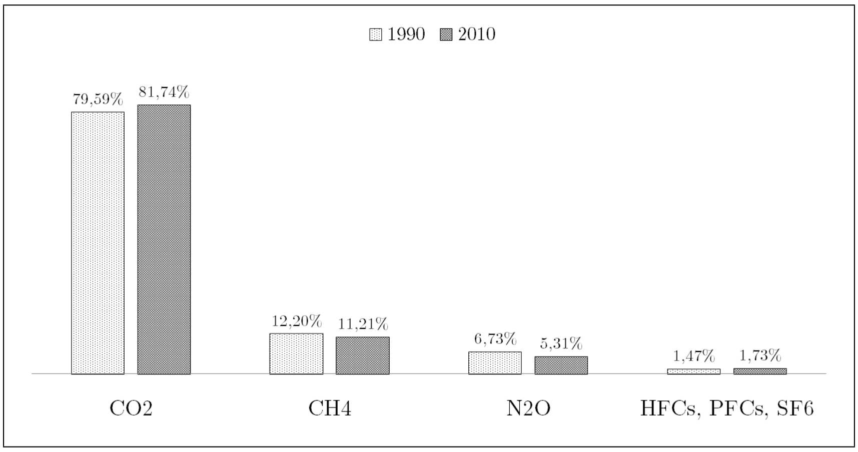

Figure 1.1: Greenhouse gas emissions by gas, Annex I countries, in % of total emissions of CO_2 equivalents. Source: UNFCCC (2012, p.10)

it is therefore highly relevant to find out what the main sources of CO_2 emissions are and how international trade contributes to them. What is clear by now is that "[t]he primary source of the increased atmospheric concentration of CO_2 since the pre-industrial period results from fossil fuel use, with land-use change providing another significant but smaller contribution" (IPCC, 2007, p.2). The accounting of emissions of CO_2 from fossil fuel combustion is plagued by less uncertainty than that of land use, land use change and forestry (IPCC, 2007, p.3). Although the latter source of emissions is highly relevant in some economic sectors - think of agriculture in a country like Brazil - it can not be accounted for in my thesis due to a lack of reliable estimates on a sectoral level.

The main focus of my research is the dispersion of production and consumption between countries with a different income level. The high degree of dispersion, or in other words the growth of world trade, that we observe today has been made possible by two main factors: a liberalization of trade restrictions and an improvement of transport technology in terms of speed and size to an extent unknown before (WTO, 2008, p.82ff.). The basic idea behind my research strategy is shaped, among others, by the work of Shui and Harriss (2006) and Li and Hewitt (2008). They examine trade between China and the United States (respectively the United Kingdom) and find out that China emits significantly more CO_2 in the production of export goods for the US (the UK), than the partner country emits in its production of export goods to China. These results show us that, assuming the composition of regional consumption to be constant no matter the origin of the product (which is of course a naive assumption), trade leads to a different allocation of CO_2 emissions, away from the high-income countries US and UK towards the rising middle-income country China. This result is also confirmed in my analysis of embodied CO_2[4] in trade flows of the BRICs, as analysed in chapter 4.

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[4] The term "embodied CO_2" means the amount of CO_2 emissions generated during the production of a (traded) good.

Is it that emerging economies are somehow forced to do the "dirty" work for the rich world? Or do they want to attract emission intensive industries because of their market potential? It is important to understand that the empirical results from studies like Shui and Harriss (2006) and Li and Hewitt (2008) do not tell us *why* we observe this regional pattern of production, consumption and pollution. In order to handle this question we need theories that we subsequently test empirically. Two influental and connected hypotheses trying to explain this pattern are the competitiveness hypothesis and the pollution haven hypothesis. They try to answer the question how environmental regulation influences trading patterns. In discussions on environmental regulation, the threat of production relocation is used frequently by various industries.[5] It is said that the rich world's competitiveness suffers from stricter environmental laws as they increase production costs whereas less regulated emerging economies would gain relative competitiveness (competitiveness hypothesis) and attract industries that are pollution intensive (pollution haven hypothesis). The main difference between these two hypothesis lies in the question if the effects of environmental regulations are strong enough to cause relocations or if these effects are marginal compared to effects of labor costs, education or infrastructure (Copeland, 2008, p.65).

To analyze the effects of pollution in a neoclassical framework, we need environmental quality to explicitly enter the utility function of consumers. If the pollution haven hypothesis were true and industries decided upon their location based on differences in environmental regulations, we could observe two welfare effects in a country raising its environmental standards (call it Rich). Rich would suffer a welfare loss because of the exit of some pollution-intensive industries. Conversely, welfare would be increased due to the reduction of pollution. The net effect of such a measure can be both positive or negative. However, in a world with trade, consumers in Rich are still left with the possibility to reduce the welfare loss from the exit of some producers by consuming the pollution-intensive goods via imports from another country (call it Poor). The pollution level in Poor however does not enter consumers' utility function in Rich. So consumers in Rich are left with a welfare increase due to a cleaner environment whereas the welfare loss from losing an industry has almost vanished. The environmental effects of the production in this industry have been externalized by Rich. If we return to the example of China and the US (the UK), discussed above, trade opens up the possibility for consumers in the US (the UK) to consume more goods than they actually paid for in terms of CO_2 emissions. Consumers in China on the other hand pay more in terms of CO_2 emissions than they actually consume. Interpreted in this way, with CO_2 emissions as a cost factor, this can be analyzed as a classical case of an externality. How this externality can be

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[5] From an interview with Wolfgang Eder, CEO of the Voestalpine AG, in the *Industriemagazin*, 02 Apr 2013. "Der Industrie droht mit Energie- und Klimaschutz-Abgaben, Umweltauflagen und hohen Lohnnebenkosten die Vertreibung aus Europa. Wir haben viele Male nachgerechnet: Kann es sein, dass ich 5000 oder 6000 Kilometer Transportweg habe und trotzdem noch um so viel billiger produziere als in Europa? Ja, es kann sein. [...] Wenn sich in den kommenden fuenf Jahren auf der Kostenseite in Europa keine deutliche Wende zum Positiven ergibt, gehe ich davon aus, dass bis 2030 mehr als die Haelfte der heutigen Stahlproduktion in Europa nicht zu halten sein wird."

internalized is the core topic of chapter 5.

To conclude this introductory section, an overview of the paper: The remaining sections of the introduction will go even deeper into motivating what is to come and giving some perspective on the economic relations between the countries analyzed. The research question and hypotheses outlined in section 1.2 will provide a guideline for the rest of this paper, while section 1.3 will discuss economic characteristics of the BRICs-countries. In chapter 2, I will give an overview of what economists already know concerning the relationship between trade and the environment, also specifically trade and CO_2 emissions, and what could be done to get rid of the externality created by these emissions. This will help to put the empirical results of my analysis in chapter 4 and my discussion of abatement policies in chapter 5 into perspective. Before this, a possibly rather dry but very important part is handled in chapter 3, where I discuss data (quality) issues and the methodological approach. Concluding this paper is chapter 6 where I ask the question if we can learn something new from my analysis and what we should draw from it in terms of policy advice.

1.2 Research Question and Hypotheses

Research Question *What are the effects of trade between the BRICs countries and their high-income trading partners on country-specific CO_2 emissions and does this trade lead to an overall increase of CO_2 emissions? Which political tools could be used to internalize for consumers in high-income countries the environmental costs externalized by trade?*

Hypotheses

H1: The BRICs are net exporters of embodied CO_2 to the high-income countries under consideration.

H2: Ceteris paribus, the overall CO_2 emissions of all countries under consideration are higher in a situation of trade as opposed to an autarky situation (no trade).

H3: A carbon emission tax on consumption rather than on production would reduce the incentive of high-income countries to relocate their production in relatively CO_2-intensive industries to low- and middle-income countries.

The research question consists of two parts, an empirical and a theoretical part. The empirical question of my thesis aims to find out how trade distributes consumption and production activities of a number of sectors between high- and middle-income countries. The group of middle-income countries to be considered are the so-called BRICs countries, comprised of Brazil, the Russian Federation, India and China. As high-income trading partners I consider the most important partners for each of the BRICs in terms of monetary value, which in all cases cover between 30% and 50% of exports and imports. The research question asks specifically about the "effects of trade". As discussed in section 1.1 this poses some non-trivial questions of how to establish causality. Chapters 3 and 4 - which discuss data, methodology and results - will show that I deal with this problem in a not completely satisfactory way that still gives us some insight how an increased participation in world trade changes country-specific and overall CO_2 emissions and also why this happens. To already also give a hint on the problem with my approach: It lacks dynamics. Hypothesis 1 and 2 try to give a provisional answer to the empirical question. Their expectation that the BRICs act as net exporters of CO_2 and that trade between middle- and high-income countries increases overall emissions is in line with the empirical evidence accumulated so far (see section 2.2).

The theoretical part of the research question deals with political abatement strategies for what can be considered an externality of production technologies that produce pollution, i.e. the emission of some CO_2. It seeks to find systems of taxation and redistribution between nations to allocate the environmental costs of a product to its consumer. Behind this part of the research question as well as Hypothesis 3 lies the concept of consumer responsibility, which posits that consumers should bear the costs of their consumption activities, a principle that is abrogated if trade allows to externalize environmental costs. Another principle would be producer responsibility. A further discussion of these concepts will be provided in section 2.3. Popular ways of dealing with environmental externalities are (carbon) taxes or trade barriers. In reality we observe mixed strategies at work, where some of the costs are born by producers (e.g. direct emission taxes) and some by consumers (e.g. mineral oil tax). As a benchmark case, however, it will be interesting to analyze the pure effects of these two extreme cases. So the second part of my research question is trying to compare the effectiveness of production and consumption taxes as well as trade barriers to reduce this externality. Useful for this task will be a two-country neoclassical trade model where we introduce emission targets for producers and consumers.

1.3 The BRICs: Common Features, Differences and Trade Relations

BRICs is the name for a group of four countries: Brazil, the Russian Federation, India and China. [6] Depending on one's position, the country grouping of the BRICs may seem

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[6] The term BRICs was coined in 2001 by Jim O'Neill, Head of Goldman Sachs' Economic Research Group in London. He argued that the group of four emerging economies was going to increase its share in world GDP substantially and that this group should therefore gain power in international economic negotiations, e.g. among the G7 group (O'Neill, 2001).

logical or rather random. All four of them are important regional powers belonging to the group of so-called emerging countries. All four of them experienced (much) higher growth rates than almost all high-income economies during the last 15 years. They are seen to be the most important and dynamic future markets for Western investors. From this viewpoint, it is a concept that reflects not so much the interests of the BRICs themselves but more those of their high-income trading partners. And indeed, if we want to look for separating features of these five countries, we don't have to look far. As the Mexican economist Gerardo Rodriguez put it in the Financial Times: "The appeal of the concept of the BRICs contrasts with the deep political and economic differences among its member countries"[7]. The differences are found in political as well as economic structures within these countries, called "different models of economic development" by Ghosh et al. (2009a).

> Brazil is a domestically oriented service economy; Russian economic development is heavily dependent on energy and raw material resources; the Indian economy is essentially service-led, supported by exports; and China's economic development is driven by manufacturing exports and investment (Ghosh et al., 2009a, p.1).

To the original four-country group of the BRICs, we could add South Africa whose development model rested heavily on resource extraction for a long period of time. More recently, following a common model of other minerals economies, the development of heavy and chemicals industries became increasingly important. The "large surpluses generated from resource extraction" allow South Africa to bypass the stage of labour-intensive manufacturing dominance, so important in China and India for example (Mayer and Altman, 2005, p.34). Other countries frequently compared to the BRICs are Indonesia or Turkey.

> Looking at the more recent policies and future development plans of the BRICs, a certain 'convergence' of their development strategies can be observed: More export orientation and state-led industrial policy in Brazil; greater industrial diversification and promotion of investment in Russia; more emphasis on the development of other sectors than services, higher expenditures on infrastructure investment in India; and a gradual switch from exportoriented to more domestic-market oriented growth with less dominance of manufacturing in China (Ghosh et al., 2009b, p.68).

In addition to this convergence of policies, these countries share a relatively low absolute income level. Figure 1.2 shows levels of GDP per capita in 2009, the year for which I perform the empirical research in this thesis. We can observe some significant inter-country differences among the BRICs, the resource-based economies with high inequality like the

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[7] *Financial Times Online*, 22 Feb 2013, "Guest Post: The BRICs could break up"

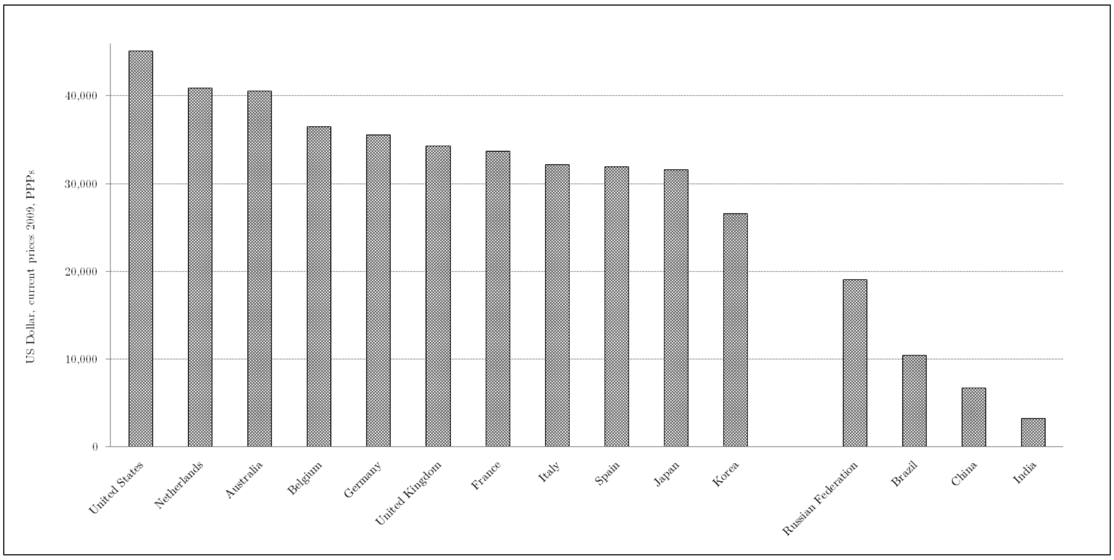

Figure 1.2: GDP per capita for the year 2009. Source: Statistical Database of the OECD, stats.oecd.org

	1990-2011	2000-2011		1990-2011	2000-2011
France	1.60%	1.38%	Brazil	2.75%	3.62%
Germany	1.72%	1.35%	Russia	0.82%	5.29%
Italy	1.02%	0.67%	India	6.51%	7.21%
Netherlands	2.30%	1.55%	China	10.11%	10.20%
Spain	2.41%	2.18%	∅	5.05%	6.58%
Belgium	1.88%	1.64%			
United Kingdom	2.04%	1.91%			
United States	2.44%	1.79%			
Australia	3.15%	2.99%			
Japan	1.09%	0.77%			
Korea	5.50%	4.51%			
∅	2.29%	1.89%			

Table 1.1: GDP growth rates. Source: Statistical Database of the OECD, stats.oecd.org

Russian Federation and Brazil exhibit higher levels of GDP (however, also significantly smaller growth rates). Nonetheless, there is a clear income gap to per capita income in high-income countries. Other similarities between Brazil, the Russian Federation, India and China are a big land size as well as a large and young population. Ghosh et al. (2009b, p.67) also stress that the state plays an important role in the economy in all of the BRICs and that the quality of political institutions is relatively low measured by various standards like rule of law, corruption or political stability.

In general, the most obvious common feature of the BRICs - and also the feature investment firms like Goldman Sachs are mostly interested - are growth rates in recent decades. Table 1.1 shows recent average growth rates for HICs and BRICs. Growth in the BRICs

		Brazil	Trade	% of total			**Russian Fed.**	Trade	% of total
	1	China	36,101,975	12.9%		1	China	39,096,993	8.3%
	2	United States	35,959,073	12.8%		2	Netherlands	38,731,122	8.2%
	3	Argentina	24,066,132	8.6%		3	Germany	33,223,826	7.0%
	4	Germany	16,040,571	5.7%		4	Italy	28,174,248	6.0%
	5	Japan	9,637,265	3.4%		5	United States	16,396,306	3.5%
	6	Netherlands	9,122,595	3.3%		6	Poland	15,001,643	3.2%
	7	Korea	7,440,732	2.7%		7	Japan	14,287,037	3.0%
	8	Italy	6,679,753	2.4%		8	Turkey	13,489,098	2.9%
	9	France	6,573,605	2.3%		9	Finland	11,998,626	2.5%
	10	United Kingdom	6,134,532	2.2%		10	France	11,262,900	2.4%
	11	India	5,605,939	2.0%		11	United Kingdom	11,234,883	2.4%
	12	Mexico	5,459,299	1.9%		12	Korea	10,355,003	2.2%
	13	Chile	5,272,527	1.9%		13	Switzerland	9,125,911	1.9%
	14	Spain	4,618,687	1.6%	...	15	Belgium	6,824,488	1.4%
	15	Belgium	4,361,334	1.6%	...	17	Spain	5,172,486	1.1%

		India	Trade	% of total			**China**	Trade	% of total
	1	China	40,983,423	9.2%		1	United States	169,896,825	7.7%
	2	United States	35,126,622	7.9%		2	Japan	167,835,769	7.6%
	3	Saudi Arabia	18,362,220	4.1%		3	Hong Kong	112,665,288	5.1%
	4	Germany	16,817,782	3.8%		4	Korea	90,045,662	4.1%
	5	Australia	13,427,246	3.0%		5	Germany	54,111,753	2.5%
	6	Singapore	12,969,173	2.9%		6	Australia	26,682,073	1.2%
	7	Hong Kong	12,448,863	2.8%		7	Malaysia	26,260,796	1.2%
	8	Korea	12,002,017	2.7%		8	Singapore	21,488,230	1.0%
	9	Switzerland	10,889,421	2.5%		9	India	21,225,527	1.0%
...	11	United Kingdom	10,582,445	2.4%		10	Brazil	20,390,740	0.9%
	12	Japan	9,904,545	2.2%		11	Netherlands	19,725,465	0.9%
	13	Belgium	9,082,290	2.0%		12	United Kingdom	17,622,303	0.8%
...	15	Netherlands	8,447,327	1.9%	...	15	France	17,342,080	0.8%
...	17	France	7,702,492	1.7%	...	17	Italy	15,675,162	0.7%
...	19	Italy	6,980,150	1.6%	...	22	Belgium	10,426,059	0.5%

Table 1.2: Main trading partners for the BRICs, 2009. Source: Statistical Database of the OECD, stats.oecd.org

persistently remained superior to that of high-income countries, at least on average. This is most striking in the period between 2000 and 2011. The average real growth rates lay between 3.62% in Brazil and 10.20% in China in this period. The largest averages in this period among the high-income group are found in Korea with 4.51%, 2.99% in Australia and 2.18% in Spain. All other countries remained below an average growth rate of two percent, many significantly. This figure is also representing the fact that emerging economies like the BRICs - here mainly China and India - acted as economic locomotives in the wake of the financial and economic crisis 2007/2008. However, the higher growth rates in the BRICs preceed the crisis. If we extend the period for the 1990ies, the picture gets slightly better for the HICs and slightly worse for the BRICs but nothing dramatic changes. Among the BRICs it is mainly the Russian Federation that loses weight. This is hardly surprising as we add the post-Soviet recession years to its average. Real GDP growth in Russia was negative in all but two years of the 90ies-decade. Also losing is

Brazil. China and India showed stable high growth rates throughout this period, peaking with 14.20% real growth for China and 9.80% for India in 2007. The year with the highest average growth rate of the BRICs was 2007 with 9.66%, whereas the corresponding year for the group of high-income countries listed in table 1.1 was 2000 with an average rate of 4.04%.

Finally, a very important element for this study are the main trading partners of the BRICs. Therefore, table 1.2 lists for each of the five countries the fifteen main trading partners, summing exports and imports of the year 2009. Highlighted in grey are the ten most important of the high-income countries considered in this study. Not included in the empirical analysis here are oil countries like Saudi Arabia, other emerging economies like Mexico or Malaysia and special cases like Hongkong or Singapur. For Brazil, India, and China the remaining most important high-income trading partners are covered in this study. For the Russian Federation I also excluded Finland and Poland from the analysis as they only play a marginal role for the other BRICs. Not surprisingly, the United States are one of the main trading partners for all of the BRICs, followed by Germany, Japan and the United Kingdom. The share of trade with the ten most important trading partners in total trade is 38.0% for Brazil, 37.2% for the Russian Federation, 29.4% for India and 46.1% for China. Performing the analysis for these ten trading partners will therefore give insight into the environmental effects of a significant fraction of the BRICs' trade.

Quite striking is also the economic importance of China for trade of middle-income countries. It is the major trading partner for the three other BRICs. In an earlier draft of this thesis, when the analysis was performed for 2004, this was the case neither in Brazil, nor the Russian Federation, nor India. It is, of course, sensible to estimate flows of embodied CO_2 among the BRICs to be substantial as well.

2 Literature Review

2.1 Economic literature on the environmental effects of North-South trade

How does trade affect the environment? For a long time, this question was far off the center of economic theory development but as the overall attitude towards environmental problems in industrial countries began to change in the 1970ies, a rise in theoretical developments dealing with it became visible. We want to distinguish general environmental effects (externalities) of economic activities from the distinct environmental effects of trade. Grossman and Krueger (1993) were among the first to introduce three nowadays widely accepted concepts capturing different effects of trade on the environment. Trade increases the scale of economic activities which leads to a rise in the pollution level, holding production technology constant (scale effect). As incomes rise and environmental quality is considered a normal good, people demand tougher technical and environmental standards which lead to a reduction of pollution (technique effect). As another consequence of the normal good character of environmental quality, less developed countries will have lower environmental standards compared to highly developed countries. In this situation the opening-up of trade will lead to a change in the composition of the national output (composition effect).

That environmental quality is a normal good is an economist's term for saying that richer societies have a higher preference for a clean environment than poorer societies. This view has frequently been criticized and contested. Martínez-Alier (1995), among others, questions the narrative of countries being “too poor to be green”. She argues that the increasing public discussions on environmental issues in high-income countries as well as the founding of green parties in many of these countries might be because wealth goes together with increasing depletion of resources and pollution of the environment (Martínez-Alier, 1995, p.9). In a recent study, Fairbrother uses data from the World and European Value Surveys to examine the evolvement of environmental concern across a large number of countries and a long time span. Controlling for within-country groups of materialists and post-materialists, he finds that the general relation between incomes and environmental concern across countries is ambiguous but rather hints at poorer societies being more willing to pay for protection of the environment. Although the share of post-materialists is larger in high-income countries, these people “are significantly less willing to pay compared with similar people in poorer countries, whereas post-materialists in wealthy countries are no more willing to pay than post-materialists in poor countries" (Fairbrother, 2013, p.918).

A positive relationship between income levels and environmental preferences is found by Franzen and Meyer (2010). They are using data from the International Social Survey Programme from the years 1993 and 2000, from which they construct a scale of environmental concern within and across 26 countries. "[O]n average, populations in richer countries have higher levels of environmental concern than inhabitants of poorer nations. The single-wealth indicator explains 63 per cent of the observed between-country differences" (Franzen and Meyer, 2010, p.229). They also find within-country differences to be much larger than across-country differences of environmental concern. Other studies supporting the normal good-assumption are e.g. Aldy et al. (2012) or Kahn and Matsusaka (1997).

Aklin et al. (2013) report an interesting finding from a survey in Brazil. Income seems to have no effect on environmental awareness once education levels are controlled for. This result suggests that it might not be the larger wealth but the higher average level of education in high-income countries that is driving their mostly tighter environmental regulation. We know, however, that income and education level are two closely linked variables in most countries. We can conclude that, at the moment, the evidence is mixed on the question of environmental quality as a normal good.

If the world's governments would represent an efficient way of forming laws out of inhabitants' preferences, we would expect these different preferences towards protection of the environment to be reflected in differences in environmental regulation across countries. If we take the normal good-character of environmental quality too far we might however end up at questionable policy prescriptions, as renowned economist Larry Summers demonstrated when he stated that pollution costs are relatively lower in low-income countries and pollution should therefore be "moved to poorer locations" (McKee, 1996, p.237).

Closely linked to these questions of environmental awareness and policy regime is the discussion on the Environmental Kuznet's Curve. This curve posits an inverted U-shaped relationship between per-capita income and environmental degradation. Grossman and Krueger (1995) present empirical evidence on such a relationship for a number of pollutants, including arsenic, lead, mercury, nickel and sulfur dioxide. For the purpose of the present study, the existence of an environmental Kuznets curve would be especially relevant as we would expect middle-income countries to have higher pollution intensities compared to low- and high-income countries. For the main greenhouse gas causing climate change, carbon dioxide, however, no inverted U can be observed. Emission continue to increase and no turning point is in sight so far (van Alstine and Neumayer, 2008; Rothman, 1998). The validity of the results of Grossman and Krueger (1995) and other studies has however been heavily criticized on theoretic and econometric grounds. "There is little evidence for a common inverted U-shaped pathway that countries follow as their income rises", concludes Stern (2004, p.1435).

The assumption of environmental quality as a normal good is one of the cornerstones of one of the most frequently cited pollution haven models of international trade, the model by Copeland and Taylor (1994). They use the three environmental effects of trade - scale, technique and composition effect - and explicitly formulate a North-South framework to show that the opening of trade between two unequally rich countries can lead to an overall increase of pollution, mainly because of a relocation of production activities (to "pollution havens"). A core assumption their model uses is however that pollution has only localized effects, i.e. the pollution caused by a production process is immediately felt by the country's citizens. For many forms of pollution, like greenhouse gases, this assumption is highly implausible. Nevertheless, in the theoretical part of this thesis under subsection 5.3.4 I discuss how we could justify such an assumption.

The two authors published a second paper where they discussed the effect of trade on forms of pollution with transboundary effects (Copeland and Taylor, 1995). Transboundary Effects complicate matters as we have to take on a game theoretic formulation of our models in order to capture the interconnected decisions of different countries on how to regulate pollution. Again, they arrive at the result that if there are high income-differences across countries, trade will lead to an increase in pollution.

The empirical strategies to test these theories are still not trivial. The pollution haven hypothesis can be split into two parts to make it empirically testable.

> First, we need to know whether more stringent environmental policy adversely affects international competitiveness in polluting industry. We shall refer to this as the competitiveness hypothesis. Second, the pollution haven hypothesis asks whether the effect of environmental policy on competitiveness is strong enough to determine the pattern of trade. [...] The competitiveness hypothesis takes the trade regime as given and ask what happens if we tighten environmental policy in one country. The pollution haven hypothesis takes environmental policy differences across countries as given and asks what happens if we reduce trade barriers (Copeland, 2008, p.60).

While the competitiveness hypothesis is supported by a number of studies, e.g. Levinson (1999) and Becker and Henderson (2000), the empirical support for the pollution haven hypothesis is low. In other words this means that while enviromental regulation adversely influences a country's competitiveness, these effects seem not to be strong enough to drive production relocations by firms. Their location decisions seem to be more strongly informed by other factors determining comparative advantage, e.g. resource endowments and skilled labor. Antweiler et al. (2001) reach this result: They basically use the pollution haven model from Copeland and Taylor (1994) and estimate it with data about sulfur dioxide (SO_2) emissions. Opening up to trade seems to be good for the environment using a North-South model with given differences in environmental policy, therefore contradicting the pollution haven hypothesis. “Our estimates of the scale and technique elasticities indicate that, if openness to international markets raises both output and income by 1 percent, pollution concentrations fall by approximately 1 percent” (Antweiler et al., 2001, p.903).

Important to understand in this discussion about pollution havens is that there has to be made a distinction between the static and dynamic effects of environmental regulation. The effect of environmental regulations on domestic industries might not be that these industries close down immediately but that future investments are highly affected by the environmental policy. The empirical evidence on this question is ambiguous. Many studies do not find an industry relocation effect, e.g. McConnell and Schwab (1990) for the US motor vehicle industry. Cole et al. (2010) show in an empirical paper on Japan that relocation occurs most often in trade between countries with high income-differences as well as in industries with the greatest environmental costs. In another paper, however, Cole and Elliott (2003) as well fail to find industry relocation effects as a consequence of environmental regulations. Other studies failing to find support for the pollution haven hypothesis are Cole et al. (2005) and Spatareanu (2007).

2.2 Empirical results on the CO_2 embodiment in trade flows

The discussions on climate change in the last decade led to an increase in political weight for the topic of greenhouse gas emissions and how they are affected by international trade. The possibility to examine these effects has always been limited by the available data. With an improving access to relevant data in recent years it became possible to utilize more accurate methods to account for pollution embodied in trade. One of the first studies to test the CO2 embodiment in trade flows was Wyckoff and Roop (1994), who found that up to 13% of the total emissions of six of the largest OECD countries were embodied in their imports.

