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The Iceberg is Melting
What can Border Carbon Adjustment do about it?

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Abstract

Global warming, caused by emissions of carbon dioxide (CO_2) and other greenhouse gases, is one of the greatest challenges that the world is facing. As a measure for coping with this problem border carbon adjustment (BCA), i.e. tax on imports produced via technology yielding high CO_2 emissions, has attracted great attention among policymakers. The effects of BCA have been simulated in computable general equilibrium (CGE) models, but the Armington structure of conventional CGE models does not coincide with stylized facts on extensive margins in disaggregate trade data. Therefore, we simulate effects of BCA, instead using the Eaton and Kortum (2002) model, which is consistent with facts on extensive margins. Our results indicate a slightly stronger effect on relocation of production and emissions than previous findings. Global manufacturing CO_2 emissions decrease by 0.69% in the short run. More importantly, we find large impact differences on countries at different stages of economic development – an aspect with strong policy implications that previous evaluations have not addressed sufficiently.

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List of Abbreviations

BCA	Border carbon adjustment
CDF	Cumulative distribution function
CEPII	Centre d'Etudes Prospectives et d'Informations Internationales
CGE	Computable general equilibrium
CO_2	Carbon dioxide
EII	Energy intensive industries
EEBT	Emissions embodied in trade
EV	Equivalent variation
FTA	Free trade agreement
GTAP	Global Trade Analysis Project
$MtCO_2$	Metric ton carbon dioxide
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization

1. Introduction

"Climate change is the greatest market failure the world has ever seen" (Stern, 2007, p. viii)

Continued failure in internalizing the external damages of polluting greenhouse gases has put the world on an unsustainable path. If we are to mitigate global warming, and the environmental, economic, and humanitarian detriments that follow climate change, leading scientists agree that immediate action is crucial (Stern, 2007). Undeniably, there is skepticism regarding these claims, but it is now no longer a question of whether measurement needs to be taken that causes the main debates. Rather it is the questions of *how* it will be done and in what way the inherent costs will be distributed that are the main causes of disagreement in international negotiations. This has been evident at global conferences in Copenhagen, Cancun and Durban, where developed and developing countries have had considerably diverging views on a way forward.

The inability to reach a first-best solution – a globally optimal "international agreement that define[s] appropriate levels of national actions" (Cosbey, 2011, p. 5) – has underlined the need for regional initiatives. Such arrangements, however, have been accompanied and possibly hindered by a fear that they lead to *carbon leakage*[1] and reduced competitiveness. It has even been suggested that strict regional policies may lead to increased global emissions, since energy intensive industries (EII) migrate to sites where regulations are comparatively lenient and emission factors higher – the so called pollution haven hypothesis (Copeland and Taylor, 2004).

To counteract these effects, one proposed solution to the dilemma is the implementation of border carbon adjustments (henceforth BCA) as a component of sub-global climate policy. The key mechanism of BCA is that countries with stringent climate policies introduce border measures such as import tariffs and/or export rebates on emission intensive goods. In this way, countries that decide to go ahead and internalize external damage caused by domestic producers would be enabled to level the playing fields in response to countries with a lower level of regulation.

[1] The phenomenon in which pollution intensive production is moved to a different country or location where the cost of polluting is lower due to environmental regulation being more lenient. Thus the emissions that were supposed to be mitigated in the first place are produced elsewhere instead.

Several justifications for including such a policy have been proposed in the academic literature and policy debates. Ismer and Neuhoff (2007) and Stiglitz (2006) are among those arguing that BCA is a requirement for economic efficiency, as it improves price signals for consumers and reduces global productive and allocative inefficiencies that arise when stringent policy is only implemented in one or few regions. Furthermore, BCA could be used to prevent emission leakage as well as to threaten or "leverage" countries to participate in a global climate protocol or alternatively take climate action (McKibbin and Wilcoxen, 2009; Cosbey, 2011).

Undeniably, there are several economic, legal and practical obstacles to implementing BCA. Regarding the former, BCA risks creating unintentional trade barriers or disguising protectionist policies. In this scenario, BCA implementation would decrease rather than increase efficiency. Furthermore, care needs to be given to the design and implementation so as not to infringe on WTO legality, an issue that has been widely discussed in recent years. Specifically, it has been debated whether BCA would contravene WTO's Article 1 on most-favored nation (MFN) treatment. It has been concluded however that WTO's "environmental window" would enable a carefully designed implementation (Bhagwati and Mavroidis, 2007; National Board of Trade, 2009; Horn and Mavroidis, 2011; Manders and Veenendaal, 2008). Legality aside, the potential difficulties in measurement and implementation that could result in high administrative costs remain the most prominent practical obstacle (Persson, Sabelström and Holck, 2010).

Despite these obstacles and a lack of consensus regarding BCA's potential impacts, it has been and will likely remain "a divisive and current topic for some time, and will probably eventually be implemented" (Cosbey, 2011, p.3). UNCSD Secretariat and UNCTAD (2011) have given BCA a "yellow light" ahead of the Rio20 climate negotiations, set to take place June 2012. This classification "requires moving slowly with caution and underlines the need to revisit the rules to seek further clarity" before implementing border carbon adjustment (p.1).