Especially well researched in recent years was China’s trade. As China’s importance in world trade grew it became the prime example for testing the environmental effects of trade between rich and emerging economies. Shui and Harriss (2006) tested the CO2 embodiment in trade between China and the United States. Li and Hewitt (2008) did a corresponding study for Great Britain and China. They basically use a single-region input-output model to estimate the CO2 embodiment in trade flows. In Section 4 (methodological approach) this approach is examined more closely, as it is the same approach to be used in my research. Shui and Harriss (2006) find that between 7% and 14% of Chinese CO2 emissions were the result of production for the US-market and that the US-China trade increased global CO2 emissions by around 720 million tons. Similarly, Li and Hewitt (2008) calculate that roughly 4% of Chinese CO2 emissions were the result of production for the UK and a total emission increase of 117 million tons. Yunfeng and Laike (2010) estimated the CO2 embodiment in China's total trade with the rest of the world. Their result is that in 2007 around 26,5% of Chinese CO2 emission came from products exported while it imported embodied emissions amounting to only around 9%. China is therefore often considered the prime example of a pollution haven. One of the purposes of this thesis is to show that we cannot draw such a conclusion from just knowing the flows of embodied emissions.

Peters and Hertwich (2008) performed a large study on the embodied CO_2 emissions in trade of Annex B countries (largely the same group as the Annex I countries mentioned above) and non-Annex B countries. As expected, they find Annex B countries to be net importers and non-Annex B countries to be net exporters of embodied emissions. Their analysis is performed for the year 2001. They find China to be exporting 24.4% of its domestic emissions and importing 6.6%. Comparing these figures to results of Yunfeng and Laike shows that China increased its net exporter position over the 2000s. For the other middle-income countries in my thesis the direction of the results is the same: the Russian Federation exports 27.5% and imports 5.9% of domestic emissions, India 13.1% and 6.2%, Brazil 19.7% and 18.9%.

The methodology of using input output-analysis to uncover the "environmental loading" of production activities was put forward by the pioneering work of Leontief (1970). Today, the most recent research on environmental effects (CO2) of trade tries to use multi-region input-output models. Examples of such studies are Ahmad and Wyckoff (2003) or Peters and Hertwich (2006). In comparison to single-region models, these models do not treat imports as using the same technology as domestically produced goods but can resort to more detailed information on production techniques in many importing regions (therefore multi-region models). Lenzen et al. (2004) showed that using single-region models produces a significant error as compared to using multi-region models in their study of Danish trade with five European trading partners. They underline, however, the complexity of these models and their high data requirements.

> At present, generalised multi-regional frameworks covering the OECD or the entire world are mostly restricted to a few tens of industry sectors. At this level of aggregation, initially varying energy and CO2 multipliers average out across sub-sectors, and differences in scenarios and feedback loops are likely to be less pronounced. [...] Therefore, multi-regional models that are spatially as well as sectorally disaggregated yet manageable are likely to be possible only for regional applications [...] (Lenzen et al., 2004, p.410)

2.3 Policy Instruments

One important issue in pollution abatement policies is the question of distribution of responsibilities for pollution between producers and consumers. If there is CO_2 emitted in the production of a certain good and if we want to internalize the environmental costs associated with this emission, who is to bear these costs: consumers or producers of the product? The Kyoto Protocol applies the so called concept of producer responsibility, where emissions are ascribed to the country of production. A competing view is that of consumer responsibility, where emissions are ascribed to the country of consumption (Wiedmann et al., 2007, p.16).

> [T]he challenge for policy is to ensure that countries that specialize in pollution intensive exports do so with clean technology, rather than moving production elsewhere (assuming production can be relocated) or not taking part in a global climate regime (Peters and Hertwich, 2008, p.1405).

What we are interested in this thesis is not so much the general question which policy instruments may foster the move to cleaner production techniques but rather the question how policy design can contribute to extinguish the possibility for firms to avoid environmental regulation via trade. This policy problem has mainly been discussed in the "carbon leakage"-literature. Carbon leakage is the name of a process that occurs as a consequence of environmental regulation, if "[d]ue to the international reallocation of energy-intensive production, carbon dioxide emissions in countries without emission reduction commitments [. . .] rise" (Kuik and Gerlagh, 2003, p.98). To quantify these effects, a rate of carbon leakage is helpful, usually defined as the increases in the non-policy-implementing countries divided by the reductions in the policy-implementing country (Antimiani et al., 2013, p.301).

Before returning to the issue of carbon leakage, we first want to study the effects of environmental taxation. Kohn (2000) showed that environmental taxation can decrease the volume of trade considerably if pollution has localized effects. For transboundary pollution the results are more ambiguous such that "environmental taxes are likely to increase trade in some goods between some countries and to decrease trade in other goods between other countries" (Kohn, 2000, p.87). The installation of a price on CO_2 emissions poses some severe problems, which mainly stem from the fact that these emissions can be seen as a global public bad (see the discussion in section 5.1). We have to deal with a "free-riding"-problem because every country has an incentive not to put a price on carbon emissions, thereby improving its competetive position for emission-intensive industries, but still gaining from the overall emission reduction (Elliott et al., 2010, p.465). "Moreover, because of distributive concerns and claims about responsibility for past emissions, many developing nations will be reluctant to impose emissions prices at the same level as developed nations" (ibid.).

Some authors also consider the question whether to use environmental taxation on consumption or production. Peters and Hertwich (2006) argue that consumption taxation would be a way to resolve carbon leakage and would have the additional advantage of not "punishing" countries with pollution-intensive resource endowments (e.g. oil-rich countries). Consumption taxation would require not only the taxation of domestic production, to which every government is authorized, but also the taxation of imports from foreign producers, which domestic governments cannot directly introduce. They could impose a tax on foreign producers via a tariff on the CO_2 content of the imported products, which can be questioned on grounds of WTO rules. Such a tariff is part of a measure called "border tax adjustment". Border tax adjustment is, however, more than just levying imports with carbon tariffs, it also includes reimbursing domestic exports with the taxes paid above the rate of the target country. "The rationale for the use of a border tax based on the carbon embodiment is that producers in foreign countries should incur the same cost as if their production took place in the domestic country" (Dissou and Eyland, 2011, p.557). As Copeland and Taylor convincingly show, the legal possibility of introducing border tax adjustment is a politically sensitive area, using their usual North-South framework.

> The North prefers a regime that allows pollution policy to be used as an instrument of trade policy, whereas the South prefers that such actions be banned. This proposition suggests that GATT Article XX outlawing environmental policy as disguised trade policy works in favor of lower-income nations. A regime that removes the ability of net importers of pollution services to manipulate their terms of trade via pollution policy puts them at a strategic disadvantage relative to net exporters. Such a rule strengthens the South's commitment to pollute more in free trade, and this shifts the ownership of the world's pollution services to the advantage of the South (Copeland and Taylor, 1995, p.733).

From the point of view of low- and middle-income countries, environmental taxes and tariffs in high-income countries may be seen less as targeted towards eliminating environmental problems and more towards improving their terms-of-trade against their trading partners. In addition, it is far from clear if border tax adjustment is really an efficient way to eliminate carbon leakage. There are studies argueing in favor of efficiency (Elliott et al., 2010), as well as against efficiency (Jakob et al., 2013). Weber and Peters (2009) discuss current debates in trade-relevant US climate change policies and their effects. Particularly the role of "carbon tariffs" played an important role there. They reach the conclusion that if such tariffs have an environmental effect at all it might be rather small and may "in fact be counterproductive at a moment when global cooperation is desperately needed" (Weber and Peters, 2009, p.439).

3 Methodology and Data

As discussed in chapter 1, the aim of this study on environmental effects of trade between middle- and high-income countries is to arrive at flows of embodied CO_2 between the countries under consideration. How can we arrive at these flows? It is not possible to obtain a precise image of the actual flows with the available data. My investigation is performed on a national level, where I work with average, country-wide emission intensities. It is clear that these intensities will not be homogeneous within a country. Particularly problematic is this for a large country like China, where Meng et al. (2011) have shown that variation in emissions between regions can be quite fundamental. As Bartleet et al. (2010) show for New Zealand, there is also a large variation of emission intensities within manufacturing sectors, and even within subsectors. So any result can necessarily only be considered a reasonably good approximation of the actual flows.

3.1 Data

Data requirements for this thesis are primarily threefold: First, we need information on sectoral CO_2 emissions and second, we need input-output tables for all countries in this study. Both of these sets of information are provided by the World Input-Output Database (WIOD)[1] (Timmer, 2012), a project funded by the European Commission in order to study the effects of globalization on production processes. This database provides national input-output tables, a linked worldwide input-output table as well as various socio-economic and environmental accounts, among them data on sectoral emissions of carbon dioxide. It covers a total of 40 countries, among them all EU members, over a period of currently 15 years from 1995 to 2009. For our analysis we take the latest period, 2009. Compared to other available sources - such as the International Energy Agency (IEA), Global Trade Analysis Project (GTAP) or the Statistical Database of the Organization for Economic Co-operation and Development (OECD) - the WIOD was chosen for its internal consistency between input-output tables and environmental accounts and its free availability online. A disadvantage of the WIOD is that data on South Africa is not provided, a country that would otherwise have been included in the analysis to study an enlarged BRICS group. All data in this database is converted

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[1] Available online at: http://www.wiod.org/new_site/data.htm (last accessed: Jan 13, 2014)

	SECTOR	ISIC
1 agri	Agriculture, Hunting, Forestry and Fishing	01-05
2 minq	Mining and Quarrying	10-14
3 fopr	Food, Beverages and Tobacco	15-16
4 text	Textiles and Textile Products	17-18
5 leat	Leather, Leather and Footwear	19
6 wood	Wood and Products of Wood and Cork	20
7 papp	Pulp, Paper, Paper , Printing and Publishing	21-22
8 petr	Coke, Refined Petroleum and Nuclear Fuel	23
9 chem	Chemicals and Chemical Products	24
10 rupl	Rubber and Plastics	25
11 nmmp	Other Non-Metallic Mineral	26
12 meta	Basic Metals and Fabricated Metal	27-28
13 mach	Machinery, Nec	29
14 elop	Electrical and Optical Equipment	30-33
15 treq	Transport Equipment	34-35
16 manr	Manufacturing, Nec; Recycling	36-37
17 elgw	Electricity, Gas and Water Supply	40-41
18 cons	Construction	45
19 mott	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	50
20 whot	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	51
21 rett	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	52
22 hore	Hotels and Restaurants	55
23 itra	Inland Transport	60
24 wtra	Water Transport	61
25 atra	Air Transport	62
26 otra	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	63
27 pote	Post and Telecommunications	64
28 fina	Financial Intermediation	65-67
29 real	Real Estate Activities	70
30 rent	Renting of M&Eq and Other Business Activities	71-74
31 publ	Public Admin and Defence; Compulsory Social Security	75
32 educ	Education	80
33 heal	Health and Social Work	85
34 csps	Other Community, Social and Personal Services	90-93

Table 3.1: Sectors

to current US Dollar using exchange rates from the International Financial Statistics Database (IFS).

Data in the WIOD is grouped in 35 sectors correponding to ISIC Rev.2. As for the last of these sectors, Private Households with Employed Persons, we do not have information for most countries, let alone trade data, we exclude it from our analysis. We use the sectoral classification listed in table 3.1 with 34 sectors. They consist of two primary sectors (1-2), 14 secondary sectors (3-16) and 18 tertiary sectors (17-34).

The researchers of the WIOD compiled the information on sectoral emissions of CO_2 from data by the IEA, Eurostat and the UNFCCC (Timmer, 2012, p.47f.). National input-output tables are mainly based on national statistical reporting - National Accounts and annual international trade data (ibid., p.17).

A third data requirement are bilateral trade flows. There are again a number of sources providing information on this. Again, we use the information provided in the WIOD. They spent much effort on harmonizing the trade data from other sources, such as UN, OECD, WTO or IMF. In addition they are dealing with country-specific problems present in the data. Some problems with the trade statistics lie in unequal mirror statistics. Mirror statistics are the result of trade reporting by both trading partners: Country A's exports to B are reported by country B as its imports from A. Unfortunately, the numbers that country A reports for its exports and country B reports for its imports rarely match well. For a thorough discussion on the causes of these differences, see Guo et al. (2009, 8ff.). In short fashion, it can be summarized as follows.

> They can be due to statistical errors, different criteria used in the statistical offices (such as the recorded currency and the reporting threshold used), differences due to cost, insurance and freight (c.i.f.) valuation for imports versus freight on board (f.o.b.) valuation for exports, effects of merchanting, and can also stem from one of the most important factors: re-export activities. Re-exports occur when products enter a customs territory from one country and are shipped to another country without undergoing any transformation (Zhu et al., 2011, p.27).

Re-exports are a significant source of error also in the data required for my analysis. These errors are especially prominent in countries with important maritime ports. In my analysis this is the case most notably for China, the Netherlands and Belgium (Guo et al., 2009, p.11). In the case of China, many goods are exported via Hongkong or Macao, which are reported separately in trade statistics. Often it is the case that the US declares the imports as Chinese, whereas China declares its exports as going to Hongkong, and therefore giving a biased information on its exports to the United States (Ferrantino and Wang, 2008, p.503). The size of the distortions are the subject of extensive research among trade economists (Ferrantino and Wang, 2008; Fung and Lau, 2003). Mellens et al. (2007) conducted a study on the magnitude of re-exports in international comparison. They find for the Netherlands in the period 2003-2006 a share of re-exports in total exports of 47,4% (Mellens et al., 2007, p.21). This is the highest value in Europe, but fades in comparison to Hongkong, which had a share of 94% in 2005. In addition, Belgium (32,7% in 2000), France (30,6%) and Germany (16,3%) exhibit a high share (Mellens et al., 2007, p.27ff.).

To demonstrate the differences of trade values reported by the trading partners when using the OECD Bilateral Trade database, table 3.2 presents average sectoral deviations of the trade data for two of the BRICs and selected high-income countries[2]. The average

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[2] The deviation is the absolute (negative deviations enter with their absolute value), weighted (with the sectoral trade values reported by country 2) sector average. The numbers are to read as the deviation of values reported by country 1 relative to the values reported by country 2. For example: The values of German exports to France reported by Germany deviated on average by 23,5% from the values

China (CHN)						
	CHN (1) USA (2)	CHN (1) GER (2)	CHN (1) FRA (2)	CHN (1) ITA (2)	CHN (1) NED (2)	CHN (1) JPN (2)
Exports Country 1	41.4%	44.7%	53.7%	38.2%	16.6%	22.9%
Exports Country 2	34.3%	23.8%	23.4%	30.2%	21.3%	34.1%
India (IND)						
	IND (1) USA (2)	IND (1) GER (2)	IND (1) FRA (2)	IND (1) ITA (2)	IND (1) NED (2)	IND (1) JPN (2)
Exports Country 1	21.9%	27.9%	35.5%	20.6%	44.9%	30.4%
Exports Country 2	15.6%	14.3%	27.6%	21.7%	33.6%	23.4%
Selected High-Income Countries						
	GER (1) FRA (2)	USA (1) GER (2)	USA (1) JPN (2)			
Exports Country 1	23.5%	38.4%	17.3%			
Exports Country 2	22.4%	5.7%	5.4%			

Table 3.2: Average sectoral deviation of trade information by reporting country (in OECD Bilateral Trade database)

deviation between the mirror statistics is rarely below 10%, most of the time it seems to be between 20% and 50%. Table 3.2 shows that also trade information of high-income countries among themselves shows very unequal mirror statistics. Still, differences seem to be lower than for most of the BRICs.

In the WIOD, researcher corrected for re-exports and harmonized mirror trade statistics. In Chinese data, they also included information for Hongkong and Macao. For Belgium, they separated values for Luxembourg which were reported together with Belgium (Timmer, 2012, p.26f.).

Concerning trade in services, it is still very difficult to obtain reliable data on bilateral trade flows on a sectoral basis. This is true for the high-income countries in this study but even more so for the BRICs. In the documentation of the WIOD the researchers included a word of warning:

> [T]he quality of trade data in services is still far away from being comparable to trade data for merchandise goods. Due to the long tradition of tariff revenues, trade data for goods have been collected with quite high quality and accuracy. Due to intangibility and nonstorability of services, at-the-border-duties cannot be applied to services, thus having resulted in much weaker compilation practices with considerable less accuracy. Thus, services statistics has ample space for improvement in terms of measurement. [...] The WIOD Trade in Services Database should be seen in this light as the best currently available approximation to a comprehensive picture of global trade flows in services (Timmer, 2012, p.30).

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reported by France.

Following this warning, we can expect a higher probability of biasedness in the results of embodied CO_2 in services trade. As the results in chapter 4 will show, however, the services sectors are quantitatively much less relevant for flows of embodied carbon, with the possible exception of the electricity sector *17 elgw*.

3.2 Methodology

The methodology for the empirical part of the research question is largely borrowed from papers like Shui and Harriss (2006) and Li and Hewitt (2008). To test hypotheses H1 and H2, we have to determine the embodied emissions in trade between the BRICs and their high-income trading partners. To arrive at embodied emissions for exports we have to multiply sectoral exports with sectoral emission intensities.

$$f_{i,j,k} = E_{i,j,k} \times \gamma_{i,j} \tag{3.1}$$

Equation 3.1 gives us a formula for the embodied emissions $f_{i,j,k}$ of exports from country j to country k in sector i. Embodied emissions are obtained by multiplying the exports $E_{i,j,k}$ in this sector by this sectors emission intensity $\gamma_{i,j}$ in country j. The following two equations further specify how I calculate embodied emissions for a specific example, trade between a high-income country h and a middle-income country m.

$$f^*_{i,h,m} = f_{i,h,m} - f_{i,m,h} \tag{3.2}$$

$$F^*_{h,m} = \sum_{i=1}^{n} f^*_{i,h,m} \tag{3.3}$$

We calculate net embodied emissions $f^*_{i,h,m}$[3] in exports of the high-income country to the middle income country in sector i using equation 3.2. The net flow of embodied emissions between the two countries $F^*_{h,m}$ can be obtained by summing up $f^*_{i,h,m}$ over all sectors i.

The only basic data requirements we have for these calculations are sectoral trade flows $E_{i,j,k}$ and emission intensities $\gamma_{i,j}$. Bilateral sectoral trade flows can be easily obtained using the data described in section 3.1. Emission intensities are a bit more tricky. One straightforward approach would be to just take the vector of total sectoral emissions and divide it by the vector of sectoral gross output. By using this strategy we would, however, obtain biased results that relatively overestimate the emission intensity of sectors performing highly emission generating production processes and relatively underestimate

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[3] The asterisk is used to denote net quantities of the variable.

it in the reverse case. Why is this the case? The reason is that we are neglecting inter-sectoral relations within a country. To use an example, energy generation may be highly emission generating but it is used as an input for almost all other sectors of an economy. Therefore, we should ascribe part of the CO_2 emitted during energy generation to other sectors' emission balances.

The popular method to include inter-sectoral relations withan an economy is input-output analysis, first introduced by Leontief (1936). The heart of the input-output analysis is the inter-industry transaction table. Table 3.3 shows a reduced-form example economy with only three sectors (industries): agriculture, manufacturing and services. In the upper block of this table we find the inter-industry transactions. They are to be read as follows: The rows show the supply (output) of the sectors to other sectors as well as to final demand (which is equal to household consumption plus exports). The columns show the use (inputs) of other sectors products for the production process.[4] In each row we can sum up total intermediate supplies and deliveries for final demand to reach gross output.

In matrix notation we can describe the input-output system using the following variables (Perman et al., 2003, p.272ff.):

$$X = \begin{pmatrix} X_1 \\ X_2 \\ \dots \\ X_n \end{pmatrix} \qquad Y = \begin{pmatrix} Y_1 \\ Y_2 \\ \dots \\ Y_n \end{pmatrix} \qquad A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

$$R = \begin{pmatrix} r_1 & r_2 & \dots & r_n \end{pmatrix} \qquad \Gamma = \begin{pmatrix} \gamma_1 & \gamma_2 & \dots & \gamma_n \end{pmatrix}$$

X is a $n \times 1$ vector of sectoral gross output. Y is a $n \times 1$ vector of sectoral final demand. A is a $n \times n$ matrix of intermediate input coefficients $a_{ij} = \frac{X_{ij}}{X_j}$. These coefficients allow us to write total sectoral output in sector i as $X_i = a_{i1} \times X_1 + a_{i2} \times X_2 + \cdots + a_{in} \times X_n + Y_i$. The matrix formulation of this expression is found below in equation 3.4. R is a $1 \times n$ vector of sectoral emission output coefficients $r_i = \frac{z_i}{X_i}$, where z_i are total sectoral emissions. The coefficient r_i tells us the amount of CO_2 emitted for the production of one (value) unit of good i. Finally, Γ is a $1 \times n$ vector of sectoral emission intensities for final demand deliveries γ_i. The emission intensity γ_i captures the actual emission content of goods that are either domestically consumed or exported. Γ is the aim of our use of input-output analysis.

The inter-sectoral relations captured by input-output analysis can be expressed as follows:

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[4] Imports, factor payments and value added would appear at the bottom of the transaction table but are omitted here for reasons of simplicity.

		Agriculture	Manufacturing	Services	Households	Exports	Gross Output
Inter-industry transaction table	Agriculture	0	400	0	500	100	1000
	Manufacturing	350	0	150	800	700	2000
	Services	100	200	0	250	50	600
Intermediate input coefficients a_{ij}	Agriculture	0.00	0.20	0.00			
	Manufacturing	0.35	0.00	0.25			
	Services	0.10	0.10	0.00			
$(I - A)$	Agriculture	1.00	-0.20	0.00			
	Manufacturing	-0.35	1.00	-0.25			
	Services	-0.10	-0.10	1.00			
$(I - A)^{-1}$	Agriculture	1.08	0.22	0.06			
	Manufacturing	0.42	1.11	0.28			
	Services	0.15	0.13	1.03			
Sectoral CO2 emissions z_i		50.00	400.00	60.00			
Emission output coefficients r_i		0.05	0.20	0.10			
Emission intensities γ_i		0.15	0.25	0.16			
Embodied emissions in exports f_i		15.25	172.67	8.08			

Table 3.3: Input-Output Analysis: Example Table

$$X = AX + Y \tag{3.4}$$

Equation 3.4 states the fact that each sectors gross output can be expressed in terms of its deliveries to other sectors' production (intermediate inputs) and to final demand (households and exports). Subtracting AX on both sides of 3.4, factoring out X and bringing $(I - A)$ to the other side yields the so-called "Leontief inverse" $(I - A)^{-1}$.

$$X - AX = (I - A)X = Y \iff X = (I - A)^{-1}Y \tag{3.5}$$

This formulation on the righthand side gives a direct correspondence between gross output and final demand. Premultiplying both sides of equation 3.5 with R introduces emissions into the system.

$$Z = \sum_{i=1}^{n} z_i = RX = \Gamma Y \text{ with } \Gamma = R(I - A)^{-1} \tag{3.6}$$

That RX equals the sum of total economy-wide emissions Z is a result of the construction of R. The core part $RX = \Gamma Y$ states that total emissions are equal to the amount of final demand multiplied by its emission intensity. For our empirical analysis, we have data on total sectoral production X, on final demand for household consumption and exports and on total sectoral emissions z_i (from which we can find R). Therefore we can calculate the vector of emission intensities Γ from equation 3.6.

Returning to our example economy in table 3.3, the second block shows the intermediate input coefficients matrix, obtained by dividing a sector's intermediate inputs by its gross output. In the fourth block we obtain the Leontief inverse, which we multiply by the emission output coefficient vector R to arrive at the emission intensity vector Γ.

4 Empirical Results

4.1 Emission intensities

Figures 4.1 and 4.2 show the average CO_2 emission coefficients for the 34 sectors in two country groups relevant for this study: the BRICs and the group of high-income countries which are considered to be their most important trading partners[1]. In all of the 34 sectors the BRICs exhibit a larger average emission coefficient, in most sectors significantly larger.

To combine the results for the BRICs to a single average value does not really capture the diversity of emission intensities among these countries. In 33 out of 34 sectors Brazil exhibits the smallest emission intensity among these four countries. This can be thought to capture the generally lower emission generating energy base of the Brazilian economy. For 26 sectors Brazil's emission intensity is even lower than the average of the high-income countries. The other three BRICs have much more similar emission intensities, e.g. although China has the highest intensity in only four out of 34 sectors, its deviation from the top intensity is in general rather low. China is also clearly above the HIC average in all sectors.[2] Clearly the relatively most emission intensive two countries of the BRICs are the Russian Federation and India, with Russia taking the lead having the highest intensity in 20 sectors.

Intra-group variation is much higher among the BRICs compared to the group of HICs. The gap between the highest and lowest emission intensity in each sector is on average 186% higher among the BRICs. Even if we reduce the BRICs group to a three-country group by excluding the outlier Brazil (we could call it RICs) their intra-group gap is still on average 59% higher than among the eleven high-income countries of this study.

Among the HICs, Korea shows the highest emission intensity in 28 out of 34 sectors. The United States are highest in three sectors, the United Kingdom in two and Australia in one sector. Korea is somewhat like an outlier among the HICs. The average

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[1] The average is not weighted for the economic size of the countries. In the calculation of the average HICs-emission coefficient are included: Germany, France, Italy, Netherlands, Belgium, United Kingdom, Spain, Japan, Korea, Australia, United States

[2] Information for sector *19 mott* is not available for China as the input-output table for this sector only listed zeros.

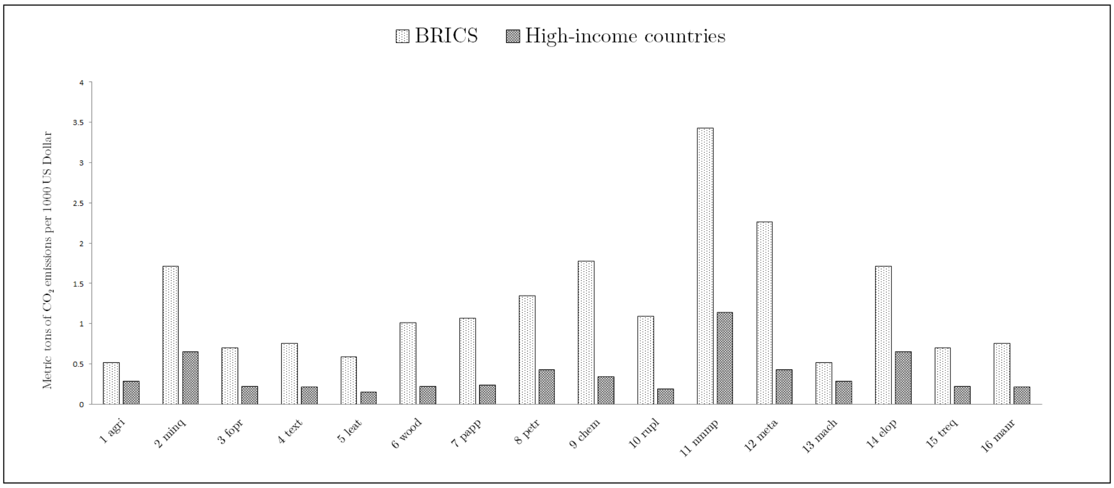

Figure 4.1: Sectoral CO_2 emission intensities (primary and manufacturing sectors), average for BRICs and HICs

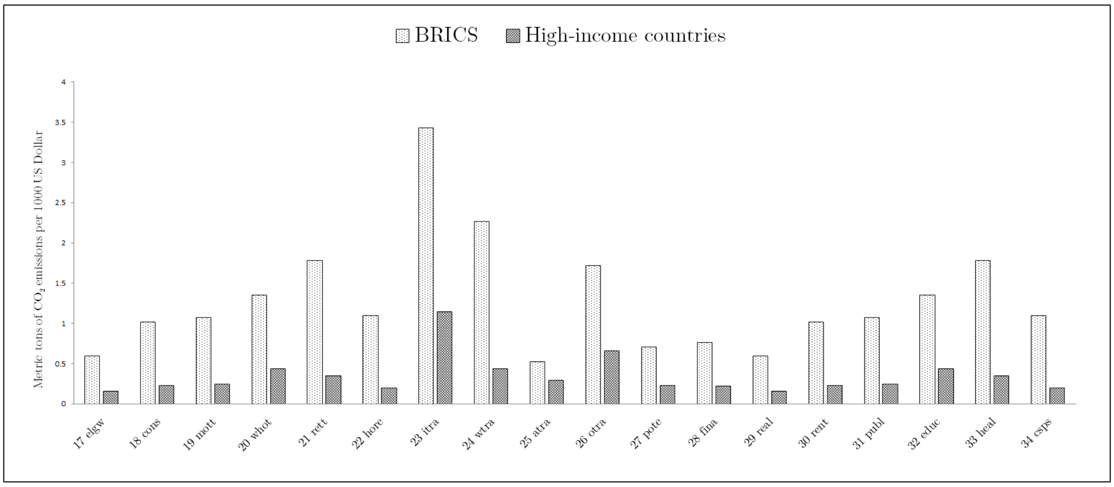

Figure 4.2: Sectoral CO_2 emission intensities (service sectors), average for BRICs and HICs

emission intensity of this country group would be on average by 16% lower if Korea were excluded. Korea exhibits an above average emission intensity in each sector. What we can, perhaps surprisingly, observe from the averages of emission intensities is that there are hardly differences between average emission intensities in primary and manufacturing sectors compared to service sectors. This were different if we would not perform input-output analysis to trace down inter-sectoral relations. The sectoral emission output coefficients, defined as the vector R in section 3.2, reveal a different picture: Manufacturing is clearly more emission intensive than services on average. This proves the importance of considering the flows of intermediate inputs between sectors.