Aside from the qualitative assessments and legal discussions, until recently little has been done to quantify the magnitude of BCA policies' potential impact. McKibbin and Wilcoxen (2009) along with others have called for empirical research to determine economic and environmental effects of BCA. Although evaluations have been made, especially by the use of computable general equilibrium (CGE) models, we are still far from a conclusive agreement on the policy's potential impact on important variables such as economic welfare and emissions. More significantly, the CGE studies that do exist have yielded contradicting results – inconveniently most of which are qualitative ones – and are generally based on assumptions that have often been portrayed as outdated and failing to match characteristics of world trade (Hummels and Klenow, 2005).

Thus, in order to assess whether BCA is a plausible candidate as a viable solution, more research on the policy's economic and environmental implications is essential. Our ambition is to introduce and evaluate a BCA policy in a more current and theoretically convincing framework than the hither-to applied models. We aim to contribute to the current state of knowledge as well as facilitate future discussions and conclusions for a potential implementation of border carbon adjustments.

1.1 Aim and Research Questions

The aim of this thesis is to evaluate the economic impacts of a border carbon adjustment policy intended to mitigate CO_2 emissions. The following research questions provide a basis for our analysis:

- How are emissions, trade flows, income and production affected by the policy?
- What are the implications of applying the Eaton and Kortum (2002) framework instead of the predominantly used Armington CGE models?

The outline of this thesis is as follows: Section 2 provides an overview of the literature on border carbon adjustments and the Ricardian trade models that will constitute our modeling framework. Our methodology including the main model elements, calibration, and our implementation of BCA into the model is found in Section 3. Section 4 contains the data description. Our results are presented in Section 5, to be followed by sensitivity analysis and alternative specifications in Section 6. After a discussion on the validity of the results and potential policy implications in Section 7, Section 8 concludes.

2. Literature Overview

2.1 BCA in Economic Literature

Theoretical Models

A key question for decision makers is whether the costs of implementation of a given policy are economically justified given potential benefits. In order to assess whether legal, political and practical obstacles in implementing BCA are worth overcoming, evaluations of economic and environmental effects are necessary. Economic theories and models of trade, production and competition have had much to offer in recent years. Despite the rapidly growing number of economic articles in this realm there is still no convincing answer and Burniaux, Chateau and Duval (2010, p. 6) highlight that "surprisingly little economic analysis has been performed to assess the actual economic effects of [BCA]."

Papers based on economic theory provide a basis for such analysis. Ismer and Neuhoff (2007) as well as Gros (2009) evaluate BCA's impacts in the context of partial equilibrium models. The former finds that BCA may be a way to mitigate inefficiencies resulting from regional differences in climate policy stringency. The latter evaluates the effect of a CO_2 import tariff on global welfare (accounting for negative externalities of carbon). The results indicate that BCA will increase global welfare when no domestic carbon tax is in place in non-imposing countries, or when the tax is not sufficiently large to offset the negative external effects of CO_2 emissions. While both articles suggest possible impacts of BCA and indicate economically efficient designs, empirical evidence in a more sophisticated setting is indispensable for making informed decisions.

CGE Models

The demand for more advanced applications has during the most recent years partly been met by computable general equilibrium (CGE) models that are used to bridge economic theory with empirical observations on e.g. trade, production and consumer preferences. CGE modeling is, according to Bergman (2005, p. 1275), "an attempt to use general equilibrium theory as an operational tool in empirically oriented analyses of resource allocation and income distribution issues in market economies." In recent years, traditional CGE models have been developed into versions that allow more detailed modeling of variables related to energy and emissions. Several have been applied to evaluate effects of a potential BCA implementation.

Some of the studies that are most relevant and closely linked to our evaluation include Burniaux, et al. (2010) and Elliott, et al. (2010) who assess different policies with respect to their effectiveness in combating leakage. Using the CIM-EARTH CGE model, Elliott, et al. (2010) study the effect of BCA imposed by Kyoto Annex I countries[2] alongside a domestic carbon tax. They find that BCA reduces leakage by 44% by moving production from non-Annex I to Annex I countries, and consumption in the opposite direction. Although the effect on global emissions is not their focus, they comment that this is "not hugely affected" (p. 469).

In another CGE set-up, Böhringer, et al. (2012) estimate the welfare costs of different unilateral (mainly EU) strategies to achieve a global emissions target and assess leakage implications. Welfare costs decrease when applying the policy to total embodied emissions rather than to solely direct and electricity-related emissions. In terms of the design of the BCA policy, they find that country-specific tariffs are less detrimental to welfare than uniform cross-region tariffs, which also is the case when the tariff size is based on EU (domestic) rather than non-EU countries' (origin) emission averages. Another characteristic of the more efficient specifications is that a larger share of the costs is shifted to the countries outside the coalition. The effect on total emissions is however not assessed.

Manders and Veenendaal (2008) acknowledge as well as investigate the WTO compatibility of BCA and evaluate what they deem to be a more legitimate implementation, a combination of import levies and export refunds. They further simulate different types of BCA implementations using the CGE model WorldScan. When studying the effects of a BCA import tariff imposed by the EU, they find that the effect on employment would be 0.8% in the EU and -0.2% in the world. Leakage would decrease but the effect on total emissions is also not here investigated. The welfare would increase in the EU due to the terms of trade effects, while it may be negative in the rest of the world.

Winchester, Paltsev and Reilly (2010) use another CGE model, MIT EPPA that is a successor to OECD's GREEN model. They examine the effects of BCA imposed by the U.S. or a larger coalition as part of a policy package to reach a specified lower emissions level by 2025. The findings indicate a reduction of leakage with approximately 33% (U.S.) or 60% (coalition), and the effect of

[2] Mainly industrialized countries with emission restrictions under the Kyoto Protocol, including the U.S., Australia, Canada, Japan, New Zealand, Russia and the EU countries.

the latter on total global emissions is 0.6%. Changes in output differ between various industries and regions, but are typically not larger than ±2%. The welfare effects (measured as equivalent variation in consumption[3]) are slightly negative for the U.S. but positive for the coalition countries when they impose BCA together. The largest reduction in welfare is among non-imposing countries, and the global difference approximately -0.28%.

Unlike the various multi-region models, Bao, et al. (2011) make use of a single country CGE model to evaluate how China's sectoral emissions are affected when the U.S. and the EU adopt a BCA policy. They provide no total figure but find that the sectoral reductions of CO_2 are only modest, and therefore suggest that focusing on energy-efficient technologies and fuels may be more effective than BCA in the case of China.

ENV-Linkages

Among the CGE models most likely to have an impact on climate policy formulation is the ENV-Linkages, developed by the OECD and another successor of their GREEN model. It is a global economic model built primarily on a database of national economies and is used for example in their impact analyses and environmental and economic outlooks. It features 12 regions, 22 sectors and includes emissions both of CO_2 and other greenhouse gases (Burniaux and Chateau, 2008). Due to it being both an important and rather representative CGE model, it will both serve as a comparison to our analysis and also an illustration of the potential shortcomings of using such a model.

Using ENV-Linkages, Burniaux, et al. (2010) compare and study the results for emissions, output and welfare in a baseline scenario with one in which either the EU or the group of Annex I countries under the Kyoto protocol apply BCA on imported goods from non-participating countries. They evaluate various designs of BCA, of which we primarily focus on the case where BCA is imposed on both direct and indirect CO_2 content. They find that BCA can reduce carbon leakage more effectively if the coalition of imposing countries is small. If the EU alone imposes border adjustment, leakage will in effect disappear completely, whereas it will be reduced with approximately 60% when the coalition is larger. Nonetheless, the reduction on global CO_2 emissions is greater when the coalition is larger; 0.5% under Annex I policy compared with 0.2% under EU

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[3] Hicksian equivalent variation is a utility-based welfare measurement, and essentially is a measurement of the amount a consumer would pay before a price increase to stop the price increase in the first place.

policy. Welfare effects, here also measured using Hicksian equivalent variation (EV) in income, are small and marginally negative (<0.1%) for the world as a whole, but positive for the implementing countries (0.2-0.3%). A further result is that BCA does not necessarily have a positive impact on the "domestic" EII they are intended to support. One reason is the increased price of energy intensive intermediate products.

The Armington Assumption

Like other CGE models that have been used to evaluate BCA, ENV-Linkages rests on the Armington (1969) assumption (Burniaux and Chateau, 2008). This assumption implies that goods produced in different locations are imperfect substitutes. In all categories of goods, all countries produce a single variety that is not produced anywhere else. Due to this national product differentiation and consumers' assumed "love of variety," all countries must trade with all others in each category of goods. The Armington model thus explains variations in trade through the intensive margin (i.e. the volume of each traded good). The rationale behind the central assumption is to prevent extreme specialization patterns.

In ENV-Linkages, the Armington assumption is implemented using two CES (constant elasticity of substitution) nests. At the top nest, domestic agents choose an optimal combination of domestic goods and a bundle of imported goods. At the lower nest, they allocate their spending on imported goods among goods from the different trade partners. The parameters that are assumed to represent the elasticity of substitution of goods from different countries are the Armington elasticities. The elasticities vary between sectors and are higher for more homogenous goods that are thus more substitutable. In a model such as ENV-Linkages, the value of the Armington elasticities are central in explaining trade flows and evaluating effects of changes in e.g. policy or trade costs (Burniaux and Chateau, 2008).

The importance of correct estimates of the Armington elasticities is emphasized by McDaniel and Balistreri (2003, p. 302), who find that "a modeler's central Armington choice will drive key quantitative, and sometimes qualitative, results that policymakers use." In their review of some literature estimates, they find that less aggregation of sectors result in substantially higher estimates, as do long run estimates and cross-sectional studies. The direction and magnitude of effects are due to the value of the Armington elasticities as revealed when performing a sensitivity analysis. Hertel, et al. (2007) and Fischer and Fox (2011) provide similar hesitations, and Bergman (2005) means that the assumptions on elasticities and other key parameters in CGE models are often rather strong and with a questionable empirical basis. While the Global Trade Analysis Project (GTAP) database, that Burniaux, et al. (2010) make use of for their Armington elasticities, is well established, there are still more reservations to be kept in mind. For example, Elliott, et al. (2012, p. 32) claim that the GTAP data and elasticities are "all somewhat uncertain" and Liu, Arndt and Hertel (2004) reject their validity. Peters and Hertwich's (2008, p. 1403) cautionary note display similar apprehensions; "While the GTAP database has impressive coverage, care needs to be taken with its consistency and accuracy." These findings create uncertainty surrounding the parameter values used in ENV-Linkages and many other CGE models, and perhaps more importantly the results that follow.