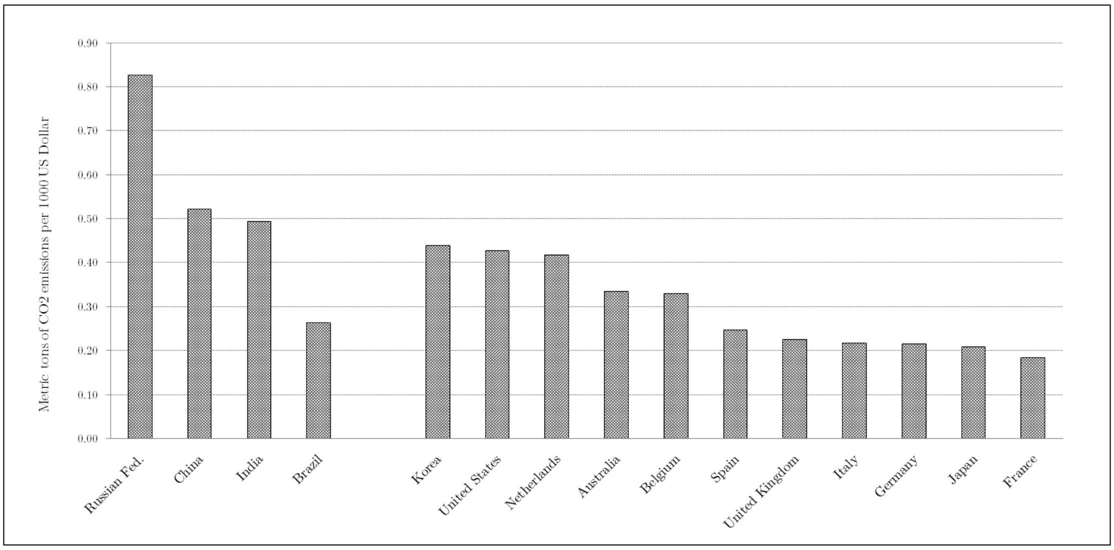

Figure 4.3: CO_2 emission intensities for sector *1 agri*

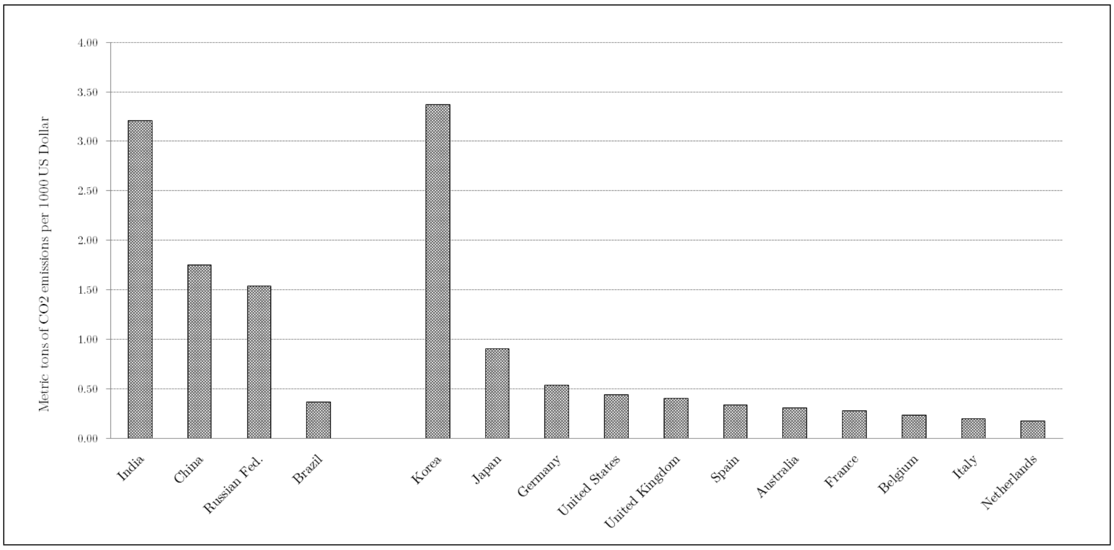

Figure 4.4: CO_2 emission intensities for sector *2 minq*

The figures 4.3 to 4.6 illustrate the differences in emission intensities in four of the dominant sectors in determining the CO_2 trade balance, the agricultural sector *1 agri*, the mining sector *2 minq*, the chemicals sector *9 chem* and the electrical and optical equipment sector *14 elop*. We can already guess from these figures that huge differences in production technologies may be a main driver of carbon dioxide shifting between middle- and high-income countries. We can also forecast that Brazils net embodied CO_2 exports will be highly driven by the bilateral trade and less by differences in emission intensities.

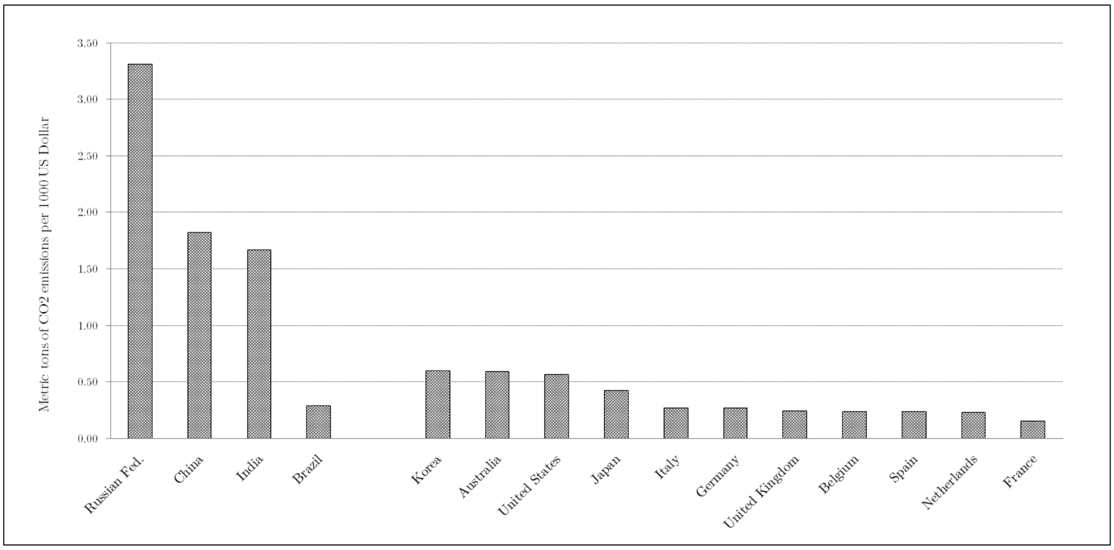

Figure 4.5: CO_2 emission intensities for sector *9 chem*

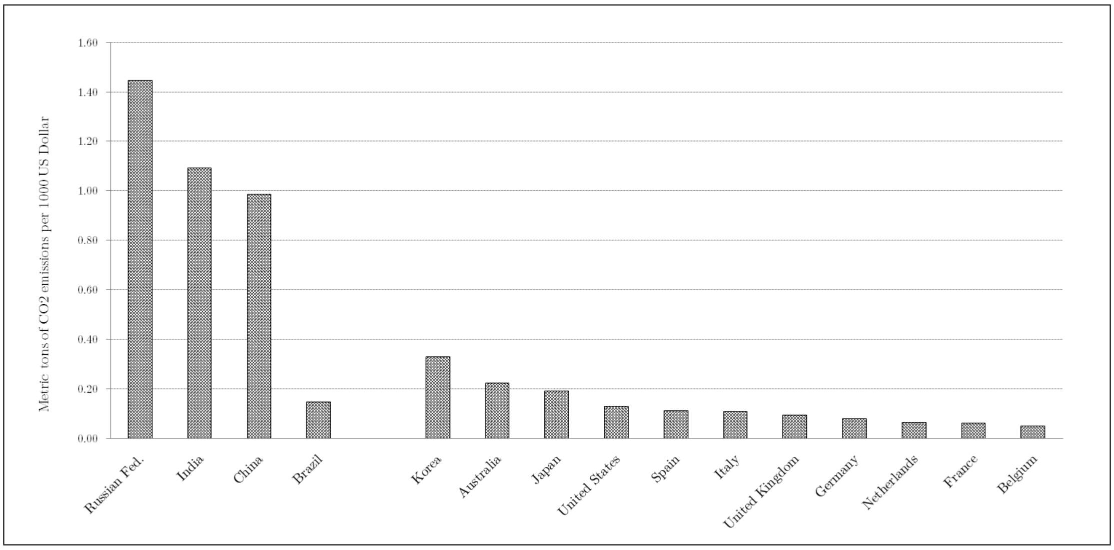

Figure 4.6: CO_2 emission intensities for sector *14 elop*

Both, the agricultural sector *1 agri* and the mining sector *2 minq* are important for Brazil and the Russian Federation. Agricultural trade values are much bigger in Brazil which is a traditional agricultural producer, whereas Russias trade is mainly confined to neighbors like Korea and Japan. The high emission intensity in *1 agri* lets these flows become substantial. For China and India, the agricultural sector plays a minor role for international trade. The mining sector *2 minq* is *the* driver of emission shifting for the Russian Federation. Its emission intensity for this sector is almost three times the average of the HICs.

The chemicals sector *9 chem* is a very important CO_2 intensive import sector for all of the BRICs. This could be seen as environmentally benefitial as the HIC partner countries show significantly lower emission intensities, again with the exception of Brazil. The electrical and optical equipment sector *14 elop* is a characteristic sector for China's and India's international trade. Both countries exhibit an emission intensity at least five times the average of the HICs.

On average over all sectors, the Russian Federation exhibits the highest levels of emission intensities, India and China lie mostly significantly below Russia's values on very comparable levels, whereas Brazil is far below the other three countries. You can find a full table of all CO_2 emission coefficients for all sectors and all countries in the Appendix to this chapter, subsection 4.4. The result that emission intensities in emerging economies are larger than in high-income countries is what we would expect. As the discussion in the next section 4.2 will emphasize, the resulting flows of embodied emissions are dominated by not too many sectors.

4.2 Trade in embodied emissions of CO_2

I cannot present here in detail all the sectoral inter-country flows of embodied CO_2. The presentation here starts with an overview over the most general results which is followed by an analysis of what drives these results for each of the four BRICs. Just as a reminder, for information on how these results are obtained please refer to chapter 3, in particular section 3.2. In addition, the readers need to remind themselves, that these estimations are not based on current data, but are based on data for the year 2009.

What we have to consider when interpreting the results obtained with the methodology described under section 3.2 is that flows of embodied CO_2 are the result of two separate influences, emission intensities and the magnitude of trade flows. Why is this important? Imagine a situation where both trading partners have exactly the same sectoral emission intensities. Then it follows logically that the flows of embodied carbon emissions will only mirror the trade balance of the two countries. Now imagine another situation where both trading partners export the exact same value in each sector to the other country. Then the resulting CO_2 trade balance will only be a result of differences in the respective emission intensities. In reality, we always observe a mixture of these two sources. It is therefore emphasized in the country results section where a specific result comes from.

Table 4.1 lists the aggregate values of embodied CO_2 trade for each of the BRICs. This is the main result of our analysis. First, we turn our attention to the highlighted rows stating each of the BRICs' net exports to the various partner countries. For the Russian Federation, India and China these values are all positive here (India's trade with Australia is balanced in terms of CO_2 flows). What does this tell us? These three BRICs countries

	USA	GER	FRA	ITA	NED	GBR	ESP	BEL	JPN	KOR	AUS
Brazil											
Embodied CO2-Exports	5.415	3.182	0.959	0.830	1.429	0.713	0.722	0.502	1.294	0.936	0.160
Embodied CO2-Imports	7.787	3.943	0.640	0.859	0.279	0.986	0.584	0.803	1.195	1.837	0.267
Net embodied CO2-Exports	-2.372	-0.760	0.318	-0.029	1.150	-0.274	0.138	-0.301	0.098	-0.901	-0.108
Russian Federation											
Embodied CO2-Exports	19.849	34.670	20.095	37.606	16.512	8.673	6.973	4.748	11.561	7.943	0.446
Embodied CO2-Imports	2.175	4.243	1.031	2.171	0.653	0.876	0.706	0.432	1.846	3.002	0.297
Net embodied CO2-Exports	17.675	30.427	19.064	35.435	15.859	7.796	6.267	4.316	9.715	4.941	0.149
India											
Embodied CO2-Exports	44.569	14.216	5.322	5.578	4.103	12.069	3.582	4.222	6.438	3.228	4.712
Embodied CO2-Imports	6.335	1.584	0.353	0.630	0.365	1.043	0.249	1.502	1.249	2.755	4.714
Net embodied CO2-Exports	38.233	12.632	4.969	4.948	3.738	11.026	3.333	2.720	5.190	0.473	-0.002
China											
Embodied CO2-Exports	319.286	87.716	39.070	26.545	24.759	41.473	18.384	11.616	139.289	77.773	49.645
Embodied CO2-Imports	33.376	11.587	3.262	2.425	2.535	3.063	0.796	1.666	33.705	49.134	18.320
Net embodied CO2-Exports	285.910	76.129	35.808	24.119	22.224	38.410	17.588	9.949	105.584	28.639	31.324

Table 4.1: Embodied CO_2 Emissions in Trade (in million metric tons), Summary Table

are net exporters of embodied CO_2 with regard to the partner countries given in table 4.1, which include for each country at least its ten most important high-income trading partners. To put it differently, the products these BRICs export cause the emission of significantly more carbon dioxide than the products these countries import from their high-income trading partners. From the perspective of the HICs, their imports from the BRICs cause much more emissions than their exports. How does this change the carbon footprint of the countries involved (assuming full consumer responsibility and abstracting from re-exports)? In short, the carbon footprint of high-income countries increases while the BRICs' carbon footprint gets smaller.

To give a brief overview on the following subsections: What are common features, what are distinguishing features of the country- and sector-specific results? In general, it is found that all of the BRICs, except Brazil, are heavy exporters of embodied carbon dioxide and only modest importers. Among the 11 high-income countries for which the analysis was performed, it were basically the same few trading partners that were responsible for the largest part of embodied emissions from and to the BRICs: First and foremost the United States, which were the number one trader of embodied emissions for all BRICs except Russia (number three). Germany was the only other country exhibiting relatively large flows for each of the BRICs. Mostly high emission shifts, except for Brazil, occured also in trade with Japan. Other high-income countries were important for some of the BRICs but of relative low weight for others, e.g. Australia which is a major trading partner for India and China, while almost irrelevant for the Russian Federation and Brazil. Concerning the high-income countries we can generally observe that Australia behaves atypically in its emission shifting. This is because Australia is also a strong exporter in sectors that generally are very emission intensive, e.g. the mining sector *2 minq*.

In terms of the sectoral drivers of international emission shifting, we can broadly distinguish two country groups among the BRICs. For Brazil and the Russian Federation the most relevant sectors are the mining sector *2 minq* and, first and foremost for Brazil, the agricultural sector *1 agri*. For China and India, the results of embodied CO_2 flows were mainly driven by the electrical and optical equipment sector *14 elop*, the textile sector *4 text* and, mainly for India, the manufacturing nec[3] sector *16 manr*. To some extent this result has to be qualified however as China is a heavy net exporter of embodied emissions in almost all manufacturing sectors. The basic and fabricated metals sector *10 meta* and, to a lesser extent, the chemicals sector *9 chem* were among the most important sectors in shifting CO_2 for all of the BRICs. In general, we can also observe that the service sectors were far less important in determining the CO_2 trade balance.

Taking away and summing up the results leads us to partly dismiss the proposition of hypothesis H1 (see section 1.2): We cannot confirm that all BRICs are net exporters of embodied CO_2 to the high-income countries under consideration. This is certainly true for China, India and the Russian Federation. But, it seems not to be true for Brazil: If we add up the exports and imports of embodied CO_2 for its ten most important high-income trading partners, Brazil turns out to be a net importer of embodied CO_2. This is hardly surprising, considering Brazil's sectoral emission intensities, which are on average roughly around the HIC average.

4.2.1 Brazil

Aggregate embodied emissions from Brazil's trade with its ten most important high-income trading partners[4]:

- Total exports of embodied CO_2 emissions: 15.98 million metric tons, 6.36% of emissions in sectors 1-34, 4.95% of total emissions[5]
- Total imports of embodied CO_2 emissions: 18.91 million metric tons, 7.53%, 5.86%
- Net exports: -2.93 million metric tons, 1.17%, 0.91%

How can we interpret these numbers? As embodied emissions in trade can only be calculated for sectors 1-16, due to missing trade data for the energy sector and the service sectors, we have two different shares in order to present their relative importance. On the one hand, during the production of export goods for its ten most important high-income trading partners, Brazil emitted 15.98 million metric tons of CO_2, which corresponds to

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[3] nec...not elsewhere classified

[4] The most important trading partners are chosen according to the information presented in table 1.2.

[5] Total emissions also include direct emissions from household consumption.

a share of 6.36% of the total emissions emitted in the production of sectors 1-34 and to a share of 4.95% of Brazil's overall CO_2 emissions. On the other hand, imported products from these countries amounted to a share of 7.53% of emissions in the traded sectors 1-34 and 5.86% of total countrywide emissions. The first share values are especially interesting if compared across the BRICs (see the following subsections for the other BRICs' values). The second share values, the values of exported emissions relative to the overall emissions of the country, depend on the emissions from household consumption, not contained in the sectoral breakdown of this thesis. The share of household emissions ranges from 7.20% of total emissions for China to 22.40% for Brazil. In contrast, the share only refering to the production in sectors included in our trade analysis gives us concrete, comparable values of the importance of exports and imports in determining the carbon footprint of the country in question. Brazil is therefore a net importer of 2.93 million metric tons of CO_2 (the only net importer among the BRICs). If we would want to calculate a simplistic version of the "carbon footprint" of its population, again assuming full consumer responsibility, Brazil would have to increase its overall emissions by 0.91%.

The following paragraphs discuss which sectors are driving the results for Brazil:[6]

- The United States are Brazil's major trading partner with a share of 12.8% of overall Brazilian trade (or 33.7% of the trade with its MITPs[7]), followed by Germany with 5.7% and 15.1%, respectively. The US exhibits an even higher share of embodied CO_2 in trade at 37.8% (with Germany being second at 20.4%).

- There are three sectors exhibiting a major positive influence on Brazil's CO_2 trade balance. These are, ordered by magnitude, the mining sector *2 minq*, the agricultural sector *1 agri* and the food products sector *3 fopr*. An important sector for export flows of embodied CO_2 is also the the basic and fabricated metals sector *12 meta*, mainly with the trading partner United States, Japan and Korea. This sector, however, exhibits also a large import of embodied emissions from roughly the same countries plus Germany, making the net effect of *12 meta* smaller than that of the abovementioned three. The largest postive net flow occurs in trade with the United States, with 1.22 million metric tons in sector *2 minq*.

- For sectors *2 minq*, *1 agri* and *3 fopr*, Brazil's emission intensity is generally significantly below the high-income country average. Therefore, the flows of embodied CO_2 are mainly driven by the unequal trade flows, meaning Brazil imports very small quantities while exporting large quantities. A good example for this is Korea from which Brazil imports goods worth around four million US Dollar in sectors 1-3, while it exports goods worth 1585 million US Dollar to Korea. In the basic

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[6] A detailed table with sectoral results for the three most important high-income trading partners can be found in the Appendix under subsection 4.4.

[7] In the following, "MITPs" refers to the country-specific 10 most important trading partners.

and fabricated metals sector *12 meta*, Brazil's emission intensity is 20% above the HIC average. If we, however, consider only the main three high-income trading partners in this sector, Brazil's emission intensity is again lower.

- As the only country among the BRICs, Brazil is a net importer of embodied CO_2. Thus, there are also a couple of sectors with a large negative effect on its CO_2 trade balance. These are the chemicals sector *9 chem*, the electricity, gas and water sector *17 elgw*, the electrical and optical equipment sector *14 elop* and the transport equipment sector *15 treq*. The single largest flow of embodied CO_2 occurs in sector *9 chem* with the United States, a net embodied import of 1.93 million metric tons. Brazil exhibits a lower than the HIC-average emission intensity in this sector and in addition bilateral trade flows in the chemicals sector are very unequally distributed with Brazil importing much more than it exports. In the case of the United States the ratio of imports to exports lies at 3.2, for Germany at 5.6 and for Japan at 2.0.

- Brazil is the only BRICs country where the electricity, gas and water sector *17 elgw* plays a significant role in determining the CO_2 trade balance. In general, we have to be careful when interpreting the import side as we assume in our single-region input-output model that imports from other trading partners than the MITPs considered in this thesis are produced with the domestic emission intensity. Brazil's emission intensity in *17 elgw* is very low, in fact it is the lowest of all countries in our sample. This difference determines the magnitude of estimated flows of carbon: Whereas the ratio between imports and exports in *17 elgw* between Brazil and Germany is only 1.9, the ratio between embodied imports of CO_2 and the corresponding embodied exports lies at 13.3.

- Interestingly, the electrical and optical equipment sector *14 elop*, one of the defining sectors for China and India, is a sector of large embodied imports for Brazil. Again it is a mixture of a bilateral trade balance skewed towards imports and a much higher emission intensity of importers that causes these flows.

- Brazil has an overall negative trade balance for the sectors 1-34 with all its MITPs, except for the Netherlands and Spain. Thus it can be argued that the fact that Brazil is a net importer of embodied CO_2 emissions is highly driven by bilateral trade flows, even more so as the other variable in this equation (3.1), the sectoral emission intensities are very similar to that of its MITPs.

4.2.2 Russian Federation

Aggregate embodied emissions from the Russian Federation's trade with its ten most important high-income trading partners:

- Total exports of embodied CO_2 emissions: 168.63 million metric tons, 11.96% of emissions in sectors 1-34, 10.55% of total emissions
- Total imports of embodied CO_2 emissions: 17.14 million metric tons, 1.21%, 1.07%
- Net exports: 151.50 million metric tons, 10.74%, 9.48%

The following paragraphs discuss which sectors are driving the results for the Russian Federation:

- The Russian Federation's main trading partners are the Netherlands, Germany, Italy and the United States. Russia does not have a predominant trading partner, trade with the Netherlands covers 8.2% of overall trade or 22.0% of trade with the MITPs. Germany follows with 7.0% respectively 18.9%, then Italy with 6.0% respectively 16.0% and the United States with 3.5% respectively 9.3%. Some doubts about the Netherlands' trade data are advisable, the results should therefore be cautiously interpreted. With regard to the overall flows of embodied CO_2 to and from the MITPs, trade with Italy covers 21.4%, followed by Germany with 21.0%, the United States with 11.9% and France with 11.4%.
- The three most important sectors in determining carbon dioxide flows in Russia's trade are the mining sector *2 minq*, the basic and fabricated metals sector *12 meta* and the inland transport sector *23 itra* with net exports of 66.45, 31.44 and 28.30 million metric tons, respectively. The dominant Russian sector is *2 minq*. 44.5% of all Russian exports to its MITPs are from this sector, and 39.4% of its carbon emissions embodied in exports. The emission intensity in *2 minq* is slightly lower than the BRICs average and 2.3 times higher than the HIC average. The single biggest net CO_2 export occurs as well in this sector with 20.85 million metric tons exported to Italy, followed by 11.00 million to Germany. In sector *12 meta*, Russia has the highest emission intensity of all BRICs with 3.633 metric tons per 1000 US Dollar, which is roughly eight times the MITP average. If we only looked at trade flows the basic and fabricated metals sector would rank fifth, the high emission shift is clearly a result of this massive difference in emission intensities. The third sector mentioned above, sector *23 itra*, shows again the highest emission intensity among the BRICs. In no other country of this middle-income group, the inland transport sector plays a similarly important role. This might be related to the Russian Federation's vast landmass.
- Other important sectors for embodied CO_2 exports are the petroleum sector *8 petr*, the wholesale trade sector *20 whot* and the chemicals sector *9 chem*. In all three of these, the Russian Federation exhibits the highest emission intensity among the BRICs.

- The six abovemention sectors make up 94% of all embodied exports of carbon dioxide. The divide between the defining sectors of the CO_2 trade balance is nowhere among the BRICs as clear-cut as in the Russian Federation. The corresponding share for the six most important sectors lies between 64% and 70% in India, Brazil and China.

- An interesting pattern is shown by the agricultural sector *1 agri*, which basically tends to be a net importer of CO_2 if there were not the exports to Japan and Korea, both countries weak exporters in this sector. These embodied exports overturn the result and make the agricultural sector a net exporter of embodied emissions in the end (tenth place among net exporting sectors).

- In 13 out of 34 sectors the Russian Federation is a net importer of embodied CO_2. Compared to the net exporting sectors the magnitude of these flows is very low. The most important of these sectors is the transport equipment sector *15 treq* with net inflow of 4.33 million metric tons. Although the Russian Federation exhibits a slightly bigger than average emission intensity in this sector, the driver of this result is clearly the imbalance between exports and imports of transport equipment. Russian exports in this sector amount to 0.1% of total MITP-exports, in comparison *15 treq* is the most important import sector with 26.8% of total MITP-imports. Following are the textile sector *4 text*, the food products sector *3 fopr* and the non-metallic mineral products sector *11 nmmp*. The negative net flow from *4 text* is in stark contrast to the Asian powers China and India. The negative value in *3 fopr* is also a difference to Brazil, otherwise in many ways structurally similar.

4.2.3 India

Aggregate embodied emissions from India's trade with its ten most important high-income trading partners:

- Total exports of embodied CO_2 emissions: 104.46 million metric tons, 6.96% of emissions in sectors 1-34, 6.36% of total emissions

- Total imports of embodied CO_2 emissions: 20.53 million metric tons, 1.37%, 1.25%

- Net exports: 83.93 million metric tons, 5.59%, 5.11%

The following paragraphs discuss which sectors are driving the results for India:

- The fraction of overall trade performed with its ten MITPs is smallest among the BRICs for India with 29.4%. Among these high-income countries, the United States dominate with 7.9% of total Indian trade and 27.0% of Indian trade with its MITPs. Trade with the other nine MITPs is relatively equally distributed from Gemany (with 3.8% of overall and 12.9% of MITP-trade) to Italy (1.6% respectively 5.4%). With respect to the CO_2 emissions embodied in exports and imports, the US exhibit the highest MITP-share with 40.7% followed by Germany (12.6%), the United Kingdom (10.5%) and Japan (6.2%).

- The two dominant sectors for the CO_2 trade balance are the textile sector *4 text* and the manufacturing nec sector *16 manr* with total net flows of 12.68 and 12.02 million metric tons, respectively. India exhibits the highest emission intensity of all BRICs in the textile sector with 1.207 metric tons per 1000 US Dollar. In addition there are hardly any imports in this sector to counterbalance the exports. The main trading partner for textiles are the United States with 46% of this sectors exports. The trade of net embodied CO_2 is highly positive for all MITPs. In sector *16 manr*, the situation is different: India exhibits an emission intensity that is clearly below the BRICs average and only 1.9 times above the HIC average (compared to the US this reduces to 1.5). More than two thirds of trade in the manufacturing nec sector are performed with the United States. The single biggest flow of embodied CO_2 is this sector's net export to the US of 8.12 million metric tons. The relatively small differences of emission intensities already hint at the driving force behind the manufacturing nec sector's emission shifts: It is the magnitude of trade, making up 34.7% of India's exports to its MITPs and 26.9% of its imports.

- As in all of the BRICs, the basic and fabricated metals sector *12 meta* plays an important role also in India. The net exports of embodied CO_2 are mainly a result of India's very high emission intensity of 2.845 metric tons per 1000 US Dollar (6.5 times the HIC average). Net trade flows are even directed towards India, imports exceed exports by 3390 million US Dollar. The fourth biggest net export of embodied CO_2 is accounted by the electrical and optical equipment sector *14 elop*. This can be explained by a large difference between India's and average HIC emission intensities (factor 8.2). The picture is therefore very similar to the situation in *12 meta*, as also the electrical and optical equipment sector is a net importing sector (with imports exceeding exports by 917 million US Dollar). Other sectors exhibiting a large magnitude of net embodied exports include the machinery and equipment renting sector *30 rent*, the hotels and restaurants sector *22 hore* (interestingly occuring almost exclusively with the former colonial power United Kingdom and the associated country Australia), the chemicals sector *9 chem* and the transport equipment sector *15 treq*.

- There are also considerable flows of embodied CO_2 imports, but they occur mostly in sectors with even larger exports. These are, for example, the basic and fabricated metals sector *12 meta* and the manufacturing nec sector *16 manr*.

- There are ten sectors with a negative flow of net embodied exports, i.e. net imports of embodied CO_2, all of them service sectors. However, none of these sectors shows a significant net flow, the largest flow occurs in the the electricity, gas and water sector *17 elgw* with 0.11 million metric tons.

- In general service sectors play almost no role in determining the flows of embodied CO_2 for India, with the exception of *22 hore*, *23 itra*, *30 rent* and *34 csps*.

4.2.4 China

Aggregate embodied emissions from China's trade with its ten most important high-income trading partners:

- Total exports of embodied CO_2 emissions: 817.17 million metric tons, 13.15% of emissions in sectors 1-34, 12.20% of total emissions

- Total imports of embodied CO_2 emissions: 159.07 million metric tons, 2.56%, 2.38%

- Net exports: 658.11 million metric tons, 10.59%, 9.38%

The following paragraphs discuss which sectors are driving the results for China:

- China's two major trading partners are the United States and Japan. The United States cover 13.5% of overall trade or 29.4% of trade with the MITPs, while the corresponding figures for Japan lie at 10.4% and 22.5% respectively. Further important high-income trading partners are Korea (7.1% of overall trade), Germany (4.8%) and Australia (2.7%). With regard to the overall flows of embodied CO_2 to and from the MITPs, trade with the United States covers 36.1%, followed by Japan with 17.7%, the Korea with 13.0% and Germany with 10.2%.

- China is by far the dominant country concerning the magnitude of embodied emissions in trade. This is, of course, a consequence of its large population and its recent growth experience. Whereas the Russian Federation has four, India two, and Brazil no sector where net exports of embodied CO_2 exceed 10 million metric tons, this is the case in 14 out of 34 sectors in China. The total net embodied emission in exports of China are almost three times as high as the combined of the other three BRICs.

- The sector with by far the highest net export of embodied carbon dioxide is the electrical and optical equipment sector *14 elop*, net exporting 230.83 million metric tons. The share of embodied exports from this sector among the total lies at

32.0% whereas the monetary export value of *14 elop* among total exports lies at 36.7%. This hints at the importance of the sheer magnitude of trade flows for this results. The driving force for this high emission shift, however, is to be found in the emission intensity difference between China and its MITPs. Although China is only slightly above the BRICs average (in fact, it is clearly the "cleanest" producer if compared only to India and the Russian Federation), its emission intensity of 0.989 metric tons per 1000 US Dollar is still 7.4 times higher than the HIC average, which corresponds roughly to the United States' emission intensity. The US is the trading partner for around half the production of this sector, the single biggest net flow of embodied CO_2 occurs in this sector with 123.22 million metric tons to the United States.

- Further very important sectors are the textile sector *4 text* (net embodied exports of 71.02 million metric tons), the basic and fabricated metals sector *12 meta* (57.03) and the machinery nec sector *13 mach* (51.23). All three sectors exhibit emission intensities that are roughly around the average of the BRICs but clearly above the HIC average (the factors range from 4.1 for the textile sector to 7.8 for the machinery nec sector). Whereas results for *12 meta* and *13 mach* are almost exclusively driven by this emission intensity difference as in both cases imports exceed exports by several billion US Dollar, the results for the textile sector *4 text* are aggravated by the fact that there are rarely imports to counterbalance the export overhang.

- There is a large number of additional sectors with highly significant net exports of embodied CO_2, especially if we compare the magnitude to those of other BRICs. To name just the most important of these: the chemicals sector *9 chem*, the rubber and plastics sector *10 rupl*, the air transport sector *25 atra*, the water transport sector *24 wtra* and the machinery and equipment renting sector *30 rent*.

- Only very few Chinese sectors are net importers of embodied CO_2. The net imported embodied emissions are negligible when compared to the exports. The highest values are shown by the mining sector *2 minq* (6.63 million metric tons), the public administration and defense sector *31 publ* (1.73) and the agricultural sector *1 agri* (1.69).

- An interesting pattern is shown by the agricultural sector *1 agri*. While the CO_2 trade balance is clearly positive for its neighboring countries Japan and Korea it is highly negative for two countries with a traditionally strong agricultural sector, the United States and Australia (the two countries make up 93.2% of these sectors MITP-imports). Chinese exports of agricultural goods to its MITPs lie at about 0.7% of all exports (position 21 out of 34 sectors), the major share going to its neighboring countries (45.5% to Japan and Korea).

- Another interesting pattern is exhibited by the mining sector *2 minq*. The CO_2 trade balance is positive for all of China's MITPs except for Australia, from where it imports net embodied emission of 10.69 million metric tons. This changes the direction of the CO_2 trade balance and makes the mining sector the largest net importing sector of embodied CO_2 for China.

- Trade between China and Korea offers an example that the trade balance and the CO_2 trade balance can run in opposite directions. China has a trade deficit of around 35 billion US Dollar but at the same time a CO_2 trade surplus of roughly 29 million metric tons.

4.3 Static Analysis: Change in emission levels with home emission coefficients

This section offers a static analysis of the CO_2 emissions embodied in trade between the BRICs and high-income countries. I am following authors like Shui and Harriss (2006) or Li and Hewitt (2008), who estimated the amount of emissions avoided by the United States respectively the United Kingdom as a consequence of engaging in trade with China. This should give us some basic idea how the possibility to trade may influence the CO_2 trade balance between middle- and high-income countries. In order to estimate this it is useful to create two scenarios, called trade and autarky. Under the trade scenario we understand the status quo in 2009. This is not to confuse with a model world of unrestricted trade. We do not ask why trade flows occur the way they do here, we just take them as given. For example do we not ask here how an existing trade restriction may influence flows of embodied carbon dioxide (this is partly examined theoretically in section 5.3.5). Under the autarky scenario we understand a purely hypothetical situation where there is no trade between the BRICs and their high-income trading partners. In fact, there is no trade whatsoever, therefore every country is forced to produce all consumption goods on its own.

The analysis is static in nature as the *dynamic* evolvement of other variables in our economic system is not taken into account. The parameter “Openness to trade” is changed from the status quo in 2009 to zero. We are now interested in how CO_2 emissions on the national level change, both in the BRICs and the high-income countries. Underlying the analysis is a ceteris paribus-assumption: I assume that the consumption pattern (both in size and in sectoral distribution) as well as the sectoral emission intensities in all countries do not change. This is clearly a non-innocent assumption. If trade between the United States and all its middle- and low-income trading partners would suddenly come to a halt, what would happen? It is very probable that consumption would be lower, at least in the short run, as the US will not immediately possess the production capabilities to make-up for the missing imports. In the longer run, the sectoral consumption mix would certainly change to a situation more in line with the US’ comparative advantage. To take an easy example: Why should US consumers go on to consume as many bananas as before if their climatic environment makes it difficult to grow them (which would raise the price drastically). Also the second assumption of constant emission intensities is unrealistic. Changes in the sectoral distribution of production, necessary because of changes in the pattern of domestic consumption, will lead to changes in emission intensities. These are only very basic examples to underline how this ceteris paribus-assumption may fail, several other channels are possible. It is, for example, not clear how differences in endowments of natural resources could possibly be compensated for with local resources, which may not exist. Finding alternative energy sources would necessarily shift again the consumption pattern.

The static analysis can, however, give us some insights into a "pseudo-causal" relationship between trade and the environment. By holding all else constant, we pretend that the effect on the distribution of CO_2 emissions is a direct consequence of trade. As discussed above, the ceteris paribus-assumption is of only limited plausibility, therefore it can be called "pseudo-causal". The present consumption pattern is only possible because of trade, the question is, however, how different it would be without trade. It is nevertheless very informative to investigate the amount of environmental damage avoided in rich countries via consuming imported products from middle-income countries. As we have seen in section 4.2, the BRICs are producing their export goods for high-income trading partners mainly in the especially emission intensive sectors, therefore the idea of rich countries outsourcing their pollution seems justified. Still, we must not forget that we are not talking about causal relationships, at best these relationships are "pseudo-causal".

Table 4.2 summarizes the resulting changes in national emission levels when comparing the actual situation to a hypothetical autarky situation, a situation where each country only produces with its home emission intensities. How do we read this table? The first two rows state the CO_2 emissions resulting from the home production of the previously traded goods. The second block of rows states the difference of country-specific emissions between the trade and the autarky scenario. Taking a look at trade between Brazil and the United States, this means Brazil emits 4.86 million metric tons of carbon dioxide for producing goods formerly imported from the US, whereas the United States emit 8.20 million metric tons for producing goods formerly imported from Brazil. Concerning the national emissions this means that Brazil reduces its emissions by 0.56, the US increases its emissions by 0.42 million metric tons. These values are easily traceable using table 4.1 in addition. Brazil exports 5.42 million metric tons of embodied CO_2 emissions to the US. Under autarky these drop out and Brazil emits a lower value for home consumption, namely the value stated in the first row of table 4.2. The third block of rows in this table takes a look at aggregate values, it compares the total emissions from the production of the (previously) traded goods under the two scenarios, trade and autarky. The autarky value is just the sum of the first two rows in table 4.2, whereas the trade value is the sum of the first two rows in table 4.1. The last, highlighted row then calculates the percentage change of these aggregate emissions from the trade to the autarky scenario. In the example of Brazil and the United States we have seen that the total emission level shrunk slightly by 1.1% as the decrease of emissions in Brazil was not accompanied by a

	USA	GER	FRA	ITA	NED	GBR	ESP	BEL	JPN	KOR	AUS
Brazil											
CO2 emissions, former Imports	4.855	3.447	1.328	1.164	0.435	1.039	0.663	0.561	1.007	0.873	0.252
CO2 emissions, former Exports	8.202	3.340	0.658	0.695	1.302	0.692	0.639	0.579	1.812	3.596	0.198
Change in Brazil	-0.559	0.264	0.370	0.334	-0.995	0.326	-0.059	0.059	-0.286	-0.063	0.092
Change in Partner Country	0.416	-0.603	0.017	-0.164	1.023	-0.294	0.056	-0.223	0.617	1.760	-0.069
Total CO2 emissions, Autarky	13.058	6.786	1.986	1.859	1.737	1.731	1.302	1.140	2.820	4.469	0.451
Total CO2 emissions, Trade	13.201	7.125	1.599	1.689	1.709	1.699	1.306	1.304	2.489	2.772	0.427
%-change under Autarky	-1.1%	-4.8%	24.2%	10.1%	1.6%	1.9%	-0.3%	-12.6%	13.3%	61.2%	5.5%
Russian Federation											
CO2 emissions, former Imports	10.074	43.592	14.243	17.844	6.444	7.427	4.616	4.808	10.759	8.897	1.226
CO2 emissions, former Exports	4.975	6.574	3.002	4.788	2.085	2.056	1.430	0.497	3.555	6.557	0.098
Change in Russia	-9.776	8.922	-5.852	-19.762	-10.068	-1.246	-2.357	0.060	-0.802	0.954	0.780
Change in Partner Country	2.800	2.331	1.971	2.616	1.432	1.180	0.724	0.065	1.709	3.555	-0.199
Total CO2 emissions, Autarky	15.048	50.166	17.245	22.631	8.529	9.482	6.047	5.306	14.314	15.455	1.324
Total CO2 emissions, Trade	22.024	38.913	21.126	39.778	17.165	9.549	7.679	5.181	13.408	10.945	0.744
%-change under Autarky	-31.7%	28.9%	-18.4%	-43.1%	-50.3%	-0.7%	-21.3%	2.4%	6.8%	41.2%	78.0%
India											
CO2 emissions, former Imports	19.902	12.698	3.786	4.507	3.144	6.656	1.474	10.130	5.930	7.950	22.690
CO2 emissions, former Exports	16.978	1.896	0.692	0.726	1.244	2.087	0.593	0.537	1.939	1.495	1.457
Change in India	-24.667	-1.518	-1.536	-1.071	-0.959	-5.413	-2.108	5.908	-0.509	4.721	17.978
Change in Partner Country	10.643	0.311	0.339	0.096	0.879	1.044	0.344	-0.964	0.690	-1.261	-3.257
Total CO2 emissions, Autarky	36.879	14.593	4.478	5.233	4.388	8.743	2.068	10.667	7.869	9.445	24.146
Total CO2 emissions, Trade	50.904	15.801	5.675	6.208	4.468	13.111	3.831	5.724	7.687	5.984	9.425
%-change under Autarky	-27.6%	-7.6%	-21.1%	-15.7%	-1.8%	-33.3%	-46.0%	86.4%	2.4%	57.8%	156.2%
China											
CO2 emissions, former Imports	115.887	101.471	24.761	19.660	17.625	14.602	5.057	10.557	156.429	128.478	80.878
CO2 emissions, former Exports	78.712	11.041	3.917	4.071	4.013	7.688	2.955	1.577	42.407	40.876	17.993
Change in China	-203.399	13.755	-14.309	-6.885	-7.134	-26.871	-13.328	-1.058	17.139	50.705	31.233
Change in Partner Country	45.336	-0.546	0.655	1.645	1.477	4.625	2.159	-0.089	8.702	-8.259	-0.327
Total CO2 emissions, Autarky	194.598	112.512	28.677	23.731	21.638	22.290	8.011	12.135	198.836	169.354	98.871
Total CO2 emissions, Trade	352.661	99.303	42.332	28.970	27.295	44.536	19.180	13.282	172.994	126.908	67.965
%-change under Autarky	-44.8%	13.3%	-32.3%	-18.1%	-20.7%	-50.0%	-58.2%	-8.6%	14.9%	33.4%	45.5%

Table 4.2: CO_2 Emissions under home production of previously traded goods (in million metric tons), Summary Table

corresponding or larger rise of emissions in the US.

The following listing shows the average[8] change of aggregate emissions under autarky compared to trade:

- Brazil: +5.7%[9]
- Russian Federation: -11.6%

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[8] The average here is actually a weighted average. The percentage autarky deviations are weighted with respect to the aggregate two-country emissions under trade. The average includes only trade with the BRICs' MITPs.

[9] This is to read as follows: If Brazil's traded goods with its MITPs would be domestically produced in both countries with the prevailing emission intensities, the overall emissions would on average be 5.7% higher than in the current situation (in 2009).

- India: +1.2%
- China: -9.6%

The predicted change of aggregate emission under autarky remains unclear with two countries showing an increase and two countries showing a decrease in the aggregate emission level. Our empirical results might, however, more likely hint towards a decrease, as we observe a relatively large decrease in the traded emissions of the two countries exhibiting the highest magnitude of embodied emissions in trade. Still, we cannot confirm hypotheses H2 (see section 1.2): We do not observe a higher aggregate emission level under trade for all of the BRICs.

Hypothesis H2 came from the following reasoning: If the BRICs are really specialized in the production of emission intensive goods, and if - in concordance with the pollution haven hypothesis - this is due to laxer environmental regulation resulting in relatively higher emission intensities, we would expect the aggregate emission level in this hypothetical autarky scenario to be lower than under trade. If, on the other hand, we had a situation where the BRICs were specialized in the relatively clean sectors - albeit having laxer regulation and higher average intensities - we would expect aggregate emissions to increase in the autarky scenario. The listing of average changes above does not indicate a clear direction of the results concerning our expectations. We could in addition try to find out whether the BRICs' exports are relatively emission intensive compared to their domestically consumed production (this is discussed in section 5.3.5, table 5.1).

4.4 * Appendix: Detailed Results

This Appendix presents a full table of emission intensities for all countries of this study. Additionally, it presents for each of the BRICs detailed calculation tables for the three most important trading partners, see Tables 4.4 to 4.7. For Brazil and the Russian Federation this would have included the Netherlands, while Belgium would be a top-3 trading partner for India. However, I decided to exclude Belgium and the Netherlands here for they are suspected to be biased because of re-exports. Finally, the Appendix presents the detailed results for the Autarky versus Trade regime in Tables 4.8 to 4.11.

Sectors	1	2	3	4	5	6	7	8	9	10	11	12
	agri	minq	fopr	text	leat	wood	papp	petr	chem	rupl	nmmp	meta
BRA	0.264	0.373	0.181	0.131	0.128	0.139	0.198	0.406	0.295	0.154	1.074	0.496
RUS	0.828	1.543	0.735	0.793	0.903	1.143	1.060	1.920	3.315	1.497	4.545	3.633
IND	0.494	3.218	1.248	1.207	0.675	1.811	1.780	1.559	1.674	1.407	4.564	2.845
CHN	0.524	1.758	0.667	0.918	0.665	0.966	1.274	1.528	1.831	1.344	3.553	2.100
USA	0.429	0.450	0.426	0.423	0.223	0.574	0.407	0.593	0.569	0.367	1.716	0.555
GER	0.217	0.542	0.176	0.141	0.099	0.169	0.182	0.328	0.273	0.117	0.950	0.324
FRA	0.185	0.283	0.176	0.073	0.061	0.115	0.104	0.262	0.162	0.073	0.698	0.195
ITA	0.219	0.205	0.198	0.193	0.114	0.147	0.238	0.475	0.274	0.174	0.990	0.202
NED	0.419	0.179	0.126	0.098	0.053	0.122	0.106	0.322	0.240	0.074	0.323	0.260
GBR	0.226	0.408	0.207	0.218	0.114	0.219	0.168	0.707	0.250	0.222	0.798	0.464
ESP	0.247	0.346	0.192	0.212	0.134	0.185	0.204	0.515	0.244	0.154	1.186	0.256
BEL	0.330	0.244	0.152	0.080	0.076	0.073	0.194	0.155	0.246	0.051	0.979	0.211
JPN	0.210	0.908	0.167	0.200	0.169	0.219	0.256	0.301	0.428	0.248	1.213	0.523
KOR	0.441	3.379	0.410	0.536	0.388	0.472	0.594	0.481	0.605	0.448	2.383	1.069
AUS	0.335	0.311	0.309	0.270	0.288	0.256	0.264	0.641	0.597	0.273	1.359	0.757

Sectors	13	14	15	16	17	18	19	20	21	22	23	24
	mach	elop	treq	manr	elgw	cons	mott	whot	rett	hore	itra	wtra
BRA	0.190	0.149	0.146	0.151	0.302	0.221	0.073	0.059	0.090	0.112	0.513	1.677
RUS	1.542	1.449	1.093	1.382	7.752	1.285	0.535	0.639	0.495	1.103	1.991	2.479
IND	1.268	1.096	1.369	0.354	16.403	1.339	0.146	0.118	0.139	1.047	1.030	2.407
CHN	1.278	0.989	1.054	0.861	10.493	1.557	n.a.	0.431	0.478	0.697	1.008	1.594
USA	0.252	0.133	0.245	0.233	5.344	0.233	0.126	0.079	0.149	0.270	0.726	1.865
GER	0.095	0.082	0.103	0.114	2.163	0.123	0.065	0.086	0.105	0.116	0.198	0.177
FRA	0.068	0.066	0.063	0.195	0.442	0.084	0.080	0.053	0.037	0.076	0.290	0.270
ITA	0.123	0.110	0.140	0.109	1.065	0.137	0.089	0.102	0.124	0.111	0.238	0.902
NED	0.063	0.066	0.059	0.067	1.393	0.072	0.087	0.061	0.075	0.143	0.300	0.911
GBR	0.139	0.096	0.124	0.185	1.741	0.110	0.077	0.098	0.075	0.093	0.372	1.509
ESP	0.129	0.114	0.125	0.133	1.059	0.159	0.128	0.103	0.083	0.066	0.399	0.796
BEL	0.066	0.051	0.043	0.055	1.312	0.116	0.067	0.071	0.062	0.069	0.573	0.220
JPN	0.176	0.193	0.203	0.257	1.407	0.213	0.140	0.071	0.129	0.174	0.251	1.609
KOR	0.419	0.331	0.392	0.464	5.651	0.554	0.261	0.290	0.436	0.462	0.961	1.470
AUS	0.282	0.227	0.243	0.260	5.410	0.269	0.188	0.163	0.187	0.253	0.493	2.041

Sectors	25	26	27	28	29	30	31	32	33	34
	atra	otra	pote	fina	real	rent	publ	educ	heal	csps
BRA	0.567	0.179	0.128	0.044	0.016	0.095	0.084	0.072	0.092	0.130
RUS	3.427	1.186	0.572	0.437	0.904	0.495	0.775	0.603	0.685	1.779
IND	1.286	1.528	0.771	0.239	0.099	0.305	0.010	0.111	0.389	0.191
CHN	2.663	0.851	0.499	0.262	0.177	0.693	0.592	0.682	1.044	0.742
USA	1.338	0.398	0.150	0.074	0.055	0.105	0.212	0.326	0.142	0.155
GER	1.032	0.189	0.129	0.051	0.035	0.052	0.070	0.072	0.061	0.083
FRA	1.282	0.029	0.026	0.022	0.007	0.029	0.037	0.040	0.027	0.136
ITA	0.875	0.114	0.072	0.032	0.014	0.069	0.062	0.026	0.061	0.110
NED	2.004	0.074	0.039	0.033	0.033	0.053	0.086	0.053	0.053	0.318
GBR	3.180	0.068	0.074	0.046	0.025	0.034	0.085	0.058	0.074	0.068
ESP	0.887	0.151	0.087	0.027	0.028	0.053	0.067	0.029	0.052	0.088
BEL	2.318	0.173	0.116	0.028	0.034	0.044	0.035	0.028	0.036	0.109
JPN	0.693	0.122	0.076	0.058	0.025	0.098	0.128	0.073	0.134	0.174
KOR	2.070	0.607	0.323	0.161	0.244	0.200	0.212	0.277	0.297	0.477
AUS	1.320	0.345	0.234	0.045	0.081	0.184	0.158	0.171	0.103	0.179

Table 4.3: Full table of sectoral CO_2 emission intensities (in 1000 metric tons per million US Dollar)

Sectors	1 agri	2 minq	3 fopr	5 leat	6 wood	7 papp	8 petr	9 chem	10 rupl	11 nmmp	12 meta	13 mach	14 elop	15 treq	17 elgw	25 atra	28 fina	34 csps
Sectoral CO2 emission intensity (in 1000 metric tons per million US Dollar)																		
BRA	0.264	0.373	0.181	0.128	0.139	0.198	0.406	0.295	0.154	1.074	0.496	0.190	0.149	0.146	0.302	0.567	0.044	0.130
USA	0.429	0.450	0.426	0.223	0.574	0.407	0.593	0.569	0.367	1.716	0.555	0.252	0.133	0.245	5.344	1.338	0.074	0.155
GER	0.217	0.542	0.176	0.099	0.169	0.182	0.328	0.273	0.117	0.950	0.324	0.095	0.082	0.103	2.163	1.032	0.051	0.083
JPN	0.210	0.908	0.167	0.169	0.219	0.256	0.301	0.428	0.248	1.213	0.523	0.176	0.193	0.203	1.407	0.693	0.058	0.174
Trading Partner: United States (USA)																		
Trade Values (in million US Dollars)																		
Exports	989.6	4744.8	879.2	687.4	463.1	761.0	1175.0	1282.3	257.5	503.4	1587.6	1217.8	710.6	1478.0	48.8	3.5	20.8	46.9
Imports	156.4	1211.4	502.1	4.9	11.9	283.2	776.4	4067.0	375.5	135.3	797.3	2333.8	2928.4	2745.8	60.9	75.8	1531.0	121.7
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	261.6	1769.4	158.9	87.8	64.2	150.5	477.4	378.6	39.7	540.7	788.0	231.1	105.6	216.2	14.7	2.0	0.9	6.1
Imports	67.1	544.6	214.0	1.1	6.9	115.3	460.7	2313.2	137.9	232.2	442.8	588.7	389.5	672.2	325.4	101.4	112.7	18.9
Net	194.5	1224.8	-55.1	86.7	57.3	35.2	16.7	-1934.6	-98.2	308.6	345.1	-357.6	-283.9	-456.0	-310.7	-99.4	-111.8	-12.7
Trading Partner: Germany (GER)																		
Trade Values (in million US Dollars)																		
Exports	1685.8	807.2	1548.6	124.4	86.4	388.5	69.7	550.6	66.8	36.1	455.3	344.7	292.5	1207.3	395.7	71.0	14.0	962.8
Imports	40.7	1.0	125.0	4.7	9.4	145.8	166.4	3089.8	319.4	100.1	869.1	2302.1	1801.9	1904.2	733.3	14.9	15.5	3.6
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	445.7	301.0	279.9	15.9	12.0	76.9	28.3	162.6	10.3	38.8	226.0	65.4	43.5	176.6	119.4	40.2	0.6	125.6
Imports	8.8	0.5	22.0	0.5	1.6	26.5	54.7	844.3	37.5	95.1	281.3	219.6	147.9	196.5	1585.9	15.4	0.8	0.3
Net	436.8	300.5	257.8	15.4	10.4	50.4	-26.4	-681.8	-27.1	-56.4	-55.3	-154.2	-104.4	-19.9	-1466.5	24.9	-0.2	125.3
Trading Partner: Japan (JPN)																		
Trade Values (in million US Dollars)																		
Exports	620.5	899.5	944.0	28.7	149.9	80.6	2.3	172.8	16.4	4.6	927.0	26.7	10.4	241.0	0.2	0.9	72.2	12.0
Imports	2.3	8.0	5.6	0.9	1.8	14.6	48.1	343.8	223.5	22.9	612.1	680.2	988.5	1090.1	12.0	3.2	15.1	37.5
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	164.0	335.4	170.6	3.7	20.8	16.0	0.9	51.0	2.5	5.0	460.1	5.1	1.6	35.3	0.1	0.5	3.2	1.6
Imports	0.5	7.2	0.9	0.2	0.4	3.7	14.5	147.1	55.4	27.8	320.0	120.0	190.5	221.4	16.9	2.2	0.9	6.5
Net	163.6	328.2	169.7	3.5	20.4	12.2	-13.5	-96.1	-52.8	-22.8	140.1	-114.9	-189.0	-186.1	-16.8	-1.7	2.3	-5.0

Table 4.4: Embodied CO_2 Emissions in Trade, Brazil (BRA), Calculation Table

Sectors	1	2	3	4	5	6	7	8	9	11	12	13	15	17	20	23	25	26
	agri	minq	fopr	text	leat	wood	papp	petr	chem	nmmp	meta	mach	treq	elgw	whot	itra	atra	otra
Sectoral CO2 emission intensity (in 1000 metric tons per million US Dollar)																		
RUS	0.828	1.543	0.735	0.793	0.903	1.143	1.060	1.920	3.315	4.545	3.633	1.542	1.093	7.752	0.639	1.991	3.427	1.186
GER	0.217	0.542	0.176	0.141	0.099	0.169	0.182	0.328	0.273	0.950	0.324	0.095	0.103	2.163	0.086	0.198	1.032	0.189
ITA	0.219	0.205	0.198	0.193	0.114	0.147	0.238	0.475	0.274	0.990	0.202	0.123	0.140	1.065	0.102	0.238	0.875	0.114
USA	0.429	0.450	0.426	0.423	0.223	0.574	0.407	0.593	0.569	1.716	0.555	0.252	0.245	5.344	0.079	0.726	1.338	0.398
Trading Partner: Germany (GER)																		
Trade Values (in million US Dollars)																		
Exports	11.4	7128.6	44.4	11.1	1.3	174.9	235.2	1320.3	444.3	13.2	2923.7	238.6	44.3	151.4	2143.4	2416.6	17.6	230.1
Imports	127.6	1.0	1531.8	2549.8	437.1	200.8	946.7	149.1	3460.9	199.8	1227.8	6636.6	6012.2	77.8	184.1	80.4	20.2	98.6
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	9.5	11000.6	32.7	8.8	1.1	199.9	249.3	2535.1	1472.9	60.0	10622.1	368.1	48.4	1173.5	1369.9	4812.0	60.4	272.8
Imports	27.7	0.6	270.0	359.9	43.2	34.0	171.9	49.0	945.7	189.9	397.4	633.0	620.4	168.3	15.8	15.9	20.8	18.6
Net	-18.2	11000.1	-237.3	-351.1	-42.1	165.9	77.5	2486.2	527.1	-129.9	10224.7	-265.0	-572.0	1005.2	1354.1	4796.1	39.6	254.2
Trading Partner: Italy (ITA)																		
Trade Values (in million US Dollars)																		
Exports	22.7	13510.7	23.9	4.0	42.5	39.7	59.8	460.2	141.9	1.2	834.7	108.2	4.1	14.9	4208.5	4553.6	9.3	28.2
Imports	88.8	13.1	393.9	3226.9	1692.4	91.7	179.9	7.5	854.6	120.3	476.5	3186.6	569.1	10.3	227.3	53.8	12.3	57.4
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	18.8	20849.2	17.6	3.2	38.4	45.4	63.4	883.6	470.4	5.3	3032.4	166.9	4.4	115.3	2689.7	9067.4	31.9	33.4
Imports	19.5	2.7	78.1	623.2	192.1	13.5	42.9	3.6	234.4	119.2	96.0	393.2	79.6	11.0	23.1	12.8	10.8	6.5
Net	-0.7	20846.6	-60.5	-620.0	-153.8	31.9	20.6	880.1	236.0	-113.9	2936.4	-226.3	-75.2	104.3	2666.5	9054.6	21.1	26.9
Trading Partner: United States (USA)																		
Trade Values (in million US Dollars)																		
Exports	71.0	3225.7	70.8	1.7	1.1	50.0	20.2	2077.6	492.0	12.7	1404.6	426.2	8.0	9.4	1006.5	1097.2	31.7	0.0
Imports	318.6	36.4	878.4	290.3	46.2	10.7	39.7	73.0	786.7	20.6	193.4	1478.2	1343.9	0.0	0.0	0.0	0.0	0.0
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	58.7	4977.8	52.0	1.3	1.0	57.2	21.5	3989.2	1631.2	57.8	5102.9	657.4	8.7	72.8	643.3	2184.7	108.6	0.0
Imports	136.7	16.4	374.4	122.7	10.3	6.2	16.2	43.3	447.5	35.3	107.4	372.9	329.0	0.0	0.0	0.0	0.0	0.0
Net	-78.0	4961.4	-322.3	-121.4	-9.3	51.0	5.3	3945.9	1183.7	22.5	4995.5	284.6	-320.3	72.8	643.3	2184.7	108.6	0.0