To their defense, Burniaux, et al. (2010) recognize the inconsistency entrenched in the parameter values and perform sensitivity analysis with different values of the Armington elasticities. They find that higher elasticities yield higher leakage and less EII output for coalition countries but mean that the environmental and economic effects are "roughly unchanged" (p.13). This is however difficult to validate as the authors merely report that Armington elasticities are changed to "low" and "high." Hertel, et al. (2007, p. 612) acknowledge that "standard 'robustness checks' such as systematically raising or lowering the substitution parameters fail to properly address" the problem of imprecise estimates. Further, Burniaux, et al. (2010) do not discuss the importance of the level of regional aggregation, despite that Burniaux and Chateau (2008) in a previous overview of ENV-Linkages find that simulation results are dependent upon this. With what has often been called the "black box" (Baldwin and Venables, 1995; Böhringer, Rutherford and Wiegard, 2003) specifications of CGE models, it is difficult to evaluate the importance of such choices.

While CGE models are a popular choice for policy evaluations due to their ease of use, we stray from this approach and the extant literature. Whereas the many assumptions of the ENV-Linkages model possibly improve the fit of the model and make it suitable for dynamic simulations, they also make it difficult to evaluate the extent to which the results are affected. Our ambition is to use a simpler framework, in which the economic logic and assumptions are more straightforward to interpret and evaluate. Simply speaking, we make use of a Ricardian model that has recently been revived in policy simulations.

2.2 International Trade

Ricardian Models

The strand of literature on Ricardian models incorporate worker productivity into international trade models to illustrate the law of comparative advantage and possible gains from specialization and trade. It is also used to determine per capita income as well as to explain income differences. The Ricardian model of two goods and two countries has for many years served as an example in trade literature – pedagogic but too simplified to realistically capture the features of world trade. The last decades however, the model has "experienced a revival" and been more extensively applied (Eaton and Kortum, 2012, p. 2).

The revival stems from the extensions of Ricardian models to cover more than two countries and two goods. Dornbusch, Fischer and Samuelson (1977) contribute to this field of trade literature with their seminal model of two countries and a continuum of goods. Another important contribution is their incorporation of trade barriers that allow goods to have different prices in different countries. Specifically they make use of Samuelson's (1954) specification of iceberg trade costs, which imply that only a fraction of the shipped good reach the destination – the rest "melts away" due to tariffs and transportation costs.

Eaton and Kortum (2002) make use of the Dornbusch, et al. (1977) framework and develop it further into a multi-country, multi-good model. Additionally, they allow geographical barriers to be asymmetric. The main contribution, however, is that they in a novel way model and estimate technology parameters that further explain comparative advantage differences in manufacturing across countries. In this way, they demonstrate that random productivity shocks suffice to make the Ricardian model empirically relevant.

This relevance has resulted in many extensions and versions of the Eaton-Kortum model since it was first published. For example Alvarez and Lucas (2007) perform a general equilibrium analysis in a setting with balanced trade, from which they estimate gains of trade. Another modification is Shikher's (2011; 2012b) addition of industries that we will follow closely. In Shikher (2011), capital is incorporated into this setting, and simulations confirm the model's ability to make predictions.

Shikher (2011; 2012a; b) is not alone in adding novel elements to the influential Eaton-Kortum model. Chor (2010) also extends to the industry level and combines it with Heckscher-Ohlin type models, adding institutional determinants and factor endowments from recent literature. Waugh (2010) extends the Eaton-Kortum framework to study the asymmetry of trade frictions between developed and developing countries and its importance in explaining the volume of bilateral trade. He argues that an exporter fixed effect, rather than Eaton and Kortum's (2002) importer fixed effect, is the key component for better fit with price and income data. In a recent paper Egger and Nigai (2012) dispute this use of exporter fixed effects and in essence show that the opposite picture is valid.

The abundance of continued developments of the Eaton-Kortum model demonstrates its relevance. Extending it to different sectors, or including other explanatory variables for even better fit to empirics has further allowed and enticed economists to use this model in particular for policy and counterfactual simulations. For example, Caliendo and Parro (2011) estimate the trade and welfare effects of NAFTA while Yaylaci and Shikher (forthcoming) evaluate KORUS. Tombe and Winter (2012) apply it to within-country trade and di Giovanni, Levchenko and Zhang (2011) evaluate the impact of China's technological growth and trade integration in different settings.

Trade and Pollution Havens

Amidst the numerous extensions to the seminal Eaton and Kortum (2002) model, only few have thus far been applied to environmental issues, especially involved in studying air pollutants and testing the pollution haven hypothesis. One such case is Broner, Bustos and Carvalho (2012) who examine whether countries with weak environmental regulation have a comparative advantage in a "dirty" rather than a "clean" sector. They discover that this is the case and that the effect is quantitatively important, which is stronger than much of previous literature and may be a result of the novel use of the Eaton-Kortum model. Erdogan (2009) investigates a similar question by incorporating factor endowments, environmental regulation and two manufacturing sectors into the Eaton-Kortum framework. Domestic environmental policies as well as trade liberalization are then simulated. She finds that uniform OECD pollution taxes as well as trade liberalization is most efficient in reducing pollution. Instead of air pollutants, Wang (2011) studies climate change policy effects on U.S. imports. He finds that countries that commit to the Kyoto protocol export less in industries with high CO_2 emissions, a pattern that emerges after the protocol went into effect.

However, these applications do not consider BCA policy, which we aim to simulate. Furthermore, they only take into account either industries, simulations or greenhouse gases. We aim to combine these three aspects, as well as consider the diverging emission patterns of the countries in our study.

2.3 Eaton-Kortum vs. Armington Framework in Simulating BCA

The environmental economic literature related to our setting has thus had a rather narrow focus. In either evaluating leakage and competitiveness effects on countries with stringent CO_2 policies, or focusing on a subset of OECD countries or industries in theoretical partial equilibrium models, few apply a broader perspective. As Gros (2009, p.12) acknowledges that "climate change policy is motivated in the first instance by a concern for global welfare. Hence one should not look at these issues from a national or regional point of view," there is room for improvement in assessing BCA's global rather than regional effects on emission levels, trade and production. This especially in a context that is both theoretically and empirically convincing.

Theoretical Concepts

Interestingly enough, both the Eaton-Kortum model's and CGE models' general equilibrium framework that explains trade flows stem from the same type of trade models; the gravity equation. The gravity equation trade models' underlying rationale is that the volume of bilateral trade depends on the size of the two economies and the distance between them. It is in the interpretation of this trade volume aspect of the gravity equation that the two types of models' paths diverge and similarities cease to exist. Simply speaking, trade volume depends on two components; consumption and production. CGE models interpret the consumption side that is driven by consumers' preferences, whereas the Eaton-Kortum trade model also considers the production side that is driven by costs of production and trade. The choice of model is thus of importance for the simulation and analysis of results. In particular, the BCA policy that we aim to evaluate affects production of goods rather than consumption and will – if it is implemented – possibly have long run effects on how and where goods are being produced. It is of higher interest to use the production based Ricardian framework rather than the consumption based Armington models that have been standard in the BCA literature so far.

Of importance is also how the chosen model manages to capture features of world trade. In a comprehensive analysis of world trade, Hummels and Klenow (2005) find that the extensive margin (i.e. the set of traded goods) accounts for 62% of the greater export of larger countries. As the

Armington model specification only explains variations in trade through the intensive margin (i.e. the quantity of each traded good), the channel constituting the majority of differences in exports of goods between countries of different size is therefore inherently omitted. Haveman and Hummels (2004) estimate that for the average country 27% of available good categories are not imported at all, and in most of the cases where importing does occur, importers buy from fewer than 10% of potential suppliers. Simulating a policy change in an Armington model with national product differentiation, where all countries purchase goods in all categories from all suppliers, is therefore somewhat unconvincing. This especially since each country's goods is here distinct solely by assumption (Eaton and Kortum, 2001).

On the other hand, the Eaton-Kortum model permits that countries only buy from one supplier even when multiple suppliers exist. Furthermore, the extensions to the model that consider a number of industries allow for that not all countries need to produce all goods. Both of these features speak in favor of using the Eaton-Kortum framework as countries can produce the same good and export to different parts of the world, which is more consistent with the mentioned characteristics of world trade (Eaton and Kortum, 2002; Haveman and Hummels, 2004).

Bringing also the Armington-type model to the sector level, accentuates another extensive margin problem. The often discussed "stuck on zero trade" issue entails that the Armington specification locks in baseline trade patterns and prevents the model from generating large changes in sectors where there is originally little or zero trade. Thus, bilateral trade flows that are originally very small or zero will remain small even in the case of significant changes in trade costs (Zhai, 2008).

As a result, this may reduce or distort the economic and environmental impacts of a policy that alters trade costs, such as BCA. The problem amplifies if zeros are prevalent in bilateral trade data, e.g. due to the inclusion of many developing countries or – as in ENV-Linkages – disaggregation into many different sectors (Zhai, 2008). Grouping countries together into regions, as in Burniaux, et al. (2010), could prevent this from being a major disadvantage. On the other hand, different countries in the same region are then not permitted to react differently to a policy such as BCA, due to variations in e.g. sector specialization, technology and emissions factors (for our country-level simulations, see Appendix A). Accounting for the regional differences in our modification of the Eaton-Kortum model may overcome the "stuck on zero" problem while still making it possible to study the effects on disaggregate levels.

Furthermore, the Armington supposition of national product differentiation and in turn countries' implicit monopoly power over their products may overestimate the terms of trade effect of tariffs. Brown (1987) was the first to show that in such a model, the terms of trade effects of a tariff will be strong, regardless of the size of the imposing country. She questions "the appropriateness of Armington-type models for policy analysis" (p.525) since they will result in positively biased welfare effects of tariffs for imposing countries.

The discussions above aim to illustrate some of the reservations to be kept in mind regarding the results found in the extant economic literature on BCA. As exemplified, the majority focuses on assessing the effectiveness on combating leakage, or simulating welfare effects in the framework of CGE models. Instead we aim to investigate a broader set of variables, namely the policy's impacts on trade flows, welfare, production and emissions levels. We use an extension of Eaton and Kortum (2002) as a means to complement and address some of the above uncertainties. An advantage of using this type of model is that we do not need the Armington assumption, whose validity has been questioned. Further, we are able to apply a model that better captures important features of world trade, in an unexplored area with potential policy implications.