Table 4.5: Embodied CO_2 Emissions in Trade, Russian Federation (RUS), Calculation Table

Sectors	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	22	23	30
	agri	minq	fopr	text	leat	wood	petr	chem	rupl	nmmp	meta	mach	elop	treq	manr	hore	itra	rent
Sectoral CO2 emission intensity (in 1000 metric tons per million US Dollar)																		
IND	0.494	3.218	1.248	1.207	0.675	1.811	1.559	1.674	1.407	4.564	2.845	1.268	1.096	1.369	0.354	1.047	1.030	0.305
USA	0.429	0.450	0.426	0.423	0.223	0.574	0.593	0.569	0.367	1.716	0.555	0.252	0.133	0.245	0.233	0.270	0.726	0.105
GER	0.217	0.542	0.176	0.141	0.099	0.169	0.328	0.273	0.117	0.950	0.324	0.095	0.082	0.103	0.114	0.116	0.198	0.052
AUS	0.335	0.311	0.309	0.270	0.288	0.256	0.641	0.597	0.273	1.359	0.757	0.282	0.227	0.243	0.260	0.253	0.493	0.184
Trading Partner: United States (USA)																		
Trade Values (in million US Dollars)																		
Exports	2018.9	12.5	562.5	4883.4	275.0	1040.4	298.3	2466.9	377.5	217.6	2600.2	1034.8	3336.7	802.6	30879.2	0.0	72.5	12882.1
Imports	155.3	55.8	169.1	105.7	4.5	64.3	175.4	1545.3	164.7	170.9	570.1	1079.3	5335.0	736.0	12094.9	29.6	285.2	619.8
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	998.0	40.2	702.1	5896.4	185.6	1884.0	465.1	4130.0	531.1	993.2	7397.0	1311.8	3656.7	1098.8	10946.1	0.0	74.7	3932.6
Imports	66.6	25.1	72.1	44.7	1.0	36.9	104.1	878.9	60.5	293.3	316.6	272.2	709.6	180.2	2823.9	8.0	206.9	65.0
Net	931.4	15.1	630.0	5851.7	184.6	1847.1	361.1	3251.1	470.6	699.9	7080.4	1039.6	2947.1	918.7	8122.2	-8.0	-132.2	3867.6
Trading Partner: Germany (GER)																		
Trade Values (in million US Dollars)																		
Exports	324.8	152.3	160.5	1414.1	206.9	69.5	35.7	598.1	197.0	81.9	684.6	360.1	2593.1	736.5	1931.9	680.9	582.9	4141.2
Imports	14.1	0.5	43.7	59.6	9.0	18.3	34.0	876.2	149.9	297.2	810.4	1771.8	1155.0	1363.8	1558.7	54.6	48.8	571.5
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	160.6	490.1	200.4	1707.4	139.7	125.8	55.6	1001.4	277.2	373.8	1947.6	456.5	2841.8	1008.3	684.8	712.8	600.6	1264.2
Imports	3.1	0.3	7.7	8.4	0.9	3.1	11.2	239.4	17.6	282.5	262.3	169.0	94.8	140.7	177.6	6.3	9.7	29.9
Net	157.5	489.8	192.7	1699.0	138.8	122.7	44.5	761.9	259.7	91.3	1685.3	287.5	2747.0	867.6	507.2	706.4	590.9	1234.2
Trading Partner: Australia (AUS)																		
Trade Values (in million US Dollars)																		
Exports	66.7	4.9	51.1	301.8	19.1	49.6	10.6	118.8	57.3	20.1	215.7	155.1	526.5	60.0	1436.3	1468.0	100.5	155.9
Imports	86.3	2509.3	95.2	12.9	4.0	3.9	27.3	88.3	12.2	7.4	4429.1	69.3	44.1	7.7	92.6	1229.7	19.5	152.4
Flows of Embodied CO2 (in 1000 metric tons)																		
Exports	33.0	15.7	63.7	364.5	12.9	89.8	16.5	198.9	80.7	91.6	613.6	196.7	577.0	82.1	509.1	1536.7	103.6	47.6
Imports	28.9	781.1	29.4	3.5	1.1	1.0	17.5	52.7	3.3	10.0	3352.5	19.5	10.0	1.9	24.1	311.6	9.6	28.0
Net	4.0	-765.4	34.3	361.0	11.7	88.8	-1.0	146.1	77.3	81.6	-2738.9	177.1	567.0	80.3	485.0	1225.2	94.0	19.6

Table 4.6: Embodied CO_2 Emissions in Trade, India (IND), Calculation Table

Sectors	2	3	4	5	6	9	10	11	12	13	14	15	16	20	24	25	30
	minq	fopr	text	leat	wood	chem	rupl	nmmp	meta	mach	elop	treq	manr	whot	wtra	atra	rent
Sectoral CO2 emission intensity (in 1000 metric tons per million US Dollar)																	
CHN	1.758	0.667	0.918	0.665	0.966	1.831	1.344	3.553	2.100	1.278	0.989	1.054	0.861	0.431	1.594	2.663	0.693
USA	0.450	0.426	0.423	0.223	0.574	0.569	0.367	1.716	0.555	0.252	0.133	0.245	0.233	0.079	1.865	1.338	0.105
JPN	0.908	0.167	0.200	0.169	0.219	0.428	0.248	1.213	0.523	0.176	0.193	0.203	0.257	0.071	1.609	0.693	0.098
KOR	3.379	0.410	0.536	0.388	0.472	0.605	0.448	2.383	1.069	0.419	0.331	0.392	0.464	0.290	1.470	2.070	0.200
Trading Partner: United States (USA)																	
Trade Values (in million US Dollars)																	
Exports	417.3	4591.9	25845.6	13356.1	1977.9	11093.9	9112.4	2880.1	12949.8	21172.2	127852.4	6861.9	14459.7	n.a.	225.9	4623.9	26818.1
Imports	325.9	2305.4	821.3	69.7	501.5	9570.8	1155.9	534.5	6674.9	9032.9	24231.4	10199.9	1457.1	n.a.	19.6	2558.0	7462.4
Flows of Embodied CO2 (in 1000 metric tons)																	
Exports	733.4	3063.5	23729.5	8883.3	1911.0	20314.9	12243.2	10232.5	27188.1	27061.0	126447.7	7232.3	12445.7	n.a.	360.2	12312.0	18572.4
Imports	146.5	982.6	347.2	15.5	287.7	5443.6	424.5	917.2	3707.3	2278.5	3222.9	2497.0	340.2	n.a.	36.5	3422.1	782.4
Net	586.9	2080.9	23382.4	8867.8	1623.3	14871.3	11818.7	9315.3	23480.8	24782.5	123224.8	4735.3	12105.5	n.a.	323.7	8889.9	17790.0
Trading Partner: Japan (JPN)																	
Trade Values (in million US Dollars)																	
Exports	958.1	7122.1	16960.6	3269.6	1498.2	4777.4	4516.4	1318.3	6684.3	7615.6	35817.4	3107.6	2280.7	5452.0	9299.3	2816.1	2272.2
Imports	585.9	525.4	2908.9	89.9	270.6	12649.5	4277.9	1423.2	14299.6	14020.3	47073.7	12434.0	689.4	46.3	176.7	1493.1	303.6
Flows of Embodied CO2 (in 1000 metric tons)																	
Exports	1684.0	4751.5	15572.0	2174.7	1447.5	8748.2	6068.1	4683.7	14033.7	9733.8	35423.9	3275.3	1963.0	2350.5	14824.2	7498.4	1573.6
Imports	531.9	87.9	581.5	15.2	59.2	5411.8	1059.5	1726.2	7477.4	2473.0	9072.4	2524.9	177.1	3.3	284.3	1035.4	29.7
Net	1152.1	4663.6	14990.5	2159.5	1388.3	3336.4	5008.6	2957.5	6556.3	7260.8	26351.5	750.4	1785.9	2347.2	14540.0	6463.0	1543.9
Trading Partner: Korea (KOR)																	
Trade Values (in million US Dollars)																	
Exports	976.2	1999.2	3716.2	752.8	249.7	4266.3	833.8	976.1	7398.2	3065.9	21050.1	2393.9	571.4	1778.2	3889.2	579.5	1616.8
Imports	3.0	390.1	2038.0	560.9	4.7	18125.8	1681.7	194.2	6996.7	8119.9	48544.1	3878.9	189.1	0.0	211.6	1933.8	0.0
Flows of Embodied CO2 (in 1000 metric tons)																	
Exports	1715.8	1333.7	3412.0	500.7	241.3	7812.4	1120.2	3467.9	15532.5	3918.6	20818.8	2523.1	491.8	766.6	6199.9	1542.9	1119.7
Imports	10.1	160.1	1092.5	217.7	2.2	10960.8	754.3	462.7	7479.3	3403.0	16071.9	1521.4	87.7	0.0	311.1	4003.6	0.0
Net	1705.6	1173.7	2319.5	283.0	239.0	-3148.5	366.0	3005.2	8053.2	515.6	4746.9	1001.7	404.1	766.6	5888.9	-2460.7	1119.7

Table 4.7: Embodied CO_2 Emissions in Trade, China (CHN), Calculation Table

Sectors	1 agri	2 minq	3 fopr	5 leat	6 wood	7 papp	8 petr	9 chem	10 rupl	11 nmmp	12 meta	13 mach	14 elop	15 treq	17 elgw	25 atra	28 fina	34 csps
Trading Partner: United States (USA)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
BRA	41.3	451.7	90.7	0.6	1.7	56.0	315.4	1200.8	57.9	145.3	395.7	442.8	435.3	401.6	18.4	43.0	66.9	15.9
USA	424.6	2133.0	374.7	153.2	265.7	309.9	697.1	729.3	94.6	863.9	881.8	307.2	94.5	361.8	260.7	4.6	1.5	7.3
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
BRA	-220.2	-1317.6	-68.2	-87.2	-62.5	-94.5	-161.9	822.2	18.2	-395.4	-392.2	211.7	329.7	185.4	3.7	41.0	66.0	9.7
USA	357.5	1588.5	160.7	152.2	258.8	194.6	236.5	-1583.8	-43.3	631.7	438.9	-281.5	-295.0	-310.4	-64.8	-96.8	-111.2	-11.6
Total Sectoral Emissions of CO2 in both countries																		
Autarky	466.0	2584.8	465.5	153.9	267.3	365.9	1012.6	1930.1	152.5	1009.2	1277.5	750.0	529.8	763.4	279.0	47.6	68.4	23.1
Trade	328.7	2313.9	372.9	88.9	71.0	265.9	938.0	2691.8	177.6	772.9	1230.8	819.7	495.1	888.3	340.1	103.4	113.6	25.0
Diff.	137.3	270.8	92.6	65.0	196.3	100.1	74.5	-761.7	-25.1	236.3	46.7	-69.8	34.7	-124.9	-61.1	-55.7	-45.2	-1.8
Trading Partner: Germany (GER)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
BRA	10.8	0.4	22.6	0.6	1.3	28.8	67.6	912.3	49.3	107.5	431.4	436.8	267.9	278.5	221.3	8.5	0.7	0.5
GER	366.1	437.7	272.9	12.3	14.6	70.5	22.9	150.5	7.8	34.3	147.4	32.9	24.0	124.6	855.7	73.2	0.7	80.2
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
BRA	-434.9	-300.7	-257.3	-15.3	-10.7	-48.0	39.3	749.7	39.0	68.7	205.4	371.4	224.4	101.9	101.9	-31.8	0.1	-125.2
GER	357.3	437.1	250.9	11.8	13.0	44.1	-31.8	-693.9	-29.6	-60.8	-133.9	-186.7	-123.8	-71.9	-730.2	57.8	-0.1	79.9
Total Sectoral Emissions of CO2 in both countries																		
Autarky	376.9	438.0	295.5	12.9	15.9	99.4	90.5	1062.7	57.1	141.8	578.7	469.7	291.9	403.1	1077.0	81.6	1.4	80.7
Trade	454.5	301.6	301.9	16.4	13.6	103.3	83.0	1006.9	47.8	133.9	507.3	285.0	191.3	373.1	1705.3	55.6	1.4	125.9
Diff.	-77.6	136.5	-6.4	-3.5	2.4	-4.0	7.5	55.8	9.3	7.9	71.5	184.7	100.5	30.0	-628.3	26.0	0.0	-45.2
Trading Partner: Japan (JPN)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
BRA	0.6	3.0	1.0	0.1	0.3	2.9	19.5	101.5	34.5	24.6	303.8	129.1	146.9	159.4	3.6	1.8	0.7	4.9
JPN	130.6	816.6	158.0	4.8	32.8	20.6	0.7	73.9	4.1	5.6	484.8	4.7	2.0	48.9	0.3	0.6	4.2	2.1
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
BRA	-163.4	-332.5	-169.6	-3.5	-20.5	-13.1	18.6	50.5	32.0	19.6	-156.3	124.0	145.4	124.2	3.5	1.3	-2.5	3.3
JPN	130.1	809.4	157.0	4.7	32.4	16.9	-13.8	-73.2	-51.3	-22.2	164.7	-115.3	-188.5	-172.4	-16.5	-1.6	3.3	-4.4
Total Sectoral Emissions of CO2 in both countries																		
Autarky	131.2	819.6	159.0	5.0	33.1	23.5	20.2	175.4	38.6	30.2	788.5	133.8	149.0	208.4	4.0	2.4	4.8	7.0
Trade	164.5	342.7	171.6	3.8	21.2	19.7	15.4	198.1	57.9	32.8	780.2	125.0	192.1	256.6	16.9	2.7	4.0	8.1
Diff.	-33.3	476.9	-12.6	1.1	11.9	3.8	4.8	-22.7	-19.3	-2.5	8.4	8.7	-43.1	-48.2	-13.0	-0.3	0.8	-1.1

Table 4.8: CO_2 Emissions under home production of previously traded goods (in million metric tons), Brazil (BRA)

Sectors	1 agri	2 minq	3 fopr	4 text	5 leat	6 wood	7 papp	8 petr	9 chem	11 nmmp	12 meta	13 mach	15 treq	17 elgw	20 whot	23 itra	25 atra	26 otra
Trading Partner: Germany (GER)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
RUS	105.6	1.6	1125.6	2022.3	394.8	229.4	1003.7	286.2	11473.0	908.1	4460.9	10236.1	6570.3	603.4	117.6	160.1	69.2	117.0
GER	2.5	3865.0	7.8	1.6	0.1	29.6	42.7	433.7	121.4	12.5	946.2	22.8	4.6	327.4	183.7	478.1	18.2	43.4
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
RUS	96.1	-10999.0	1093.0	2013.5	393.7	29.5	754.4	-2248.9	10000.2	848.1	-6161.2	9868.1	6521.8	-570.1	-1252.2	-4651.9	8.8	-155.8
GER	-25.2	3864.4	-262.2	-358.3	-43.1	-4.4	-129.2	384.7	-824.3	-177.4	548.9	-610.3	-615.9	159.1	167.9	462.2	-2.6	24.8
Total Sectoral Emissions of CO2 in both countries																		
Autarky	108.0	3866.6	1133.5	2023.9	394.9	259.0	1046.4	719.9	11594.4	920.7	5407.1	10258.9	6574.8	930.8	301.4	638.3	87.4	160.3
Trade	37.2	11001.2	302.6	368.6	44.4	233.9	421.2	2584.1	2418.6	249.9	11019.5	1001.1	668.9	1341.9	1385.6	4827.9	81.3	291.4
Diff.	70.9	-7134.6	830.8	1655.2	350.5	25.2	625.2	-1864.2	9175.8	670.7	-5612.4	9257.8	5906.0	-411.0	-1084.3	-4189.6	6.1	-131.0
Trading Partner: Italy (ITA)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
RUS	73.5	20.2	289.4	2559.3	1528.7	104.8	190.7	14.4	2833.2	546.9	1731.0	4914.9	621.9	79.9	145.3	107.2	42.1	68.0
ITA	5.0	2766.0	4.7	0.8	4.8	5.8	14.3	218.7	38.9	1.1	168.2	13.4	0.6	15.8	428.1	1083.1	8.1	3.2
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
RUS	54.7	-20829.1	271.9	2556.1	1490.3	59.4	127.3	-869.2	2362.8	541.7	-1301.4	4748.0	617.5	-35.4	-2544.4	-8960.2	10.2	34.7
ITA	-14.5	2763.3	-73.4	-622.4	-187.3	-7.6	-28.6	215.1	-195.5	-118.1	72.2	-379.9	-79.1	4.9	405.0	1070.3	-2.6	-3.3
Total Sectoral Emissions of CO2 in both countries																		
Autarky	78.5	2786.2	294.2	2560.1	1533.5	110.6	205.0	233.1	2872.1	548.1	1899.3	4928.3	622.5	95.7	573.4	1190.3	50.3	71.2
Trade	38.3	20851.9	95.7	626.3	230.5	58.8	106.3	887.2	704.7	124.5	3128.5	560.2	84.1	126.3	2712.8	9080.2	42.6	39.9
Diff.	40.2	-18065.7	198.5	1933.7	1303.0	51.8	98.6	-654.1	2167.3	423.6	-1229.2	4368.1	538.4	-30.6	-2139.4	-7889.9	7.6	31.3
Trading Partner: United States (USA)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
RUS	263.7	56.2	645.5	230.3	41.7	12.3	42.1	140.2	2608.0	93.4	702.8	2279.9	1468.6	0.0	0.0	0.0	0.0	0.0
USA	30.5	1450.1	30.2	0.7	0.3	28.7	8.2	1232.7	279.9	21.8	780.1	107.5	1.9	50.2	79.5	796.1	42.4	0.0
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
RUS	205.0	-4921.5	593.4	228.9	40.7	-44.9	20.6	-3849.0	976.8	35.6	-4400.1	1622.5	1459.9	-72.8	-643.3	-2184.7	-108.6	0.0
USA	-106.3	1433.7	-344.2	-122.0	-10.0	22.5	-7.9	1189.3	-167.6	-13.5	672.7	-265.3	-327.0	50.2	79.5	796.1	42.4	0.0
Total Sectoral Emissions of CO2 in both countries																		
Autarky	294.1	1506.3	675.6	231.0	42.0	41.0	50.3	1372.8	2887.9	115.2	1482.9	2387.4	1470.6	50.2	79.5	796.1	42.4	0.0
Trade	195.5	4994.2	426.4	124.1	11.3	63.3	37.6	4032.5	2078.6	93.0	5210.4	1030.3	337.7	72.8	643.3	2184.7	108.6	0.0
Diff.	98.7	-3487.8	249.2	106.9	30.6	-22.4	12.7	-2659.7	809.2	22.2	-3727.5	1357.1	1132.9	-22.6	-563.7	-1388.6	-66.2	0.0

Table 4.9: CO_2 Emissions under home production of previously traded goods (in million metric tons), Russian Federation (RUS)

Sectors	1	2	3	4	5	6	8	9	10	11	12	13	14	15	16	22	23	30
	agri	minq	fopr	text	leat	wood	petr	chem	rupl	nmmp	meta	mach	elop	treq	manr	hore	itra	rent
Trading Partner: United States (USA)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
IND	76.8	179.5	211.0	127.7	3.0	116.4	273.5	2587.0	231.7	780.1	1621.8	1368.3	5846.6	1007.6	4287.4	31.0	293.8	189.2
USA	866.4	5.6	239.7	2064.3	61.3	596.8	177.0	1403.1	138.6	373.4	1444.2	261.0	443.8	196.5	7209.5	0.0	52.6	1350.6
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
IND	-921.2	139.4	-491.0	-5768.7	-182.6	-1767.6	-191.6	-1543.0	-299.4	-213.1	-5775.2	56.4	2189.9	-91.2	-6658.7	31.0	219.1	-3743.3
USA	799.7	-19.5	167.7	2019.6	60.3	559.9	72.9	524.2	78.1	80.1	1127.5	-11.2	-265.8	16.3	4385.7	-8.0	-154.3	1285.6
Total Sectoral Emissions of CO2 in both countries																		
Autarky	943.1	185.1	450.8	2192.0	64.3	713.3	450.5	3990.1	370.3	1153.5	3066.0	1629.3	6290.4	1204.1	11497.0	31.0	346.4	1539.8
Trade	1064.7	65.2	774.1	5941.1	186.6	1920.9	569.2	5008.9	591.6	1286.5	7713.6	1584.1	4366.3	1279.0	13770.0	8.0	281.6	3997.5
Diff.	-121.5	119.9	-323.4	-3749.1	-122.3	-1207.7	-118.7	-1018.8	-221.3	-133.0	-4647.7	45.2	1924.1	-74.9	-2273.0	23.0	64.8	-2457.7
Trading Partner: Germany (GER)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
IND	7.0	1.6	54.5	71.9	6.1	33.2	53.0	1466.9	210.9	1356.6	2305.3	2246.1	1265.8	1867.1	552.5	57.2	50.3	174.5
GER	70.5	82.6	28.3	199.6	20.5	11.8	11.7	163.4	23.1	77.8	221.6	34.3	212.8	76.0	220.1	79.0	115.3	217.0
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
IND	-153.6	-488.5	-145.9	-1635.5	-133.6	-92.6	-2.7	465.6	-66.4	982.8	357.7	1789.6	-1576.1	858.8	-132.3	-655.6	-550.2	-1089.7
GER	67.5	82.3	20.6	191.2	19.6	8.7	0.6	-76.0	5.5	-204.6	-40.7	-134.6	118.0	-64.7	42.5	72.6	105.7	187.1
Total Sectoral Emissions of CO2 in both countries																		
Autarky	77.5	84.2	82.8	271.5	26.5	44.9	64.7	1630.4	234.0	1434.4	2526.9	2280.5	1478.5	1943.2	772.7	136.1	165.6	391.5
Trade	163.6	490.4	208.1	1715.8	140.6	128.9	66.8	1240.8	294.8	656.3	2209.9	625.5	2936.6	1149.1	862.4	719.1	610.2	1294.1
Diff.	-86.1	-406.2	-125.3	-1444.3	-114.0	-84.0	-2.1	389.6	-60.8	778.1	317.0	1655.0	-1458.1	794.1	-89.8	-583.0	-444.6	-902.7
Trading Partner: Australia (AUS)																		
CO2 Emissions from Home Production of Previously Traded Goods																		
IND	42.7	8074.7	118.8	15.6	2.7	7.1	42.6	147.9	17.2	33.6	12599.9	87.8	48.4	10.6	32.8	1287.2	20.1	46.5
AUS	22.4	1.5	15.8	81.6	5.5	12.7	6.8	70.9	15.7	27.3	163.3	43.7	119.4	14.6	373.8	372.0	49.5	28.7
Change of Domestic Sectoral Emissions of CO2 under Autarky																		
IND	9.7	8059.0	55.1	-348.9	-10.2	-82.7	26.1	-51.0	-63.5	-58.0	11986.2	-108.8	-528.6	-71.6	-476.3	-249.5	-83.5	-1.1
AUS	-6.6	-779.6	-13.6	78.1	4.4	11.7	-10.7	18.2	12.3	17.3	-3189.3	24.2	109.4	12.7	349.7	60.4	39.9	0.7
Total Sectoral Emissions of CO2 in both countries																		
Autarky	65.0	8076.2	134.6	97.1	8.2	19.8	49.3	218.8	32.9	60.9	12763.1	131.5	167.7	25.2	406.6	1659.2	69.6	75.2
Trade	61.9	796.8	93.1	367.9	14.0	90.8	34.0	251.6	84.0	101.7	3966.2	216.2	587.0	84.0	533.2	1848.3	113.2	75.6
Diff.	3.1	7279.4	41.5	-270.8	-5.9	-71.0	15.4	-32.8	-51.1	-40.8	8797.0	-84.6	-419.3	-58.9	-126.6	-189.1	-43.6	-0.4

Table 4.10: CO_2 Emissions under home production of previously traded goods (in million metric tons), India (IND)

Sectors	2	3	4	5	6	9	10	11	12	13	14	15	16	20	24	25	30
	minq	fopr	text	leat	wood	chem	rupl	nmmp	meta	mach	elop	treq	manr	whot	wtra	atra	rent
Trading Partner: United States (USA)																	
CO2 Emissions from Home Production of Previously Traded Goods																	
CHN	572.8	1538.1	754.0	46.4	484.5	17525.8	1553.0	1898.9	14014.1	11545.4	23965.2	10750.4	1254.1	n.a.	31.2	6811.2	5167.9
USA	187.6	1957.1	10925.5	2977.5	1134.6	6309.9	3346.4	4942.3	7192.4	5340.5	17004.9	1679.8	3376.0	n.a.	421.4	6185.9	2811.7
Change of Domestic Sectoral Emissions of CO2 under Autarky																	
CHN	-160.6	-1525.4	-22975.5	-8836.9	-1426.5	-2789.1	-10690.2	-8333.6	-13174.0	-15515.7	-102482.5	3518.1	-11191.5	n.a.	-329.0	-5500.8	-13404.5
USA	41.1	974.5	10578.3	2961.9	846.9	866.3	2921.9	4025.1	3485.1	3062.0	13782.0	-817.2	3035.8	n.a.	384.9	2763.8	2029.3
Total Sectoral Emissions of CO2 in both countries																	
Autarky	760.4	3495.2	11679.5	3023.8	1619.1	23835.6	4899.4	6841.2	21206.6	16885.9	40970.1	12430.2	4630.1	n.a.	452.6	12997.1	7979.7
Trade	879.9	4046.1	24076.7	8898.8	2198.6	25758.4	12667.7	11149.7	30895.5	29339.5	129670.6	9729.3	12785.8	n.a.	396.7	15734.2	19354.8
Diff.	-119.5	-550.9	-12397.2	-5875.0	-579.5	-1922.8	-7768.3	-4308.5	-9688.9	-12453.6	-88700.5	2701.0	-8155.7	n.a.	55.9	-2737.0	-11375.1
Trading Partner: Japan (JPN)																	
CO2 Emissions from Home Production of Previously Traded Goods																	
CHN	1029.7	350.5	2670.7	59.8	261.5	23163.6	5747.7	5056.5	30022.2	17920.0	46556.5	13105.0	593.4	20.0	281.7	3975.7	210.2
JPN	869.8	1191.7	3390.4	551.2	328.0	2043.9	1118.6	1598.9	3495.3	1343.3	6903.0	631.1	586.0	389.3	14958.6	1952.9	222.3
Change of Domestic Sectoral Emissions of CO2 under Autarky																	
CHN	-654.3	-4401.0	-12901.3	-2114.9	-1186.1	14415.4	-320.5	372.8	15988.5	8186.2	11132.6	9829.7	-1369.6	-2330.5	-14542.5	-3522.7	-1363.3
JPN	337.9	1103.8	2808.9	536.0	268.7	-3368.0	59.1	-127.3	-3982.1	-1129.7	-2169.4	-1893.9	408.9	386.0	14674.3	917.4	192.6
Total Sectoral Emissions of CO2 in both countries																	
Autarky	1899.5	1542.2	6061.1	611.0	589.4	25207.5	6866.3	6655.4	33517.5	19263.3	53459.5	13736.1	1179.4	409.3	15240.3	5928.6	432.5
Trade	2215.8	4839.5	16153.5	2189.8	1506.8	14160.0	7127.7	6409.9	21511.1	12206.8	44496.3	5800.3	2140.1	2353.8	15108.5	8533.9	1603.3
Diff.	-316.3	-3297.2	-10092.4	-1578.8	-917.3	11047.4	-261.4	245.5	12006.4	7056.5	8963.2	7935.8	-960.8	-1944.5	131.8	-2605.2	-1170.7
Trading Partner: Korea (KOR)																	
CO2 Emissions from Home Production of Previously Traded Goods																	
CHN	5.3	260.3	1871.2	373.1	4.5	33191.6	2259.5	689.9	14689.6	10378.3	48010.8	4088.3	162.8	0.0	337.3	5149.1	0.0
KOR	3299.0	820.3	1992.0	292.1	117.9	2579.9	373.9	2325.6	7908.5	1284.9	6969.2	939.0	265.0	515.6	5718.3	1199.7	323.5
Change of Domestic Sectoral Emissions of CO2 under Autarky																	
CHN	-1710.5	-1073.5	-1540.8	-127.6	-236.7	25379.3	1139.3	-2778.0	-842.9	6459.7	27192.0	1565.1	-329.0	-766.6	-5862.7	3606.1	-1119.7
KOR	3288.8	660.2	899.6	74.5	115.7	-8381.0	-380.3	1862.9	429.2	-2118.1	-9102.7	-582.5	177.3	515.6	5407.3	-2803.9	323.5
Total Sectoral Emissions of CO2 in both countries																	
Autarky	3304.2	1080.6	3863.2	665.2	122.5	35771.5	2633.5	3015.5	22598.1	11663.2	54980.0	5027.2	427.8	515.6	6055.6	6348.8	323.5
Trade	1725.9	1493.8	4504.4	718.3	243.5	18773.2	1874.5	3930.5	23011.8	7321.6	36890.7	4044.6	579.5	766.6	6511.0	5546.5	1119.7
Diff.	1578.3	-413.3	-641.2	-53.2	-121.0	16998.3	759.0	-915.0	-413.7	4341.6	18089.3	982.7	-151.7	-251.1	-455.4	802.2	-796.2

Table 4.11: CO_2 Emissions under home production of previously traded goods (in million metric tons), China (CHN)

5 Abatement Policy Instruments

The results presented in chapter 4 are of an essentially descriptive nature. By themselves, they can tell us something on the magnitude of international trade of embodied emissions but they do not tell us *why* they are occuring in this pattern. In a next step it would be interesting to find out what is *causing* a country to have a high or a low number of embodied exports of CO_2. For this question we would have to use econometric techniques - techniques that create an additional demand for data. Hypothesis 3 of this thesis suggests that a consumption tax would be a way to eliminate the incentive to relocate production activities because of differences in environmental policy. It is thereby assumed that environmental policy is a major causing factor of flows of embodied CO_2. To test its influence econometrically is however hardly possible due to a lack of comparable quantitative data. Environmental policy can be implemented using a wide variety of strategies. An often discussed abatement policy instrument are carbon taxes. Very few countries have, however, implemented such taxes which makes them a problematic option to proxy for a country's environmental policy.