3. Methodology

We implement border carbon adjustment into an extension of the Eaton and Kortum (2002) model, namely Shikher (2011; 2012b). Shikher's (2011; 2012b) key revision of Eaton and Kortum (2002) is to allow for industries and inter-industry linkages in production, rather than modeling the general manufacturing level. Including the industry-dimension is particularly important in our context as different industries have considerably different impact on the environment. Our contribution is the incorporation of BCA policy and emission factors into Shikher's (2012b) extension of the Eaton-Kortum model.

Another important aspect of the Shikher (2011; 2012b), and Eaton and Kortum (2002) model is that it allows for asymmetric trade costs. This, as proposed by Waugh (2010), is not only a vital factor in predicting and explaining income differences across countries but will also be useful for our approach since BCA will be asymmetric and depend on importer, exporter and industry.

3.1 Main Model Elements

Introducing the Model

We have M countries, I industries, where $i = 1, \dots, I-1$ represent manufacturing industries, and the last I is nonmanufacturing. Subscript m is for importing country and x stands for exporting country. Industry i is using (final) industry where j is source (intermediate) industry.

Productivity

The departure point for the Eaton and Kortum (2002) framework we use to model intra-industry production, trade and prices, is Dornbusch, et al. (1977). According to their specification, each industry $i < I$ includes a continuum of goods that are indexed by $l \in [0,1]$ and produced with their individual productivity level $z_{mi}(l)$.

"The description of these productivities is the key element of the Eaton-Kortum model," as acknowledged by Shikher (2012a, p.4). Eaton and Kortum (2002) assume productivities to be random and result from the research and development process of technological innovation. They are drawn independently from the Fréchet distribution (also called type II extreme value)[4] with cumulative distribution function (CDF) $F_{mi}(z) = e^{-T_{mi}z^{-\theta}}$, with technology parameters $T_{mi} > 0$ and comparative advantage parameter $\theta > 1$. Note that although the productivities are drawn independently across industries and countries, this distribution is country-industry specific and depending on technological sophistication.

In Shikher's (2011; 2012b) extension, parameter T_{mi} represents average industry level productivity and is therefore the determinant of comparative advantage across industries. For example, when $T_{mi}/T_{mj} > T_{xi}/T_{xj}$, then country m has a comparative advantage in industry i. Parameter θ is different in that it determines the comparative advantage not across industries, but across goods within each industry. A low θ means that there is more dispersion of productivities among producers, leading to stronger forces of comparative advantage within industries. θ is assumed to be the same across all countries but the estimated value varies in the literature.[5]

Production

In line with Eaton and Kortum (2002) and Shikher (2012b) we assume that labor is the only factor in production of goods, implicitly lumping capital together with intermediate inputs. Similar to Eaton and Kortum (2002) labor is immobile between the manufacturing industries $i = 1, \ldots, I-1$ and nonmanufacturing sector, but mobile between the industries. This is a deviation from Shikher (2012b), where labor is assumed to be fully mobile within the country.

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[4] The use of the Fréchet distribution stems from Kortum (1997) and Eaton and Kortum (1999). Technology for making good l results from innovation over time. The productivities of new inventions are drawn from the Pareto distribution – resulting from having many bad outcomes and few good ones. In any country, only the best technology for any good l will be used. Thus, the technology's productivity is the maximum of the Pareto draws, which defines the Fréchet, or Type II extreme value, distribution.

[5] From trade and disaggregated price data of OECD countries in 1990, Eaton and Kortum (2002) estimate θ = 8.28, which they also use for their simulations. This value is later used by e.g. Chor (2010) and Shikher (2011; 2012b). Anderson and van Wincoop (2004) posit that a θ in between 5 and 10 is valid. Waugh (2010) uses a larger number of countries and finds that for OECD countries, 7.9 is reasonable, while 5.5 is reasonable for non-OECD countries. In a more recent article, using a larger sample, Simonovska and Waugh (2011) find bias in Eaton and Kortum's estimate and suggest a value of 4.12. Alvarez and Lucas' (2007) preferred value is 6.67, resulting from estimations including the 60 largest economies in the late 1990s. We follow Alvarez and Lucas (2007) since we have a similar base year and also include both OECD and non-OECD countries, but perform sensitivity analysis with respect to different values of θ in Section 6.3. For a further discussion on how θ is derived, see Anderson and van Wincoop (2004) and Simonovska and Waugh (2011).

Of particular note is that we further assume that wages are rigid, implying that wages do not adjust in the short run and that unemployment may follow. Concerns for unemployment levels are often one of the main considerations in trade policy discussions. A framework that allows for unemployment may therefore be an important bridge between theory and policy. Wage constraints and rigid prices in relation to international trade and tariff reforms have been discussed and implemented previously by e.g. Brecher (1974), Kreickemeier (2005) as well as Falvey and Kreickemeier (2009). What makes the assumption of rigid wages plausible in our case is that we use a static and short term model. It should still be noted that this assumption implies that our results are likely to show the maximum effect on employment, i.e. the primary impact that would likely be smoothened in a dynamic, long run model.

Costs of Production

The cost c_{mi} of producing (final and intermediate) goods in industry i of country m is composed of labor wage w_m and the price ρ_{mi} of inputs:

$$c_{mi} = w_m^{\beta_i} \rho_{mi}^{1-\beta_i} \tag{1}$$

β_i is labor's share in production in industry i, and is assumed to vary across industries but be constant across countries. ρ_{mi} is the price of inputs and is a Cobb-Douglas function of industry prices where nonmanufacturing price is normalized to 1. In using nonmanufacturing price as numeraire, we assume that parts of it can be traded costlessly.