5.1 Externalities: Property Rights or Taxes?

Economists tend to understand environmental problems as a form of market failure. The market does not work efficiently in allocating the given resources because some consumption or production processes do not enter all the affected parties' utility or cost functions. What this previous statement frames in a rather technical way is the concept of external effects. Following Perman et al. (2003) an externality can be defined as follows:

> An external effect [...] is said to occur when the production or consumption decisions of one agent have an impact on the utility or profit of another agent in an unintended way, and when no compensation/payment is made by the generator of the impact to the affected party (Perman et al., 2003, p.134).

Figure 5.1 depicts the typical case of a production externality. We have the partial market equilibrium for a single good with a negative sloping demand and a positive sloping supply curve which form an equilibrium price P_M and quantity Q_M. This standard scenario is

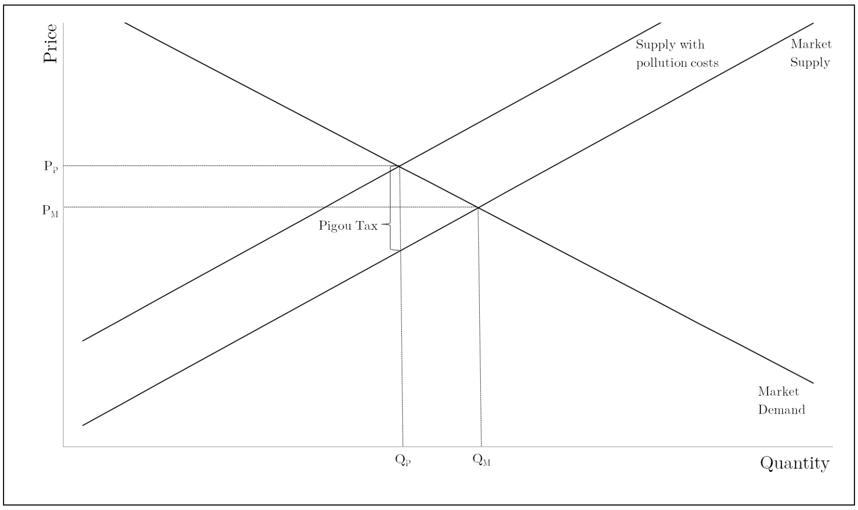

Figure 5.1: Market equilibrium for a good that produces pollution

extended by introducing pollution costs. During the production of this good some amount of pollution is emitted. This pollution is not priced and therefore is not reflected in the market supply curve of the firm. Incorporating the social cost of pollution in the firm's production costs would shift the supply curve up, i.e. would increase the marginal costs for producers. This would then lead to a new equilibrium with price P_P (higher than in the free market scenario) and quantity Q_P (lower). In other words, by just letting the market work too much of this good is produced and sold at a price too low, in contrast to the situation where we account for all costs involved in production (private and social costs).

In his famous article "The Problem of Social Cost", Ronald Coase (1960, p.2ff.) begins his discussion with a straightforward example of a farmer and a cattle-raiser, operating on neighboring properties. The straying cattle destroys a part of the farmer's crops. The cattle-raiser therefore exerts an externality on the farmer, as the destroyed crops are not reflected in the cattle-raiser's production costs. To internalize these costs, a legal obligation to compensate the farmer could be introduced for the cattle-raiser. Thereby the external effect would enter the cattle-raiser's cost function as well as the farmer's benefit function. In this scenario, the market would then again find the efficient price, with the externality extinguished.

What makes the situation in this example relatively easy to handle is the nature of the externality. Coase assumes that an additional cattle is associated with a known value of crop loss. This means that the value of social cost can be exactly determined and handled. In many environmental problems it is typically the case that we cannot rationally evaluate the social costs of some production process. Even if we assumed that external costs can be estimated, for some production activities they could not be handled, i.e. these activities would become uneconomical. Think of atomic power plants: If we would internalize the cost of a nuclear disaster by using the probability of its occurance, atomic energy would have a hard time becoming marketable. The same problem of evaluating the social costs is present with the emissions of CO_2. The multitude of current and future effects of the anthropogenic climate change would have to be priced which seems impossible.

In addition to problems with estimating the true social costs of environmental effects, the emissions of CO_2 are a special form of externalities in yet another way: They represent what is called a "pure public bad". This denomination refers to the idea of public goods with the feature that its production is not desireable as opposed to the production of public goods like security, infrastructure or education. The core characteristics of public goods are non-rivalry and non-excludablity (Perman et al., 2003, p.126). Non-rivalry means that consumption of one agent does not hinder another agent's consumption, non-excludability refers to the possibility of preventing one's consumption. The cattle-raiser/farmer problem is clearly not a problem of this form. It is easily possibly for the farmer to protect his fields from intrusion by the cattle-raisers animals by erecting a fence. And consumption of the soil is clearly rival between the economic activities of growing crops and using it as animal feed. Contrary to this example, the "consumption" of CO_2 emissions fulfills both of these conditions: The rising concentration of CO_2 in the atmosphere is "consumed" by all individuals to equal amounts and as we cannot escape the earth's atmosphere permanently we cannot exclude ourself from this "consumption". Of course, in reality some people (societies) can protect themselves better from the consequences of climate change than others, which would imply that the condition of non-excludability is not fulfilled for all people (societies) to the same extent. These arguments have been examined in debates about climate vulnerability and climate justice (Sachs, 2009). As an example, it is obviously the case that economies very dependent on agriculture face higher uncertainty in their production due to an increase of weather extremes. Adaptation costs for these societies (to exclude themselves from the "consumption" of the consequences of climate change) are higher (Adger, 2001, p.925ff.). Notwithstanding these arguments, it is true that, on a general level, all people are affected by climate change and that the effect on one person is not lessened by the effect on other persons.

What made Coase's abovementioned article famous was his idea that the attribution of property rights can eliminate externalities without the state getting fiscally involved. This solution to the externality problem can, however, only work in very limited scenarios. Whenever a large number of persons, or interested parties, are involved negotiation becomes either very difficult or even infeasible (Perman et al., 2003, p.139). Whenever pollution takes the form of a public bad, as in the CO_2 case, well-defined property rights for the atmosphere will not solve the problem. As noone can be excluded from breathing the atmospheric air and suffering (at least some of) the consequences of climate change, people will try to "free-ride", they benefit from the measures undertaken by others but do not bear any of the costs themselves. If everyone behaves like this, no climate policies will be employed. The Coase theorem can therefore be ruled out for the internalization of externalitites like carbon dioxide emissions.

The alternative, and in fact the older solution is depicted in figure 5.1, where we can see one of the most popular ways of (theoretically) dealing with external effects: the Pigou tax. It again assumes that we can evaluate the social cost of the production activity. Instead of a direct transfer between the generator and the victim of the externality as in the cattle-raiser versus farmer example, the state comes in and levies a tax exactly as high as the external costs. This seems more appropriate for complex situations with many involved interests. Without transaction costs and bureaucratic inefficiencies this would be an efficient way of reaching a societal environmental goal, e.g. reducing the production of a heavily polluting good and redistributing income to those damaged by its production. This also clarifies the underlying way of thinking that economists usually pursue with externalities: It is not a concept dealing with *normative* issues such as injustice nor does it in itself deal with distributional issues (at least in the way Coase interpreted it), externalities are seen in a *positive* fashion as causing an inefficient market outcome. Inefficiency here means that the basic principle of Pareto-optimality is not fulfilled: It is possible to make at least one person better off without making anyone else worse off. Distributional goals are assumed to be pursued via lump-sum redistributions. The following models all incorporate Pigouvian taxes to internalize the external effects.

5.2 One-World-Scenario: Government by a Supranational Authority

The One-World-Scenario will serve as a useful benchmark for results derived under different conditions. We derive the Pigouvian tax from optimizing behaviour of firms and consumers and checks efficiency conditions. The main features of this scenario are that the whole world is assumed to be one political territory and that this territory is subject to taxation from a common authority. In other words, the one-world-scenario could be considered a case where there exists a supranational taxation authority to which all countries must obey.

The following basic general equilibrium model with externalities is largely drawn from Baumol and Oates (1988, p.36ff.), although I present a less general version here by stripping down the economy to only two consumers, two producers and two goods. The major results derived from this model, however, all carry over to the many-consumers-producers-goods case. The agents in this economy act as price takers, meaning no consumer and no producer has enough power to influence the market price. This assumption usually is associated with perfect competition, where there is a large number of consumers and firms on the market. By only using two agents on each side of the market and restraining them to a as-if-perfect-competition behavior, the model becomes more accessible. As we later use a two-country scenario, we already introduce here a high-income country h and a middle-income country m. In each of these countries we have one consumer and one producer which can be thought of as being representative for the respective group. For the sake of our One-World-Scenario we assume however a common government of these two territories and we also assume that there are no tariffs, quotas and the like in place.

The interpretation of general equilibrium models has to bear in mind that these models are based on a very restrictive set of assumptions. This warning, in the following paragraph formulated by Stiglitz and Charlton (2005), cannot be overemphasized, as experience with discussions on trade policy suggest.

> *The results of general equilibrium models are sensitive to their assumptions.* Much of the analysis of the impacts (including, for instance, judgements about whether particular types of agricultural subsidies are trade-distorting) relies on a particular model of the economy, the neo-classical model, which assumes full employment of resources, perfect competition, perfect information, and well-functioning markets, assumptions which are of questionable validitiy for any country, but which are particularly problematic for developing countries (Stiglitz and Charlton, 2005, p.69, original emphasis).

Let us introduce the following notation:

x_{ij} ... amount of good i consumed by individual j (i=1,2) (j=h,m)
y_{ik} ... amount of good i produced by firm k (k=h,m)
r_i ... resource endowment of good i
z_k ... amount of emissions by firm k
Z ... total emission level (Z=$\sum_{k=h}^{m} z_k$)

Each individual follows a utility function of the following form:

$$\begin{aligned} U^h &= U^h(x_{1h}, x_{2h}, Z) = u(x_{1h}, x_{2h}) - \eta Z \\ U^m &= U^m(x_{1m}, x_{2m}, Z) = u(x_{1m}, x_{2m}) - \eta Z \end{aligned} \tag{5.1}$$

$$\frac{\partial U^j}{\partial x_{ij}} > 0, \qquad \frac{\partial U^j}{\partial Z} = -\eta < 0 \qquad \text{(for all i,j)} \tag{5.2}$$

Both individuals derive utility from their consumption of the two goods and both of them lose utility with an increase in the overall emission level. Note that we consider here only positive values of consumption, i.e. $x_{ij} \geq 0$. This utility function represents the existence of an "undepleteable" externality, which "in fact exhibits two types of market failure at the same time: the external effect itself, and a public good (or bad) character" (Verhoef, 1999, p.201). $\eta > 0$ is the parameter that defines the strength of the negative effect of emissions on individual utility.

The two firms in our model economy produce with production sets of the following form:

$$\begin{aligned} F^h &= F^h(y_{1h}, y_{2h}, z_h, Z) = 0 \\ F^m &= F^m(y_{1m}, y_{2m}, z_m, Z) = 0 \end{aligned} \tag{5.3}$$

For the moment, we stick to this general formulation, which allows the firm emission level z_k to vary independently of production levels y_{1k} and y_{2k}. Moreover, it also captures the case where production activities of our two firms can be affected by the general emission level Z. Later on starting in subsection 5.3, we will return to these questions and assume a stricter framework. The quantities of y_{1k} and y_{2k} are to be interpreted as net outputs. This follows from the sign convention that outputs are measured by positive values and inputs are measured by negative values. As an example, take a production set $F^h(10, -5, 20, 50)$: Good 1 is a net output of this firm with 10 units whereas good 2 is a net input with 5 units. This firm emits 20 units of the externality, e.g. CO_2, and is affected by the overall emission level of 50.

Efficiency

We are now interested in an efficient framework for taxing an externality. Therefore we first have to look at the efficiency conditions for an economy with an externality and then compare this situation with the market outcome with and without a Pigouvian tax. For a situation to be Pareto-efficient, one consumer's utility must be maximized given all other consumers' utility levels stay at least constant. Furthermore we also have to take into account the production and resource constraints (Baumol and Oates, 1988, p.38). The following maximization problem emerges:

$$\begin{aligned} &\max U^h(x_{1h}, x_{2h}, Z) \\ &\text{subject to} \\ &U^m(x_{1m}, x_{2m}, Z) = U^{*m} \\ &F^h(y_{1h}, y_{2h}, z_h, Z) = 0 \\ &F^m(y_{1m}, y_{2m}, z_m, Z) = 0 \\ &x_{1h} + x_{1m} - y_{1h} - y_{1m} = r_1 \\ &x_{2h} + x_{2m} - y_{2h} - y_{2m} = r_2 \end{aligned}$$

Consumer h's utility is to be maximized, holding fixed an arbitrary utility level U^{*m} of consumer m. We also take into account the resource constraint, saying that total consumption must equal total production plus the available resources. The maximization problem can be formulated using a Lagrangian.[1]

$$\begin{aligned} L = {} & \lambda_h[U^h(x_{1h}, x_{2h}, Z) - U^{*h}] + \lambda_m[U^m(x_{1m}, x_{2m}, Z) - U^{*m}] \\ & - \mu_h[F^h(y_{1h}, y_{2h}, z_h, Z)] - \mu_m[F^m(y_{1m}, y_{2m}, z_m, Z)] \\ & + \omega_1[r_1 - x_{1h} - x_{1m} + y_{1h} + y_{1m}] + \omega_2[r_2 - x_{2h} - x_{2m} + y_{2h} + y_{2m}] \end{aligned} \tag{5.4}$$

The following set of first-order conditions emerges.[2]

Consumption efficiency:

$$\frac{\partial L}{\partial x_{1h}} = \lambda_h U_1^h - \omega_1 = 0 \tag{5.5}$$

$$\frac{\partial L}{\partial x_{2h}} = \lambda_h U_2^h - \omega_2 = 0 \tag{5.6}$$

$$\frac{\partial L}{\partial x_{1m}} = \lambda_m U_1^m - \omega_1 = 0 \tag{5.7}$$

$$\frac{\partial L}{\partial x_{2m}} = \lambda_m U_2^m - \omega_2 = 0 \tag{5.8}$$

Production efficiency:

$$\frac{\partial L}{\partial y_{1h}} = -\mu_h F_1^h + \omega_1 = 0 \tag{5.9}$$

$$\frac{\partial L}{\partial y_{2h}} = -\mu_h F_2^h + \omega_2 = 0 \tag{5.10}$$

$$\frac{\partial L}{\partial y_{1m}} = -\mu_m F_1^m + \omega_1 = 0 \tag{5.11}$$

$$\frac{\partial L}{\partial y_{2m}} = -\mu_m F_2^m + \omega_2 = 0 \tag{5.12}$$

Emission efficiency:

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[1] Just setting $\lambda_1 = 1$ and $U^{*h} = 0$ gives us the usual formulation of Lagrangian problems. The formulation here is more clear with regard to the emerging shadow prices.

[2] A note to the notation for first derivatives: $U_1^h = \frac{\partial U^h}{\partial x_{1h}}$, $U_2^m = \frac{\partial U^m}{\partial x_{2m}}$, and so on. Similarly for the production side: $F_1^h = \frac{\partial F^h}{\partial y_{1h}}$, and so on.

$$\frac{\partial L}{\partial z_h} = -\mu_h F_z^h + \lambda_h U_Z^h + \lambda_m U_Z^m - \mu_h F_Z^h - \mu_m F_Z^m = 0 \tag{5.13}$$

$$\frac{\partial L}{\partial z_m} = -\mu_m F_z^m + \lambda_h U_Z^h + \lambda_m U_Z^m - \mu_h F_Z^h - \mu_m F_Z^m = 0 \tag{5.14}$$

Combining equations 5.5 to 5.8 yields

$$\frac{U_1^h}{U_2^h} = \frac{\omega_1}{\omega_2}$$
$$\frac{U_1^m}{U_2^m} = \frac{\omega_1}{\omega_2}.$$

where $\frac{U_1^h}{U_2^h}$ is the marginal rate of substitution (MRS) between goods 1 and 2 for consumer h. We arrive at the following familiar consumption efficiency condition:

$$MRS_h = \frac{U_1^h}{U_2^h} = \frac{U_1^m}{U_2^m} = MRS_m \tag{5.15}$$

Similarly, on the production side we can combine equations 5.9 to 5.12 to arrive at

$$\frac{F_1^h}{F_2^h} = \frac{\omega_1}{\omega_2}$$
$$\frac{F_1^m}{F_2^m} = \frac{\omega_1}{\omega_2}.$$

where $\frac{F_1^h}{F_2^h}$ is the marginal rate of transformation (MRT) between goods 1 and 2 for firm h. This yields the familiar production efficiency condition:

$$MRT_h = \frac{F_1^h}{F_2^h} = \frac{F_1^m}{F_2^m} = MRT_m \tag{5.16}$$

Market behavior

We have now found a set of conditions to be fulfilled if we are to achieve an efficient market outcome. In a next step we will study the market behavior of individuals and firms. Therefore, in line with Baumol and Oates (1988), we assume that consumers minimize their expenditure function and firms maximize their profit functions. In order to allow for the internalization of the externality, we also introduce a set of compensatory taxes on individuals and firms and a price for the emission of CO_2. While the price for the emission of CO_2 is constant per unit of emissions (t_e), the compensatory taxes are varying with respect to the individual valuations of each consumer (t^j) and each firm (t^k).

Expenditure minimization by consumers:[3]

$$\begin{aligned} &\min\ p_1x_{1j} + p_2x_{2j} + t^j \\ &\text{subject to } U^j(x_{1j}, x_{2j}, Z) = U^{*j} \end{aligned}$$

$$\begin{aligned} L^h &= p_1x_{1h} + p_2x_{2h} + t^h + \alpha_h[U^{*h} - U^h(x_{1h}, x_{2h}, Z)] \\ L^m &= p_1x_{1m} + p_2x_{2m} + t^m + \alpha_m[U^{*m} - U^m(x_{1m}, x_{2m}, Z)] \end{aligned} \tag{5.17}$$

$$\frac{\partial L^h}{\partial x_{1h}} = p_1 - \alpha_h U_1^h + t_1^h = 0 \tag{5.18}$$

$$\frac{\partial L^h}{\partial x_{2h}} = p_2 - \alpha_h U_2^h + t_2^h = 0 \tag{5.19}$$

$$\frac{\partial L^m}{\partial x_{1m}} = p_1 - \alpha_m U_1^m + t_1^m = 0 \tag{5.20}$$

$$\frac{\partial L^m}{\partial x_{2m}} = p_2 - \alpha_m U_2^m + t_2^m = 0 \tag{5.21}$$

Profit maximization by firms:[4]

$$\begin{aligned} &\max\ p_1y_{1k} + p_2y_{2k} - t_z z_k - t^k \\ &\text{subject to } F^k(y_{1k}, y_{2k}, z_k, Z) = 0 \end{aligned}$$

$$\begin{aligned} L^h &= p_1y_{1h} + p_2y_{2h} - t_z z_h - t^h - \beta_h[F^h(y_{1h}, y_{2h}, z_h, Z)] \\ L^m &= p_1y_{1m} + p_2y_{2m} - t_z z_m - t^m - \beta_m[F^m(y_{1m}, y_{2m}, z_m, Z)] \end{aligned} \tag{5.22}$$

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[3] Recall that $t_i^j = \frac{\partial t^j}{\partial x_{ij}}$

[4] Recall that $t_i^k = \frac{\partial t^k}{\partial y_{ik}}$

$$\frac{\partial L^h}{\partial y_{1h}} = p_1 - \beta_h F_1^h - t_1^h = 0 \tag{5.23}$$

$$\frac{\partial L^h}{\partial y_{2h}} = p_2 - \beta_h F_2^h - t_2^h = 0 \tag{5.24}$$

$$\frac{\partial L^h}{\partial e_h} = -\beta_h F_z^h - t_z = 0 \tag{5.25}$$

$$\frac{\partial L^m}{\partial y_{1m}} = p_1 - \beta_m F_1^m - t_1^m = 0 \tag{5.26}$$

$$\frac{\partial L^m}{\partial y_{2m}} = p_2 - \beta_m F_2^m - t_2^m = 0 \tag{5.27}$$

$$\frac{\partial L^m}{\partial e_m} = -\beta_m F_z^m - t_z = 0 \tag{5.28}$$

Now, we want to reformulate these first-order conditions to get results comparable to the efficiency conditions 5.15 and 5.16.

Combining equations 5.18 to 5.21 yields:

$$\frac{\alpha_h U_1^h - t_1^h}{\alpha_h U_2^h - t_2^h} = \frac{p_1}{p_2} \tag{5.29}$$

$$\frac{\alpha_m U_1^m - t_1^m}{\alpha_m U_2^m - t_2^m} = \frac{p_1}{p_2} \tag{5.30}$$

Similarly, on the production side we can combine equations 5.23 to 5.24 and equations 5.26 to 5.27 to arrive at:

$$\frac{\beta_h F_1^h - t_1^h}{\beta_h F_2^h - t_2^h} = \frac{p_1}{p_2} \tag{5.31}$$

$$\frac{\beta_m F_1^m - t_1^m}{\beta_m F_2^m - t_2^m} = \frac{p_1}{p_2} \tag{5.32}$$

As a first step, we can see that our conditions 5.15 and 5.16 are not fulfilled by the optimizing behavior of the model agents, i.e. the market outcome of our model does not equalize the marginal rate of substitution between goods 1 and 2 for both consumers and it does also not equalize the marginal rate of transformation between the two goods for both firms. In order to fulfill this condition, it is necessary to drop compensatory taxes for consumers and firms ($t^j = t^k = 0$). As a consequence, the marginal rates of substitution for h and m will be equal to the relative price of good 1 and equal to each other. The same is true for the marginal rates of transformation. Expressed formally:

$$\frac{U_1^h}{U_2^h} = \frac{U_1^m}{U_2^m} = \frac{F_1^h}{F_2^h} = \frac{F_1^m}{F_2^m} = \frac{p_1}{p_2} \tag{5.33}$$

Recall that this result only implies that for efficiency reasons we should not use compensatory taxes, however we still have to analyse the efficient level for our Pigouvian emission tax t_e. In order for the tax level to be efficient we need equation 5.25 to be identical to equation 5.13. The same needs to be true for equations 5.28 and 5.14. Suppose a central planner declares the (shadow) prices in this economy to be $p_1 = \omega_1$, $p_2 = \omega_2$, $\alpha_h = \lambda_h$, $\alpha_m = \lambda_m$, $\beta_h = \mu_h$, $\beta_m = \mu_m$. This allows us to arrive at the following efficient emission tax rate:

$$t_z = \mu_h F_Z^h + \mu_m F_Z^m - \lambda_h U_Z^h - \lambda_m U_Z^m \tag{5.34}$$

The interpretation of this emission tax is straightforward: It is the sum of the marginal emission damages suffered by firms and consumers. In our model with two individuals and two firms, this gives four terms.

Baumol and Oates (1988, p.43f.) show that dropping compensatory taxes, setting the emission tax according to equation 5.34 and the assumptions on the (shadow) prices are necessary conditions for an market equilibrium that fulfills Pareto-efficiency in a perfect competition environment.

As stated in the introduction to this subsection, the One-World-Scenario is an unrealistic benchmark case. However, it clearly derives the result that each unit of CO_2 emitted in a country's firms should be taxed with the sum of its marginal damages.

5.3 Emissions with Transboundary Effects: The Jakob/Marschinski/Hübler model

As the emergence of a supranational authority to regulate international emissions is not to be expected soon, the solution presented in the previous section, a simple Pigouvian tax internalizing the marginal damage to all affected parties, is necessarily unsatisfying. In reality, government authority ends at country borders, however, a fully rational consumer will not distinguish between where the emissions of carbon dioxide occur as it is the global atmospheric concentration of greenhouse gases that causes climate change. Therefore we want to have a model of trade where CO_2 emissions are a transboundary externality in order to study the policy tools necessary to internalize these external effects. Using the model of Jakob et al. (2013), I will consider only unilateral policies, that is, my approach will not be concerned with how the trading partners react to the setting of unilateral environmental policies.

This may seem very problematic at first, considering the low international willingness to enter large-scale climate commitments unilateral measures may still be the biggest hope for progress. Burniaux et al. write that the 2009 climate change conference in Copenhagen "confirmed that global climate policy action [...] will likely be built out of a collection of fragmented domestic commitments" (Burniaux et al., 2013, p.2231). In addition, it is also reasonable to assume that in the short run the analysis of unilateral abatement policies may be more relevant than a game theory style analysis of long-run policy equilibrium.

While currently these country-by-country policies seem to be the only politically feasible measures, there is "growing concern that such unilateral reductions could foster 'carbon leakage' and undermine the international competitiveness of domestic industries" (Burniaux et al., 2013, p.2232). This is one of the major motivations for pursuing strategies of consumer responsibility (also referred to as the "destination principle"), where the emission taxes are to be levied where it is consumed (i.e. at the destination of a good). The Jakob/Marschinski/Hübler model allows us to not only study the efficiency of the resulting Pigouvian emission taxes, different outcomes under producer and consumer responsibility, we can also examine conditions for the occurance of carbon leakage.

5.3.1 The basic model

We have again two countries, h (high-income) and m (middle-income), we have representative consumers in each of these countries and both countries produce goods 1 and 2. We choose good one as a numeraire good, meaning that we set the price $p_1 = 1$. Hence, $p = \frac{p_2}{p_1} = p_2$ denotes the relative price of good 2 in terms of good 1. Individuals follow a utility function as defined in equation 5.1, $U^h = u(x_{1h}, x_{2h}) - \eta Z$. The supply side of the economy is modeled by a representation equivalent to equation 5.3 using a transformation function T^h:

$$y_{1h} = T^h(y_{2h}, z_h) = T^h(y_{2h}) \tag{5.35}$$

$$\frac{\partial T^h}{\partial y_{2h}} < 0, \qquad \frac{\partial T^h}{\partial^2 y_{2h}} < 0 \tag{5.36}$$

There are two things to note with regard to equation 5.35 compared to 5.3. First, we exclude the term Z, the overall pollution level, from the production relation. This is to model so-called "eyesore pollution". This type of pollution does only affect the utility functions but leaves production functions unaffected. "Eyesore pollution" is commonly assumed in the literature in this field (Markusen, 1975; Copeland and Taylor, 1995) and is, for the most part, also sensible regarding carbon dioxide emissions.[5] Second, we see the term z_h disappearing after the last equality sign. This is related to how pollution is modeled:

$$Z = z_h + z_m = \gamma_{1h} y_{1h} + \gamma_{2h} y_{2h} + \gamma_{1m} y_{1m} + \gamma_{2m} y_{2m} \tag{5.37}$$

This introduces the parameter γ_{ik} which denotes the emission intensity of the production of good i in firm k. In other words, γ_{ik} is sectoral firm emissions divided by sectoral firm output.[6] In this trade model, γ_{ik} is a fixed parameter, so we cannot model here how environmental policy induces technological change and leads to decreasing emission intensities. Instead, the firms' decision variables in a perfectly competitive framework are only the quantities they produce. With deciding the quantities, the level of firm emissions is already determined. Therefore, the firm emission level z_k can be dropped from the list of arguments in equation 5.35.

In accordance with Jakob et al. (2013), we also assume a particular pattern of trade without loss of generality: The high-income country h exports good 1 and imports good 2 from the middle-income country m, and vice versa as we are in a two-country world. Thereby we assume that for some unknown reason, h has a comparative advantage in the production of good 1, m in good 2. This can be seen equal to just observing a particular pattern of trade in reality, without asking where it came from in the first place. After all, we are interested in the optimal design of environmental regulation, assuming that no such regulation is yet in place. Country h faces the following balanced trade condition, where E stands for exports and M for imports:

$$E_{1h} - p^* M_{2h} = 0 \tag{5.38}$$

The balanced trade condition has the usual meaning: The value of exports and the value of imports of one country must coincide. A second equilibrium condition imposes market clearing:

$$\begin{aligned} x_{1h} &= y_{1h} - E_{1h} \\ x_{2h} &= y_{2h} + M_{2h} \end{aligned} \tag{5.39}$$

Total production in each sector is either used for consumption at home or traded in international markets.

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[5] We can, of course, argue that in sectors like agriculture the overall emission level and its consequences do adversely affect the output, via higher frequency of natural disasters for instance.

[6] As we use only one firm per country, this corresponds exactly to the country emission intensities used for the empirical part of this thesis, discussed in section 4.1.

An important additional assumption that Jakob et al. (2013) introduce regards market power: Country h can be thought of as being a large country with the possibility to manipulate the relative price of the traded goods, i.e. the terms of trade. Country m on the other hand does not have this possibility and faces the relative world market price p^*. Governments have often tried to pursue so-called terms-of-trade goals via environmental policy. As the rules of the WTO forbid direct manipulation of export or import prices for many goods, environmental taxes or other trade barriers can be used "as a second-best method" (Lapan and Sikdar, 2011, p.1) to influence the relative prices (terms-of-trade). The terms-of-trade argument is outlined in Stiglitz and Charlton (2005, p.222ff.) among others. In our model, the ability for country h to influence the world market price is described by a function G^h.

$$G^h = \frac{dp^*}{dM_{2h}} > 0 \tag{5.40}$$

This function expresses the relationship between import demand in the high-income country and the world price $p^*(M_{2h})$. Country h can strategically choose its import quantity of good 2 and - as it is large enough - it thereby affects the world relative price. This change in the relative world price will induce a shift in the production of the middle-income country m towards its export good 2.

To determine the efficiency conditions for the policy in h we assume that a social planner maximizes the welfare function W^h of the high-income country which - in this case - corresponds to the utility maximization for the representative consumer in h. Using equations 5.35 and 5.37 to 5.40, the maximization problem for the social planner can be expressed as follows:

$$\begin{aligned}\max W^h = U^h &= u(x_{1h}, x_{2h}) - \eta Z = \\ &= u(T^h(y_{2h}) - p^*(M_{2h})M_{2h}, y_{2h} + M_{2h}) - \\ &- \eta[\gamma_{1h}T^h(y_{2h}) + \gamma_{2h}y_{2h} + \gamma_{1m}T^m(y_{2m}(p^*(M_{2h}))) + \gamma_{2m}y_{2m}(p^*(M_{2h}))]\end{aligned}$$

We have now a welfare function that only depends on the variables y_{2h}, the high-income country's production in sector 2, and M_{2h}, its imports from the middle-income country in this sector. The resulting first-order conditions are as follows:[7]

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[7] Recall that $U_1^h = \frac{\partial U^h}{\partial x_{1h}}$ and $T_2^h = \frac{\partial T^h}{\partial y_{2h}}$. Please note as well the derivation of the utility function $U^h = u(x_{1h}, x_{2h}) - \eta Z$ with respect to the production of good 2: $\frac{\partial U^h}{\partial y_{2h}} = \frac{\partial U^h}{\partial u}\frac{\partial u}{\partial x_{1h}}\frac{\partial x_{1h}}{\partial y_{2h}}$, where the last partial derivative $\frac{\partial x_{1h}}{\partial y_{2h}}$ is equal to T_2^h, due to the fact that $x_{1h} = T^h(y_{2h}) - p^*(M_{2h})M_{2h}$.

$$
\begin{aligned}
\frac{\partial W^h}{\partial y_{2h}} =& U_1^h T_2^h + U_2^h - \eta(\gamma_{1h} T_2^h + \gamma_{2h}) \overset{!}{=} 0 \\
\Longleftrightarrow & \; U_1^h T_2^h + U_2^h = \eta(\gamma_{1h} T_2^h + \gamma_{2h})
\end{aligned} \tag{5.41}
$$

$$
\begin{aligned}
\frac{\partial W^h}{\partial M_{2h}} =& - U_1^h(p^* + G^h M_{2h}) + U_2^h - \eta R^m G^h(\gamma_{1m} T_2^m + \gamma_{2m}) \overset{!}{=} 0 \\
\Longleftrightarrow & \; - U_1^h(p^* + G^h M_{2h}) + U_2^h = \eta R^m G^h(\gamma_{1m} T_2^m + \gamma_{2m})
\end{aligned} \tag{5.42}
$$

These two maximizing conditions for the welfare in the high-income countries will provide the basis for the social planner's policy tools for internalizing the emissions. Equation 5.41 states country h's domestic trade-off between marginal utility and marginal pollution from an additional unit of y_{2h}. From equation 5.36 we know that $T_2^h < 0$ and from 5.2 we know that $U_i^h > 0$ for both goods. Therefore, assuming an increase (decrease) in y_{2h}, the lefthand side of 5.41 measures the decreasing (increasing) utility from consumption of good 1 and the increasing (decreasing) utility from consumption of good 2. This net change of utility must be equal to the valuation of the net change of pollution on the righthand side. Pollution from production of good 1 decreases (increases), while the corresponding pollution from good 2 increases (decreases).

Equation 5.42 states country h's trade-off between marginal utility from importing an additional unit of M_{2h} and marginal pollution from the shift in country m's production structure. Assuming an increase (decrease) in M_{2h}, the lefthand side sums up the increase (decrease) in utility from consuming an additional unit of imported good 2 and the decrease (increase) from consuming less of good 1, where the terms-of-trade effect is taken into account via the expression in brackets. On the righthand side we encounter a new term, R^m, which captures the effect of a change in the relative world price on production of good 2 in the middle-income country m. We will return later in more detail to this term. As for the interpretation of the righthand side of equation 5.42, we have a decrease (increase) in pollution from production of good 1 in country m, and an increase (decrease) from production of good 2.

In addition, we want to introduce the optimizing behavior of consumers and firms with respect to the prevailing market prices. Optimization by consumers minimizes the cost function given a certain utility level, i.e. the Lagrangian $L = x_{1h} + qx_{2h} + \alpha[U^{*h} - U^h(x_{1h}, x_{2h}, Z)]$, where q is the consumer price:

$$\begin{aligned}\frac{\partial L}{\partial x_{1h}} &= 1 - \alpha U_1^h \overset{!}{=} 0\\ \frac{\partial L}{\partial x_{2h}} &= q - \alpha U_2^h \overset{!}{=} 0\\ \Longrightarrow q &= \frac{U_2^h}{U_1^h} = MRS_h \qquad (5.43)\end{aligned}$$

As the transformation functions T^h and T^m already only give points on the production possibility frontier, the decision on the production quantity of one good determines the optimal production of the other good as well. Optimizing behavior by producers maximizes the function $\pi = y_{1h} + py_{2h} = T^h(y_{2h}) + py_{2h}$:

$$\begin{aligned}\frac{\partial \pi}{\partial y_{2h}} &= T_2^h + p \overset{!}{=} 0\\ \Longleftrightarrow p &= -T_2^h = MRT_h\\ \text{equivalently: } p^* &= -T_2^m = MRT_m\end{aligned} \qquad (5.44)$$

With this result, we can now further investigate the effect of a change in the relative world price on production of good 2 in the middle-income country m, an effect captured by the function R^m, introduced above. By totally differentiating the equation for the relative world price in 5.44 we get:

$$\frac{dp^*}{dy_{2m}} = -\frac{dT_2^m}{dy_{2m}} = -T_{2,2}^m \qquad \Longleftrightarrow \qquad \frac{dy_{2m}}{dp^*} = -\frac{1}{T_{2,2}^m} = R^m > 0 \qquad (5.45)$$

Dividing equations 5.41 and 5.42, our first-order conditions from the social planner's welfare maximization problem, by U_1^h and introducing the agents' optimizing behavior from equations 5.43 and 5.44 yields the following results:

$$q - p = -t_z(\gamma_{2h} - p\gamma_{1h}) \qquad = \tau^o \qquad (5.46)$$

$$q - p^* = -t_z R^m G^h(\gamma_{2m} - p^*\gamma_{1m}) + G^h M_{2h} \qquad = \theta^o \qquad (5.47)$$

The price $t_z = \frac{U_Z^h}{U_1^h} = -\frac{\eta}{U_1^h} < 0$ is the marginal rate of substitution between "consumption" of the externality (CO_2 emissions) and consumption of the numeraire good 1. It can thus be interpreted as a price for carbon emissions, with t_z giving the decrease in marginal utility from the emissions in terms of good 1.[8]

What do equations 5.46 and 5.47 tell us? There is a price differential between the producer price p and the consumer price q, that is, the prices to which producers and consumers align their optimization. Where does this price differential come from? In equation 5.46 it captures the fact that emissions do only enter the consumer's utility but not the firms profit function. The righthand side of this equation multiplies the change in the high-income country's emissions due to an increase in the production of good 2 with the emission price t_z. Jakob et al. suggest using this value to close the price differential by taxing the production of sector 2 with τ^o, the optimal emission tax.

The price differential in equation 5.47 again results from emissions not entering all agents' optimization problems. Producers in the middle-income country do not take into account the "utility cost" of their production activities for consumers in the high-income country. The first term on the righthand side of 5.47 captures the change of the middle-income country's emissions as valuated by consumers of the high-income country. The change of emissions in brackets is corrected for the effect of country h's imports on country m's production of good 2.[9] The second term on the righthand side measures the terms-of-trade effect, i.e. the effect of country h's strategic trade policy on the price of its imports. Following Jakob et al., equation 5.47 can be considered the optimal emission tariff (θ^o) on imports of good 2.

Equations 5.46 and 5.47 are efficiency conditions in the presence of an externality. In order to be efficient, a market needs to equalize producers' marginal rate of transformation and consumers' marginal rate of substitution, a result we derived in subsection 5.2, particularly in equation 5.33. From the agents' optimization we know that consumers align their MRS to the consumer price q and that firms align their MRT to the producer price p (in case of the producers in country m this is the world market price p^*). Optimality shows that consumer and producer prices (net of taxes) must not be equal.

The emission price t_z represents the social cost of an additional unit of pollution from the production of good 2 in terms of good 1 (because we use relative prices). To determine the sign of the wedge between consumer and producer prices, i.e. to determine if the social planner should install taxes or subsidies, we need to know emission intensities in monetary terms ($\frac{\gamma_{1h}}{p_1} = \gamma_{1h}$ for sector 1 and $\frac{\gamma_{2h}}{p_2} = \frac{\gamma_{2h}}{p}$ for sector 2). Then, analysing equations 5.46 and 5.47, we can state the following:

---

[8] Just imagine a hyptothetical situation where a consumption tax t_z for each unit of emissions Z is introduced. The consumer's maximization problem becomes $L = x_{1h} + qx_{2h} + t_z Z + \alpha[U^{*h} - U^h(x_{1h}, x_{2h}, Z)]$, the corresponding first-order condition is $\frac{\partial L}{\partial Z} = t_z - \alpha U^h_Z \overset{!}{=} 0$. Combine this with the first-order condition $\frac{\partial L}{\partial x_{1h}}$ from 5.43 to arrive at $t_z = \frac{U^h_Z}{U^h_1}$.

[9] The term $R^m G^h$ measures this change: $\frac{dy_{2m}}{dp^*}\frac{dp^*}{dM_{2h}} = \frac{dy_{2m}}{dM_{2h}}$

$$\begin{aligned}\gamma_{1h} &< \frac{\gamma_{2h}}{p} \implies \tau^o > 0 \\ \gamma_{1h} &> \frac{\gamma_{2h}}{p} \implies \tau^o < 0\end{aligned}$$

$$\begin{aligned}\gamma_{1m} &< \frac{\gamma_{2m}}{p} \implies \theta^o > 0 \\ \gamma_{1m} &> \frac{\gamma_{2m}}{p} \implies \theta^o - G^h M_{2h} < 0\end{aligned}$$

If the emission intensity of good 2 in the high-income country h is higher than that of good 1, then an increase in the production of good 2 will increase emissions and therefore decrease utility (or increase social cost), leading to a positive overall intake from emission taxation. If the relation between emission intensities is the other way round, an increase in the production of good 2 will decrease emissions and therefore increase utility (decrease social cost), leading to a negative overall intake.

The picture is similar, albeit slightly different, for the optimal tariff. If good 2 has a higher emission intensity than good 1 in the middle-income country, the import of an additional unit of good 2 will increase emissions, decrease utility, making the overall intake from the optimal tariff positive. Why do we compare γ_{1m} and γ_{2m} for the middle-income country in order to decide on the optimal tariff for the high-income country? At first, it might seem more straightforward to compare imported products with locally produced products, i.e. γ_{2m} and γ_{2h}. However, balanced trade requires exports to rise in concordance with imports. Therefore, importing an additional unit of good 2 increases emissions by $R^m G^h \gamma_{2m}$ and decreases them by $R^m G^h p^* \gamma_{1m}$. The net effect plus the terms-of-trade effect $G^h M_{2h} > 0$ then determines the optimal tariff. If good 1's emission intensity is higher than that of good 2 in country m, we cannot exactly determine the sign of the optimal tariff without knowing the exact size of the terms-of-trade effect. It is possible that the optimal tariff becomes negative in this scenario.

5.3.2 Emission Targets for Firms

We are now interested in the effects of government policy and the efficiency of the resulting taxes and tariffs. The government of each country can clearly not tax citizens and firms of the other country. In the recent decades, the predominant mechanism of the fight against climate change was a country-for-country regulation of domestic CO_2 (industrial) emissions. “Under current Kyoto Protocol accounting rules, responsibility for emissions is assigned according to the production-based principle” (Chang, 2013, p.850). Let us suppose that an emission target $\overline{z}^{h,prod}$ for the domestic firms in country h is determined by the government, leading to a pollution constraint for local firms:

$$\gamma_{1h}y_{1h} + \gamma_{2h}y_{2h} \leq \overline{z}^{h,prod} \tag{5.48}$$

We know that optimizing agents will exhaust pollution possibilities, so that the condition becomes a strict equality. Inserting this emission target into the social planner's maximization problem yields the following Lagrangian:

$$\begin{aligned}
\max \overline{W}^{h,prod} &= U^h = u(x_{1h}, x_{2h}) - \eta Z \qquad \text{subject to 5.48} \\
L^{h,prod} &= u(T^h(y_{2h}) - p^* M_{2h}, y_{2h} + M_{2h}) - \\
&- \eta[\overline{z}^{h,prod} + \gamma_{1m}T^m(y_{2m}(p^*)) + \gamma_{2m}y_{2m}(p^*)] + \\
&+ \mu[\overline{z}^{h,prod} - \gamma_{1h}T^h(y_{2h}) - \gamma_{2h}y_{2h}]
\end{aligned}$$

In comparison to the maximization problem of the social planner in subsection 5.3.1, with unconstrained emissions, the market power of country h is not taken into account by the economic agents. By determining an emission target before solving the optimization problem, the government implicitly determines the carbon tax rate (the normalized Lagrange multiplier $\nu(\overline{z}^{h,prod}) = \frac{\mu(\overline{z}^{h,prod})}{U_1^h}$). And although consumers and producers do not explicitly consider it, their demand via imports still influences the relative world price $p^*(\overline{z}^{h,prod})$. The first-order conditions from this maximization problem are:

$$\begin{aligned}
\frac{\partial L^{h,prod}}{\partial y_{2h}} =& U_1^h T_2^h + U_2^h - \mu(\gamma_{1h}T_2^h + \gamma_{2h}) \overset{!}{=} 0 \\
&\Longleftrightarrow U_1^h T_2^h + U_2^h = \mu(\gamma_{1h}T_2^h + \gamma_{2h})
\end{aligned} \tag{5.49}$$

$$\frac{\partial L^{h,prod}}{\partial M_{2h}} = - U_1^h p^* + U_2^h \overset{!}{=} 0 \tag{5.50}$$

Dividing equations 5.49 and 5.50 by U_1^h and introducing the agents' optimizing behavior from equations 5.43 and 5.44 yields emission tax and tariff for production targeting:

$$q - p = \nu(\gamma_{2h} - p\gamma_{1h}) \qquad = \tau^{prod} \tag{5.51}$$

$$q - p^* = 0 \qquad = \theta^{prod} \tag{5.52}$$

Here, $\nu = \frac{\mu}{U_1^h}$. If the carbon tax ν is set equal to the social cost of pollution (carbon price) t_z by an optimizing government, equation 5.51 is equal to 5.46, meaning the carbon tax on local producers is optimal, $\tau^{prod} = \tau^o$. Pollution in the high-income country is successfully internalized by this policy. The same is not true for pollution in the middle-income country, as country h' emission limit is only concerned with domestic emissions. The effect of the imported goods on the overall emission level Z is not part of the environmental regulation. A tariff of zero is not optimal for the high-income country (except under very special circumstances) as comparison between equations 5.52 and 5.47 clearly points out. $\theta^{prod} \neq \theta^o$.

5.3.3 Emission Targets for Consumers

The previous subsection showed that Kyoto-style, pure producer responsibility accounting does not lead to a welfare optimal internalization of CO_2 emissions. As discussed in the literature review of this thesis, a competing notion of emission accounting is consumer responsibility. Rather than summing up the emissions generated by a country's firms, it adds up the emissions indirectly generated by consumers via the consumption of goods from different origins. The government's emission target $\overline{z}^{h,cons}$ for the domestic consumers in country h takes the following form:

$$\gamma_{1h}x_{1h} + \gamma_{2h}y_{2h} + \gamma_{2m}M_{2h} \leq \overline{z}^{h,cons} \tag{5.53}$$

In our model the high-income country exports good 1 and imports good 2. Therefore, consumers in country h take full responsibility for domestic production and for the imported part of country m's production in sector 2. Inserting this emission target into the social planner's maximization problem yields the following Lagrangian:

$$\begin{aligned}
\max \overline{W}^{h,cons} &= U^h = u(x_{1h}, x_{2h}) - \eta Z \qquad \text{subject to } 5.53 \\
L^{h,cons} &= u(T^h(y_{2h}) - p^* M_{2h}, y_{2h} + M_{2h}) - \\
&- \eta[\overline{z}^{h,cons} + \gamma_{1m}T^m(y_{2m}(p^*)) + \gamma_{1h}E_{1h} + \gamma_{2m}x_{2m}] + \\
&+ \omega[\overline{z}^{h,cons} - \gamma_{1h}(T^h(y_{2h}) - p^* M_{2h}) - \gamma_{2h}y_{2h} - \gamma_{2m}M_{2h}]
\end{aligned}$$

Differentiation with respect to y_{2h} and M_{2h} results in the following first-order conditions:

$$
\begin{aligned}
\frac{\partial L^{h,cons}}{\partial y_{2h}} =& U_1^h T_2^h + U_2^h - \omega(\gamma_{1h} T_2^h + \gamma_{2h}) \overset{!}{=} 0 \\
\iff & U_1^h T_2^h + U_2^h = \omega(\gamma_{1h} T_2^h + \gamma_{2h}) \qquad (5.54)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\partial L^{h,cons}}{\partial M_{2h}} =& - U_1^h p^* + U_2^h - \omega(-\gamma_{1h} p^* + \gamma_{2m}) \overset{!}{=} 0 \\
\iff & - U_1^h p^* + U_2^h = \omega(-\gamma_{1h} p^* + \gamma_{2m}) \qquad (5.55)
\end{aligned}
$$

Again, dividing equations 5.54 and 5.55 by U_1^h and using the agents' optimizing behavior from equations 5.43 and 5.44 yields emission tax and tariff for consumption targeting:

$$
q - p = \rho(\gamma_{2h} - p\gamma_{1h}) \qquad = \tau^{cons} \qquad (5.56)
$$

$$
q - p^* = \rho(\gamma_{2m} - p^*\gamma_{1h}) \qquad = \theta^{cons} \qquad (5.57)
$$

Here, if $\rho = \frac{\omega}{U_1^h} = t_z$, i.e. if $\omega = \eta$, then $\tau^{cons} = \tau^o$. As in the case of production targeting, an emission restriction for consumers results in an optimal taxation of domestic producers. Comparing equation 5.57 with 5.47, clearly $\theta^{cons} \neq \theta^o$. In contrast to the emission policy aimed at domestic firms, the consumer responsibility approach does not exclude emissions embodied in imports from environmental regulation. Why does the tariff under a consumption target then differ from the optimal tariff? Competitive firms and consumers in the high-income country do not take into account their effect on the relative world price p^*. This has two consequences: First, the terms-of-trade effect $G^h M_{2h}$ is not included in the resulting tariff. Second, the shift of country m's point of production as a result of the change in the relative price is not factored in, i.e. the term $R^m G^h$ is missing. An additional difference between the optimal and the actual, consumption-based tariff regards the relevant sector comparison. The tariff in 5.57 compares the emission intensity of country h's import sector 2 to its export sector 1. The optimal tariff in 5.47, on the other hand, looks only at the trading partner's two industries and compares their emission intensities. This is optimal because it includes the change of emissions through a production shift in the partner country. While both θ^{cons} and θ^o account for increasing emissions in the middle-income country's sector 2 from additional imports M_{2h}, only the latter also accounts for the decreasing emission in country m's sector 1.

> Consumption based emission pricing is equivalent to a conventional production based pricing policy supplemented by a full border tax adjustment that puts a price identical to the domestic emisson tax on net imports of embodied emissions (Jakob et al., 2013, p.59).

Border tax adjustment is a measure frequently seen as a possibilty to mitigate the adverse effects of carbon taxes on domestic competitiveness. Important to notice is the difference between standard tariffs applying "exclusively to imported goods" and environmental taxes and border tax adjustment which are "based on an existing domestic charge and can apply to both imports and exports" (Kaufmann and Weber, 2011, p.498). This mechanism is clearly present in our consumption-based tariff θ^{cons}, where $\rho\gamma_{2h}$ can be seen as the taxation of imports and $\rho p^{*}\gamma_{2h}$ as a subsidy to exporters.

In general, we see that both, emission targets for firms and targets for consumers are not efficient and lead to distortions.

> Unfortunately, foreign producers do not produce their goods in the domestic economy and so they do not bear the other general equilibrium effects of the carbon tax. Carbon taxes entail some general equilibrium effects on the output price that need to be considered as well. Indeed, on the one hand, on the supply side, the changes in the prices of other inputs, i.e., intermediate inputs and primary factors, induced by the domestic carbon tax, can affect the price of the domestic good, and hence, its relative price to the imported good. On the other hand, on the demand side, the change in total domestic demand caused by the change in factor income and by the change in the structure of demand can affect the demand for domestic energy-intensive goods, and therefore, it can increase or decrease their prices (Dissou and Eyland, 2011, p.557).

The statement that the implementation of consumer responsibility via taxation of domestic producers and a border tax adjustment for traded goods does not fulfill efficiency criteria does, however, not preclude the possibility that these measures may nevertheless have significantly positive effects. As we have seen in the previous subsection 5.3.2, under the plausible assumption that one of the trading partners possesses market power and can influence the other country's terms-of-trade, also an emission target for domestic firms does not fulfill efficiency conditions as it results in no tariff at all.

5.3.4 A note on CO_2 Emissions as Localized Effects

In this subsection we treat emissions as having only localized effects, meaning that all inhabitants of a country are equally affected by the emission level and all individuals living outside the border are not affected at all. The interpretation of CO_2 emissions as localized environmental effects can be considered legitimate only as long as we impose some restrictions on the rationality of consumers. A rational consumer would be expected to take into account not only his/her country's emissions but also that of other countries. For the sake of the argument, let us consider a situation where the high-income country's consumers' utility function takes the following form:

$$U^h = U^h(x_{1h}, x_{2h}, z_h) = u(x_{1h}, x_{2h}) - \eta z_h \tag{5.58}$$

We could interpret this as a situation where consumers are not really affected by the consequences of climate change yet but rather are subject to public debates on future climate change. Debates on abatement strategies are largely led on a national level, focussing on national emission targets. In such a situation the welfare maximization problem would become as follows:

$$\begin{aligned}\max\ W^{h,local} &= U^h = u(x_{1h}, x_{2h}) - \eta z_h = \\ &= u(T^h(y_{2h}) - p^*(M_{2h})M_{2h}, y_{2h} + M_{2h}) - \\ &- \eta[\gamma_{1h} T^h(y_{2h}) + \gamma_{2h} y_{2h}]\end{aligned}$$

First-order conditions:

$$\begin{aligned}\frac{\partial W^{h,local}}{\partial y_{2h}} =& U_1^h T_2^h + U_2^h - \eta(\gamma_{1h} T_2^h + \gamma_{2h}) \overset{!}{=} 0 \\ \iff& U_1^h T_2^h + U_2^h = \eta(\gamma_{1h} T_2^h + \gamma_{2h}) \end{aligned}\tag{5.59}$$

$$\frac{\partial W^{h,local}}{\partial M_{2h}} = - U_1^h(p^* + G^h M_{2h}) + U_2^h \overset{!}{=} 0 \tag{5.60}$$

Dividing equations 5.59 and 5.60 by U_1^h and introducing the agents' optimizing behavior from equations 5.43 and 5.44 yields:

$$q - p = -t_z(\gamma_{2h} - p\gamma_{1h}) \qquad = \tau^{o,local} \tag{5.61}$$

$$q - p^* = G^h M_{2h} \qquad = \theta^{o,local} \tag{5.62}$$

Under the assumption of CO_2 emissions as localized effects the externality can successfully be internalized by using the standard Pigouvian tax derived in section 5.2, just setting the emission price t_z equal to the marginal damage from pollution and correcting for the domestic general equilibrium effects. The optimal tariff in equation 5.62 would be zero for a small country that does not influence the relative world price, for the assumed large country the optimal tariff is equal to the terms-of-trade effect. In any case, the general equilibrium effects in country m of border taxation in country h do not enter the picture. A naive approach to abatement policy (or one that wants to avoid legal complications discussed in section 5.4) might draw upon an argument as discussed in this subsection.

5.3.5 Carbon Leakage

In this subsection we want to answer the question if environmental regulation in the high-income country induces carbon leakage, i.e. increases emissions in the middle-income country as a consequence. Jakob et al. (2013) suggest that a welfare optimizing social planner should use a mix of emission taxes and tariffs. Why is it that we have to use both instruments in order to internalize the external effects of CO_2 emissions? This follows from the scale of jurisdiction for each government. A government can only levy taxes on its own citizens and firms. However, if for example the high-income country h only taxes its home production with an emission tax, competitiveness compared to the middle-income country m will fall and so will the share of demand met by home production. The argument on carbon leakage, already discussed in chapter 2, goes that "differences in pollution regulation are a key determinant of production costs and hence industry location" (Copeland and Taylor, 2003, p.143f.). This argument however is "subject to much controversy" according to Copeland and Taylor. The controversy is due to the question if the effects of a carbon tax on competitiveness are strong enough to motivate production relocation. Costs of environmental regulation are only one (mostly minor) part determining the attractiveness of an economy. Labor costs, natural resources, worker's education or infrastructure may be far more important factors for industry location. In their model, Jakob et al. (2013) assume all these factors to be constant across countries to filter out the pure effects of environmental regulation. For some reason, the high-income country has a comparative advantage producing good 1, while the middle-income country has a comparative advantage for good 2. This we take for given, the only thing we vary is environmental regulation.