The use of intermediate goods in the production of goods of industry i is modeled through the following Cobb-Douglas function:

$$\rho_{mi} = \prod_{j}^{I} p_{mj}^{\eta_{ij}} \tag{2}$$

η_{ij} is the share of industry j goods in the input of industry i, such that $\sum_{j=1}^{I} \eta_{ij} = 1, \forall i$. Industries can use nonmanufacturing intermediate goods in their production of final goods. Since nonmanufacturing price is normalized to 1 we can reduce the price of inputs to the following:

$$\rho_{mi} = \prod_{j}^{I} p_{mj}^{\eta_{ij}} = \prod_{j}^{I-1} p_{mj}^{\eta_{ij}} * 1 = \prod_{j}^{I-1} p_{mj}^{\eta_{ij}} \tag{3}$$

Following Eaton and Kortum (2002), we assume perfect competition and constant returns to scale in production; for each good l, price equals average cost. Hence the price p_{mxi} of a good l produced in country x and imported in country m is

$$p_{mxi}(l) = \frac{c_{xi} d_{mxi}}{z_{xi}(l)} \tag{4}$$

d_{mxi} is Samuelson's (1954) classic assumption of iceberg transportation cost. According to this specification, $d_{mxi} \geq 1$ units of an industry i good needs to be shipped from country x in order to deliver one unit of the good in country m, to compensate for costs in form of "shrinkage". Trade costs not only vary across country pairs as in Dornbusch, et al. (1977) and Eaton and Kortum (2002), but also across industries as in Shikher (2011; 2012b). As in Eaton and Kortum (2002) and Shikher (2012b), trade costs do not need to be symmetric but can vary contingent upon the importer.

Given that price $p_{mxi}(l)$ depends on the productivity $z_{xi}(l)$ that is a realization of a random variable, $p_{mxi}(l)$ is also a realization of a random variable (that we can call P_{mxi}). From the productivity CDF $F_{mi}(z) = e^{-T_{mi} z^{-\theta}}$ and the relation $p_{mxi}(l) = \frac{c_{xi} d_{mxi}}{z_{xi}(l)}$, it results that the CDF of P_{mxi} and the distribution of prices p are given by the following:

$$\begin{aligned} G_{mxi}(p) &= \Pr(P_{mxi} \leq p) = \Pr\left(\frac{c_{xi} d_{mxi}}{z_{xi}} \leq p\right) = \Pr\left(\frac{c_{xi} d_{mxi}}{p} \leq z_{xi}\right) = 1 - F_{xi}\left(\frac{c_{xi} d_{mxi}}{p}\right) \\ &= 1 - e^{-T_{xi}(c_{xi} d_{mxi})^{-\theta} p^{\theta}} \end{aligned} \tag{5}$$

Shopping Around/Finding the Best Deal

Consumers from all over the world are assumed to have the same preferences. Unlike the Armington (1969) model, their utility functions are not affected by the origin of a good. Instead they see the same type of goods from different countries as perfectly substitutable. Consumers only care about the price and buy good l at the lowest price available. Hence, the price of any good l in country m is $p_{mi}(l) = min\{p_{mxi}(l), x = 1, \ldots, M\}$.

It follows that the distribution from which this price $p_{mi}(l)$ stems from is

$$G_{mi}(p) = 1 - \prod_{x=1}^{M}[1 - G_{mxi}(p)] = 1 - e^{-\Phi_{mi}p^{\theta}} \tag{6}$$

where $\Phi_{mi} = \sum_{x=1}^{N} T_{xi}\,(c_{xi}d_{mxi})^{-\theta}$ summarizes technology, input costs, and transport costs around the world.

In the choice between different goods, consumers have dualistic preferences. They have Cobb-Douglas preferences over industries, with industry i in country m accounting for a constant share α_{mi} of final consumption. Within an industry, preferences over the continuum of goods are CES (constant elasticity of substitution), with the elasticity of substitution $\sigma > 0$. Thus, consumers are assumed to maximize the following utility objective given a budget constraint of a country's total spending X_m, and facing prices $p(l)$:

$$U = \left[\sum_{i=1}^{I}\left(\int_{0}^{1} Q_{mi}(l)^{\frac{\sigma-1}{\sigma}} dl\right)^{\frac{\sigma}{\sigma-1}}\right]^{a_{mi}} \tag{7}$$

where $Q_{mi}(l)$ is the quantity of good l from industry i consumed in country m. As in Eaton and Kortum (2002), the elasticity of substitution is $0 < \sigma < (1 + \theta)$ in order for the price index to be well defined. Aside from this restriction, the parameter σ can be ignored since it is common for all countries and only appears in the constant term of the price index.

The exact price index for the within-industry CES objective function is $p_{mi} = \gamma\Phi_{mi}^{-1/\theta}$, where $\gamma \equiv \Gamma\left(\frac{\theta+1-\sigma}{\theta}\right)^{\frac{1}{1-\sigma}}$ is a constant. Since γ is constant across countries and industries, we can normalize this definition such that $\gamma = 1$. Then, this price index can also be written as $p_{mi} = \gamma\left[\sum_{x=1}^{M} T_{xi}\,(c_{xi}d_{mx})^{-\theta}\right]^{-1/\theta}$ or $p_{mi} = 1 * \left[\sum_{x=1}^{M} T_{xi}\,(c_{xi}d_{mx})^{-\theta}\right]^{-1/\theta}$.