In our version of the Jakob/Marschinski/Hübler model, carbon leakage occurs if an increase in the relative world price of good 2 p^*, triggered by an increase of the carbon price t_z in the high-income country, leads to increase of emissions of firms in the middle-income country z_m. From equation 5.37 we have emissions in country m. By using the middle-income country correspondence to equation 5.35, we get:

$$z_m = \gamma_{1m} T^m(y_{2m}) + \gamma_{2m} y_{2m} \tag{5.63}$$

Differentiation with respect to the relative world price yields:[10]

$$\frac{\partial z_m}{\partial p^*} = (\gamma_{2m} - p^* \gamma_{1m}) R^m \tag{5.64}$$

We know that R^m is always positive, see equations 5.36 and 5.45. As a consequence,

---

[10] We use here equation 5.44 for country m, $p^* = -T_2^m$. Firms in the middle-income country align their marginal rate of transformation to the world price ratio. In addition we use equation 5.45, showing that the reaction of the middle-income country's production of good 2 to a relative world price increase is positive, $\frac{dy_{2m}}{dp^*} = R^m > 0$.

the righthand side of equation 5.64 is positive as long as $\frac{\gamma_{2m}}{p^*} > \gamma_{1m}$. In other words, in the middle-income country the emission intensity per output value has to be larger in sector 2 (country m's export sector) in order for the country emission level to increase in response to a world price increase. Intuitively, if the relative world price of good 2 increases, then this sector's production in country m will increase. As sector 2 has a higher emission intensity than sector 1, emissions in sector 2 will increase by more than they decrease in sector 1.

Equation 5.64 states the consequences on emissions in the middle-income country from world price changes. In order to be able to examine carbon leakage, we still need to analyse the influence of the high-income country's emission price t_z on the relative world price p^*. This effect is not straigthforward to prove and also somewhat problematic, it suffices for this thesis to just adapt the results of Jakob et al. for our framework. Problematic is the fact that in order to obtain the following results, Jakob et al. have to assume homotheticity of preferences, i.e. consumers with high incomes and consumers with low incomes consume goods in equal proportion. As the relative world price depends on the emission price in the high-income country (without consumers and firms taking this into account), we want to understand the different effects of production and consumption targets for domestic emissions in country h. Propositions 1 and 2 adopt the results obtained by Jakob et al..

P1: The introduction of or an increase in the high-income country's production-based carbon tax ν leads to an increase (decrease) in the relative world market price p^* if country h's sector 2 has a higher (lower) emission intensity than sector 1 (Jakob et al., 2013, p.58, proof p.67f.).

P2: The introduction of or an increase in the high-income country's consumption-based carbon tax ρ leads to an increase (decrease) in the relative world market price p^* if country h's emission intensity is higher (lower) in both sectors 1 and 2 than in the middle-income country's export sector 2 (Jakob et al., 2013, p.60, proof p.68f.).

For a more intuitive interpretation of Proposition 1, if sector 2 is more emission intensive than sector 2 the introduction of a carbon tax will make production in sector 2 relatively more expensive and therefore shift the high-income country's production structure towards sector 1. The demand for good 2 will shift in part to imported goods from the middle-income country, raising the price for these products p^*. In the case of an emission target for consumers (Proposition 2) not only domestic production is taxed but also imports via border tax adjustment. If the high-income country's emission intensities are in general higher than imports from country m, the introduction of a consumption-based carbon tax will make country h's production relatively more expensive compared to country m's. Therefore a part of the high-income country's consumers' demand will shift from domestic production to imports, thereby again increasing the price for them.

With these two results on the world price effects of introducing a carbon tax what can we say on carbon leakage? Intuitively we would probably compare emission intensities between countries. It might seem important that the high-income country produces both goods with a lower emission intensity per output value, i.e. $\gamma_{1h} < \gamma_{1m}$ and $\frac{\gamma_{2h}}{p} < \frac{\gamma_{2m}}{p^*}$. This is a pattern typically observed in the data and it is also what we would expect if we assume environmental quality to be a normal good, such that higher income leads people to demand better environmental quality. Table 4.3 also confirms this pattern. If we compare, for instance, high-income country Germany and middle-income country China, the former exhibits lower emission coefficients in all traded sectors. Our analysis so far suggests, however, that comparison between countries might result in misleading outcomes.

Let us assume that in both countries sector 2 is the more emission intensive sector, i.e. $\gamma_{1h} < \frac{\gamma_{2h}}{p}$ and $\gamma_{1m} < \frac{\gamma_{2m}}{p^*}$. This assumption would be justified if we think of sectors like those defined in the empirical part of this thesis. For example, it is true for all countries in my sample that the chemicals sector *9 chem* has a lower emission intensity than the non-metallic mineral products sector *11 nmmp*. As we have assumed for our model a certain trade structure, namely country h exports good 1 and imports good 2 and the reverse image for country m, we would have to check the average emission intensity in the export sector versus the domestic sector. Assuming $\gamma_{1h} < \frac{\gamma_{2h}}{p}$ and $\gamma_{1m} < \frac{\gamma_{2m}}{p^*}$ amounts to saying the high-income country exports the low-emission good and imports the high-emission good from the middle-income country. This is what the Pollution Haven Hypothesis would suggest, lower- and middle-income countries specialize in relatively pollution-intensive goods. By this second assumption on emission intensities we already ensure that the righthand side of equation 5.64 will be positive.

Still, this assumption is not trivial: Assuming that the export sector in the high-income country is less emission intensive than the non-export sector whereas the middle-income country's export sector is more emission intensive than its non-export sector is somewhat arbitrary. In the data we can find some support for this assumption (see table 5.1). This table shows the average emission intensity of the domestically consumed production of the primary and secondary sectors 1-16 compared to the exports thereof (in addition we also find the average of total production in these sectors).[11] About half of the high-income countries listed there - we call them HIC-Group 1[12] - exhibit a lower than average emission intensity in their export-sector, which would support the hypothesis that HICs are (relatively) specialized in low-emission-sectors. For the other half of the high-income countries - we call them HIC-Group 2[13] - it is the other way around. Their exports have on average a higher emission intensity than their domestically used products. The picture is

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[11] We only use agricultural and manufacturing sectors for these comparisons as these products are most likely to be subjected to a emission-based taxation and border tax adjustment. If we included also the service sectors, relations would be different for many countries and some of the following results would not hold.

[12] HIC-Group 1: France, Germany, Italy, Belgium, United States.

[13] HIC-Group 2: Netherlands, Spain, United Kingdom, Australia, Japan, Korea

	Exports	Non-Exports	Total 1-16	
Brazil	0.2739	0.2095	0.2277	*
Russia	1.9407	1.0314	1.4568	*
India	1.2234	1.1153	1.1443	*
China	1.1543	0.9241	1.0269	*
France	0.1296	0.1523	0.1387	
Germany	0.1775	0.1818	0.1786	
Italy	0.1989	0.2045	0.2015	
Netherlands	0.1907	0.1730	0.1892	*
Spain	0.2315	0.2171	0.2255	*
Belgium	0.1760	0.2019	0.1777	
United Kingdom	0.2510	0.2384	0.2474	*
United States	0.3529	0.3909	0.3774	
Australia	0.4005	0.3529	0.3803	*
Japan	0.2901	0.2138	0.2467	*
Korea	0.4858	0.3504	0.4547	*

Table 5.1: Average emission intensities of the export-sector and the non-export-sector (compared to the overall intensity of primary and secondary sectors). Countries are marked with an asterisk, if their export sector's emission intensity exceeds that of the non-export sector. Source: Own calculations, based on data as described in section 3.1

clear-cut for the BRICs: All of them are (relatively) specialized in high-emission-sectors. Thus, the assumption $\gamma_{1m} < \frac{\gamma_{2m}}{p^*}$ holds for these four countries.

The predicted results for carbon leakage under the abovementioned assumption $\gamma_{1h} < \frac{\gamma_{2h}}{p}$ and $\gamma_{1m} < \frac{\gamma_{2m}}{p^*}$, corresponding to the case of BRICs' trade with HIC-Group 1, are as follows:

- The introduction of a production-based tax ν has the following effects under these conditions: From P1 we know that the relative world price of sector 2 will increase and from equation 5.64 we see that emissions in the middle-income country increase, that is, carbon leakage occurs.

- In the case of a consumption-based tax ρ, the occurance of carbon leakage depends on the relation between the high-income country's emission intensity in both sectors and the emission intensity in the middle-income country's export sector 2. As we have not assumed a structure for this relation, the outcome would be uncertain. Looking at table 5.1 indicates that $\gamma_{1h} < \frac{\gamma_{2m}}{p^*}$ and $\gamma_{2h} < \frac{\gamma_{2m}}{p^*}$ is true for all countries except Australia. This would yield a decrease in the relative world price of sector 2 according to P2 and a decrease of carbon leakage according to 5.64.

- These two results would lead to the conclusion that high-income countries could avoid carbon leakage by introducing an emission target on consumption rather than production if their trading partners are (relatively) specialized in high-emission-sectors.

The predicted results for carbon leakage under the assumption $\gamma_{1h} > \frac{\gamma_{2h}}{p}$ and $\gamma_{1m} < \frac{\gamma_{2m}}{p^*}$, corresponding to the case of BRICs' trade with HIC-Group 2, are as follows:

- Production-based tax ν: From P1 we know that the relative world price of sector 2 will decrease and from equation 5.64 we see that emissions in the middle-income country decrease. So-called “negative” carbon leakage occurs.

- Consumption-based tax ρ: A priori, we again have an uncertain outcome. Assuming that $\gamma_{1h} < \frac{\gamma_{2m}}{p^*}$ and $\gamma_{2h} < \frac{\gamma_{2m}}{p^*}$, which is true for all trade flows of the BRICs except Brazil, this yields again a decrease in the relative world price of sector 2 according to P2 and a decrease of carbon leakage according to 5.64.

- Both forms of taxation lead to “negative” leakage. Thus, in the case where both countries export (relatively) emission intensive goods, the introduction of a tax on the emission content - either consumption- or production-based - will generally have a decreasing effect on the overall emission level.

In order to obtain exacter predictions of our model, we should adapt the emission intensities of export- versus non-export-sector to each specific two-country trade-case, e.g. the average emission intensity of Chinese exports to the United States and vice versa. The results of table 5.1 represent the emission intensities of the export sector to the whole world. If one high-income country wants to introduce a taxation on CO_2 emissions, the relevant emission intensity in our model concerns the exports to a specific trading partner not overall exports. For this case we can see in table 5.2 that the relative intensities of the export- versus the non-export-sector might change. Whereas China stays (relatively) specialized in high-emission-sectors, the same is not true for India. India is specialized in high-emission exports for some HICs (like Germany, France or Japan) and in low-emission exports for other HICs (like the United States or Australia).

To demonstrate the model's predictions for carbon leakage for the case where $\gamma_{1h} < \frac{\gamma_{2h}}{p}$ and $\gamma_{1m} > \frac{\gamma_{2m}}{p^*}$, corresponding to trade between India and the United States, we can state the following:

- Production-based tax ν: Again (from P1) the relative world price of sector 2 will increase. From equation 5.64 we obtain a decrease of emissions in the middle-income country, as the term in brackets becomes negative. This is equal to saying that negative carbon leakage occurs.

- Consumption-based tax ρ: A priori, we again have an uncertain outcome. If we again build on the reasonable assumption that $\gamma_{1h} < \frac{\gamma_{2m}}{p^*}$ and $\gamma_{2h} < \frac{\gamma_{2m}}{p^*}$, we obtain

	India		Exports to India		
Non-Exports	1.1153				
	exports		**exports**	**non-exports**	
France	1.1512	*	0.1397	0.1523	
Germany	1.2030	*	0.1739	0.1818	
Italy	1.3277	*	0.1716	0.2045	
Netherlands	1.2334	*	0.1660	0.1730	
Spain	1.2262	*	0.2376	0.2171	*
Belgium	0.8347		0.2889	0.2019	*
United Kingdom	1.0165		0.2697	0.2384	*
United States	0.7939		0.2643	0.3909	
Australia	0.9544		0.5788	0.3529	*
Japan	1.2843	*	0.3366	0.2138	*
Korea	1.4908	*	0.5420	0.3504	*

Table 5.2: Average emission intensities of the export-sector and the non-export-sector in trade between India and HICs. The first column compares India's non-export sector to its exports to different HICs (asterisks indicate specialization in high-emission exports to this country). The second column states the HICs' emission intensity of exports to India. Source: Own calculations, based on data as described in section 3.1

a decrease of the relative world price from P2. However as $\gamma_{1m} > \frac{\gamma_{2m}}{p^*}$, equation 5.64 results in an increase of emission in country m.

- These two results indicate that for the aim of avoiding carbon leakage with a domestic emission target, the high-income country should use a production-based carbon taxation in trade with partners that are (relatively) specialized in low-emission-sectors. Introducing a consumption-based tax in the United States for products from India would therefore induce carbon leakage.

If we keep in mind that the setup of our model is a simple two sector case, it is clear that the condition in P2 will hardly be fulfilled. In general, the Jakob/Marschinski/Hübler model predicts therefore an uncertain outcome regarding the sign of carbon leakage whenever one sector in country h is more and the other less emission intensive than country m's export sector under a regime of consumption-based carbon taxes. This ambiguous outcome demonstrates that carbon leakage is not neccessarily (even very unlikely) to be extinguished by the introduction of an emission target for consumers. But it also says that carbon leakage can occur in both ways, i.e. by increasing *or* decreasing emissions in the middle-income country. This insight calls for a case-specific decision on the appropriateness of consumption- or production-based internalization strategies. However, case-specific decision of trading restrictions, like import tariffs (via border tax adjustment), will hardly be compatible with WTO laws.

To sum up the main insight of the Jakob/Marschinski/Hübler model concerning our research question: We cannot confirm hypotheses H3 (see section 1.2). It is clearly possible that the introduction of a consumption-based emission target reduces the incentive to relocate, i.e. reduces carbon leakage, but in no way it is necessarily so. There are general equilibrium effects at work that can also result in a move in the opposite direction.

5.4 Border Tax Adjustment and the WTO

In subsection 5.3.3 we derived the result that a consumption-based emission policy can be implemented using a standard Pigouvian emission tax on local production and a border tax adjustment for imports and exports. With these two measures it is said that, on the one hand, domestic governments can implement climate change abatement policies without risking carbon leakage and, on the other hand, unilateral policy installs incentives for other governments to follow their examples in order to escape the border taxation. From these two measures, emission taxes and tariffs, only the latter is controversial in terms of WTO rules.

As we have seen in subsection 5.3.5, the consumption-based carbon tax is very unlikely to eliminate carbon leakage. Nevertheless, it is seen in public political debates as one of the only feasible measures an unilateral environmental policy can take to tackle the competitiveness problem linked to conventional production-based emission pricing. Other arguments offered in favor of border tax adjustment are incentives for environmental change within and between countries and welfare gains (Gros and Egenhofer, 2011).

Prominent figures like Joseph Stiglitz argue very much in favor of taxing carbon at the border, if the country of origin does not impose a comparable charge. In a regime where emission of CO_2 is “punished” by most countries, not taxing emissions amounts to subsidizing domestic production which could be a breach of WTO rules (Stiglitz, 2006, p.2). The same line of argument is brought forward by Brian Copeland:

> Weak environmental policy is an implicit subsidy to pollution-intensive industries. It results in excessive production of pollution-intensive goods. When environmental policy is tightened, the subsidy is reduced, and pollution-intensive output contracts as the pattern of production adjusts to reflect true social costs of all inputs, including access to the environment (Copeland, 2008, p.64).

The introduction of border taxes still poses some questions of compatibility with trade rules for the currently 159 members of the WTO. While confirming the economic rationale of Stiglitz, Fischer and Fox underline that “global trade law is unlikely to accept that the absence of regulation would be an ’actionable’ subsidy” (Fischer and Fox, 2012). Proponents of free trade might fear that environmental tariffs act as a kind of trojan horse: While officially introducing them for environmental reasons, the true motivation for some countries might be to gain competitiveness by restricting free trade, the very opposite the WTO wants to achieve. Border tax adjustment is not a new phenomenon, already in 1970 the GATT Working Party on Border Tax Adjustments first dealt with this issue.

> Generally speaking, two types of internal taxes may be distinguished: taxes on products (called indirect taxes) and taxes on producers (i.e. direct taxes). In its examination of BTAs, the 1970 GATT Working Party indicated that taxes directly levied on products (i.e. socalled indirect taxes, such as excise duties, sales taxes and the tax on value added) were eligible for adjustment, while certain taxes that were not directly levied on products (i.e. direct taxes such as taxes on property or income) were normally not eligible for adjustment (WTO and UNEP, 2009, p.103).

An example of such an indirect tax where border tax adjustment is frequently used is the taxation of tobacco consumption. Smoking exerts adverse effects on other people's health, therefore it is the cause of an externality. Many countries have a (Pigouvian-like) tax on tobacco consumption in place, a tax that is meant to discourage smoking. As the above quote indicates, border tax adjustment is eligible for this kind of indirect tax directly levied on a product (e.g. cigarettes). The rationale is that consumers can not avoid the tobacco tax by shifting their demand to foreign products as they are subject to the same duty. On the other hand, local producers of cigarettes will not be negatively affected in their competitiveness with producers from other countries, as they are reimbursed the tax for their exports of cigarettes.

The difference of this example from the case of taxing the emissions of carbon dioxide is twofold. First, the type of externality targeted is different. While cigarette smoking exerts a localized external effect, i.e. only affects the direct environment, CO_2 emissions exert transboundary effects and are therefore unlikely to be fully internalized. Second, with taxation of carbon dioxide emissions the subject of the tax is not the product itself but rather a by-product of the production process. While this may seem like splitting hairs, it turns out to be relevant for deciding the eligibility of border tax adjustment.

> Article II.2(a) allows two types of import charges (i.e. border tax adjustments): (i) charges imposed on imported products that are like domestic products; and (ii) charges imposed on articles from which the imported product has been manufactured or produced in whole or in part (WTO and UNEP, 2009, p.104).

As the emission charge is not imposed on a particular traded product, (i) of Article II.2(a) can obviously not be drawn on. Concerning point (ii), there is a debate on whether the energy input or the amount of CO_2 emissions qualify as "articles from which the imported product has been manufactured". There has been a ruling by the WTO Appellate Body, in the US-Superfund case, that the use of border adjustment is permitted for inputs that are physically incorporated in the final product (Kaufmann and Weber, 2011, p.502). More difficult to decide is the situation of inputs not physically incorporated in the final products, like energy or emissions. Here, some authors have argued that GATT Article III.2 with its formulation "products [...] shall not be subject [...] to [...] internal charges of any kind in excess of those applied, directly or indirectly, to like domestic products"[14] plays an important role. The argument goes that the phrase "applied indirectly" may contain inputs like energy or emissions and therefore legitimize the use of border tax adjustment (WTO and UNEP, 2009, p.104).

The WTO Appellate Body so far was never concerned with a dispute about carbon emission taxes (Kaufmann and Weber, 2011, p.501). The issue of border tax adjustment remains for the moment a legal gray area, as "the use of trade measures applied on the basis of processes and production methods (PPMs) - in this case, embodied taxes, carbon or energy - remains highly controversial" (Goh, 2004, p.399). It seems, however, that in recent years most commentators suggest the construction of WTO-conform border tax adjustments for emission taxes is indeed possible (Ismer and Neuhoff, 2007; Kaufmann and Weber, 2011; de Cendra, 2006) and also a related publication by the WTO does hint in this direction (WTO and UNEP, 2009, p.103ff.).

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[14] For the full text see:
http://www.wto.org/english/res_e/booksp_e/analytic_index_e/gatt1994_02_e.htm
(last accessed: Jan 13, 2014)

6 Summary & Conclusion

If we return to our research question on the effects of trade on emission shifting between middle- and high-income countries and a consumer-based internalization strategy of these emission shifts, we found answers but not necessarily the ones we thought to find. Checking the associated three hypotheses, reality seems to be more complex than easy reasoning would suggest. All three hypotheses could not be fully confirmed. Hypothesis H1 (BRICs are net exporters of embodied CO_2) is closest to being confirmed. Of the four BRICs, only Brazil does not fit into the pattern of embodied exports of carbon dioxide exceeding embodied imports. For the other three, and quantitatively more important, countries China, India and the Russian Federation we find the expected pattern. Rather not to be confirmed is also Hypothesis H2 (aggregate emissions will be lower under a hypothetical autarky scenario). We find this to be true for the two quantitatively more important countries China and the Russian Federation, and not true for Brazil and India. The result remains indecisive as also the country- and trading partner-specific evaluations did not provide a clear pattern of aggregate changes under autarky. Finally, hypothesis H3 (a consumption-based emission targeting would reduce firms' incentive to relocate) is clearly not generally confirmed as well. Our model shows that it is possible and even not unlikely to be the case that carbon leakage is lower under a consumption-based taxation strategy, but we cannot argue this would necessarily be so.

To view trade as *causing* emissions in other countries, can be misleading if interpreted trivially. The "pseudo-causal" relationship between trade and emissions, discussed and estimated in section 4.3 is criticized exactly on the grounds of easily being available for political misapplication. To give an example, the enforcement of trade restrictions cannot be justified by this thesis and similar studies. This does, of course, not mean that trade does not have a *causal* effect on the environment, it only means that a research design as provided by this thesis (in the empirical part) does not possess the power to render an informed judgment.

> [*Arguing that the rise in China's carbon dioxide pollution is caused by the manufacturing of goods for other countries is not justifiable*] on the level of entire countries, whose decisions to, for example, reduce the import of carbon-intensive goods from China will have repercussions on world markets. As a consequence, the characterization of final consumers as responsible and imported goods as the cause for carbon emitted in the exporting country should not be regarded as an indication that in the absence of the cause - that is,

> without the imports - total emissions in the exporting (developing) country would be lower and, conversely, that the emissions of the importing (industrialized) country seem lower 'than if they had continued to produce these goods domestically'. In trade theory, the question of the net effect of trade has been termed the 'but-for' question: what would global carbon emissions be but for the presence of foreign trade? Answering this counterfactual question is by no means trivial, because with differing factor productivities (that is, the quantity of goods that can be produced with one unit of a certain input factor) across countries, one country's exported goods might result in savings of an input factor in the importing country that exceeds the amount used for their production by the exporter (Jakob and Marschinski, 2012, p.21, author's note in italics).

In the absence of reliably clear estimates on the consequences of implementing a unilateral consumption-based emission target and contradicting research results, the political nature of this question moves to the foreground. As Susanne Droege expresses it, "the actual implementation of border measures is more of a political than a technical challenge" (Droege, 2011, p.1199). Although much more and better-quality information would be necessary to implement carbon taxation and border adjustment based on the carbon content of products, the biggest problem lies in the absence of international political cooperation on environmental issues that, in the first place, makes it necessary to resort to unilateral measures.

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Curriculum Vitae

Anton Hartl
E-mail: antonhartlecon@gmail.com
Born: 1987 in Ried im Innkreis, Austria

Education

2012 -	Master Economics, University of Vienna
2008 - 2014	Magister International Development, University of Vienna
2008 - 2012	Bachelor Economics, Vienna University of Economics and Business (WU), Excellence Scholarship 2010/11
2002 - 2007	Higher Technical College of Engineering in Ried im Innkreis

Work Experience

2013, 2014	Department of Economics, University of Vienna, Tutor for courses on *Development Economics* and *International Trade Theory* (5 months each)
2011, 2012	Strategic Credit Risk Management, Volksbank AG in Vienna Data Analysis (7 months)
2011	Austrian Trade Commission in Bucharest, Romania Internship (3 months)

Theses/Publications

1. Environmental Effects of Trade between High- and Middle-Income Countries - Empirical Magnitude and Political Abatement Strategies. Diploma Thesis. University of Vienna, 2014.
2. The Boom of Commodity Prices 2007/2008 - An inquiry into the causes of surging prices. Bachelor Thesis. Vienna University of Economics and Business, 2012.
3. Review for Rita Schäfer's *Women and Wars in Africa*. In: Journal für Entwicklungspolitik 3/2011.

Abstract (Deutsch)

Die Frage nach dem Einfluss internationalen Handels auf die Umwelt entwickelte sich in den vergangen 25 Jahren zu einem bedeutenden Forschungsfeld. Es zeigte sich, dass Handel die Verschiebung größerer Mengen an Umweltverschmutzung zwischen Staaten erlaubt. Die sogenannte 'Pollution Haven Hypothesis' reichert diese Überlegungen um eine Nord-Süd-Perspektive an: Ärmere Länder würden sich in verschmutzungsintensiven Industrien spezialisieren. Zu diesem Ziel würden sie niedrigere Umweltauflagen verlangen als die reicheren Länder, deren Bevölkerungen hoher Umweltqualität durch den gewachsenen Wohlstand einen immer größeren Stellenwert einräumen. Dies würde sich in höheren Umweltkosten für die Firmen verschmutzungsintensiver Branchen äußern. Schwellenländer wie die BRICs (Brasilien, Russland, Indien und China) sind verantwortlich für einen stetig wachsenden Anteil am Welthandel, daher ist die Frage nach den Umweltfolgen des Handels zwischen Ländern mit starken Einkommensunterschieden von zunehmender Bedeutung.

Wer trägt die Verantwortung für die Emissionen aus der Produktion international gehandelter Konsumgüter? Derzeitige politische Mechanismen, beispielsweise das Kyoto Protokoll, beantworten diese Frage mit dem Konzept der Produzentenverwantwortlichkeit (Länder verantworten die Emissionen der Firmen auf ihrem Staatsgebiet). Dieser Diplomarbeit liegt hingegen das Konzept der Konsumentenverantwortlichkeit zugrunde, das den Konsumenten die Emissionen der von ihnen konsumierten Produkte zuschreibt, ungeachtet der Herkunft dieser Produkte. Diese Arbeit untersucht drei miteinander verbundene Fragen: Zum ersten werden die im Handel enthaltenen Emissionen (des wichtigsten Treibhausgases Kohlendioxid) berechnet, also eine Untersuchung des empirischen Ausmaßes der Trennung von Produktionsort und Ort des Konsums, die im Handel zwischen den BRICs und ihren wichtigsten reichen Handelspartnern wie den USA, Deutschland und anderen entsteht. Zum zweiten wird der Frage nachgegangen ob eine Einschränkung des Welthandels eine Verringerung des für diese Handelsprodukte emittierten Kohlendioxids bedeuten würde. Zum dritten stellt sich die Frage nach politischen Möglichkeiten der Eindämmung möglicher negativer Folgen des Handels (beispielsweise im Rahmen von 'Carbon Leakage', übersetzt in etwa 'CO_2-Abfluss'). Zu diesem Zweck werden Produktions- und Konsum-basierte Emissionsbesteuerungen theoretisch analysiert. Die Ergebnisse zeigen, dass drei der vier BRICs (alle außer Brasilien) bedeutend mehr CO_2 für ihre Exporte emittieren als sie durch die Importe aus reichen Ländern konsumieren. Diese BRICs sind Netto-Exporteure von im Handel enthaltenen Emissionen. Eine Reduktion der Handelsströme wird die Gesamtemissionen nicht notwendigerweise reduzieren. Schließlich kann das vorgestellte Modell keine klare Vorhersage treffen bezüglich der Effekte von Produktions- oder Konsum-basierter Emissionsbesteuerung auf das Niveau der Gesamtemissionen der gehandelten Produkte. Prognosen zu bilateralen Handelsströmen und deren Emissionen zeigen sehr unterschiedliche, länderspezifische Tendenzen.

Abstract (English)

The question of how international trade affects the environment became a prominent research topic during the last 25 years. Researchers demonstrated that trade has the ability to shift considerable amounts of pollution between countries. The pollution haven hypothesis argues that, in a context of North-South income differences, the poorer countries would specialize in pollution-intensive industries. Via the imposition of low environmental standards these countries would try to attract "dirty" industries, whereas the higher incomes in the rich world leads their populations to demand higher environmental standards and therefore higher environmental costs for producers. As emerging economies like the BRICs (Brazil, the Russian Federation, India and China) are responsible for ever larger shares in world trade, the impact of trade between countries with considerable income-differences becomes an environmentally pressing question.

Who is responsible for the emissions from the production of internationally traded consumer goods? Current political mechanisms like the Kyoto-Protocol apply the concept of producer responsibility (producing countries are responsible for their emissions). Underlying this thesis is the concept of consumer responsibility, whereby consumers are ascribed the emissions of the products they consume, whatever their geographic origin. This thesis aims at three connected issues: First, we want to calculate emissions embodied in trade, that is, we want to observe the empirical magnitude of how trade between the BRICs and their high-income trading partners like the United States, Germany and others separates the place of consumption from the place of environmental damage (in our case, the emissions of the most important greenhouse gas, carbon dioxide). Second, we want to find out if these trade flows lead to higher emissions than a world with less international trade would produce. Third, we are interested in political strategies to reduce possible negative environmental effects of trade (carbon leakage). For this purpose we examine producer- and consumer-based emission taxation. It is found that three of the four BRICs (all, except Brazil) emit considerably more CO_2 in the products they export than they consume via products they import, i.e. these countries are net exporters of embodied CO_2. The reduction of trade flows will, however, not necessarily reduce overall emissions. Concerning abatement policies, we cannot make a clear prediction on wheter unilateral consumption- or production-based taxation of goods will increase or decrease total emissions from traded goods, i.e. if carbon leakage occurs. Predictions for bilateral trade flows and the emissions thereof show different, country-specific tendencies.