Continuing to follow Shikher (2012b) closely, we derive expressions for bilateral trade volumes at industry level, by starting with finding the fraction of country m's expenditure on industry i goods that comes from x. Since there is a continuum of goods on the interval $[0,1]$, this fraction is equal to the probability that a country x producer has the lowest price in country m for good l, which is given by

$$\pi_{mxi} \equiv Pr[p_{mxi}(l) \leq min\{p_{msi}(l); s \neq x\}]$$
$$= \int_0^\infty \prod_{s \neq x} [1 - G_{msi}(p)] dG_{mxi}(p) = T_{xi} \left(\frac{c_{xi} d_{mxi}}{p_{mi}} \right)^{-\theta}. \tag{8}$$

This can also be written as X_{mxi}/X_{mi}, where X_{mxi} is country m's spending on industry i goods produced in x and X_{mi} is country m's total spending on industry i goods. Therefore,

$$\pi_{mxi} \equiv \frac{X_{mxi}}{X_{mi}} = T_{xi} \left(\frac{c_{xi} d_{mxi}}{p_{mi}} \right)^{-\theta}. \tag{9}$$

Market Clearing

The market clearing equation is used to determine industry output Q_{xi} and number of workers L_{xi} through the following steps.

Given that L_{xi} is the stock of labor employed by industry i in country x and that β_x is labor's share in output, we have that labor income $w_x L_{xi} = \beta_x Q_{xi}$.

Since total output equals total expenditure we know that

$$Q_{xi} = \sum_{m=1}^{M} X_{mxi} = \sum_{m=1}^{M} \pi_{mxi} X_{mi} = \sum_{m=1}^{M} \pi_{mxi} (Z_{mi} + Y_{mi}) \tag{10}$$

where Z_{mi} is country m's expenditure on industry i intermediate goods and Y_{mi} is its expenditure on industry i final goods. Included in final expenditure is nonmanufacturing industry's consumption of manufactured goods.

Following Eaton and Kortum (2002), we assume a constant demand share $\alpha_i = Y_{mi}/GDP_m$. Thus, each country spends a fixed proportion of its income on goods from each industry.

Following Shikher (2012b) we further know that

$$Z_{mi} = \sum_{j=1}^{J} Z_{mji} = \sum_{j=1}^{J} \eta_{ji} M_{mj} = \sum_{j=1}^{J} \frac{\eta_{ji}(1-\beta_j)}{\beta_j} w_m L_{mj} \tag{11}$$

where Z_{mji} is the spending by industry j on intermediate goods from industry i in country m. M_{mj} is the total expenditure of industry j on intermediate inputs.

From the above definitions, it follows that the market clearing equation is

$$w_x L_{xi} = \beta_x Q_{xi} = \beta_i \sum_{m=1}^{M} \pi_{mxi} \left(\left(\sum_{j=1}^{J-1} \frac{\eta_{ji}(1-\beta_j)}{\beta_j} w_m L_{mj} \right) + \alpha_i Y_m \right). \tag{12}$$

GDP

Since labor is assumed to be the only factor of production, total GDP_m in country m is given by

$$GDP_m = VAQ_m + VAQ_m^{nm} = \left(\sum_{i=1}^{I-1} w_m \, L_{mi} \right) + w_m L_{mI} \tag{13}$$

where VAQ_m and VAQ_m^{nm} is value added in manufacturing and nonmanufacturing output respectively.

Shikher (2012b) assume GDP_m and wage level w_m to be constant. These assumptions imply that workers can move frictionlessly between the manufacturing and nonmanufacturing sectors, such that no unemployment exists. In his model, changes to VAQ_m are simply compensated by reverse changes to VAQ_m^{nm}.

We make a deviation from the assumption of constant GDP and instead postulate that value added from nonmanufacturing VAQ_m^{nm} is constant in the short run. The assumption of constant nonmanufacturing output is also made by Eaton and Kortum (2002) in one of their cases.

Manufacturing output Q_m, and thus VAQ_m, is however allowed to vary depending on technology and trade costs. By allowing total GDP_m to vary through the manufacturing output channel we are thus, unlike Shikher (2012b), able to simulate changes in income.

3.2 Calibrating the Model

The model is given by the above equations (1)–(13). In the model, β_i, η_{ji}, θ, α_i, w_m, d_{mxi}, T_{xi}, and Y_m are parameters that we find from the data. GDP_m, L_{mi}, p_{mi}, c_{mi} and π_{mxi}, are endogenous variables that we solve for by calibrating the model. For reference, the key parameters and how they are obtained are presented in Table 1.

Table 1: Key Parameters

Name	Details	Source
$\boldsymbol{\beta_i}$	Labor shares	Wage and output data
$\boldsymbol{\eta_{ij}}$	Intermediate goods shares	Input-output tables
$\boldsymbol{\theta}$	Technology (comparative advantage) parameter	Alvarez and Lucas (2007)
$\boldsymbol{d_{mxi}}$	Trade costs	Estimated from trade and output data
$\boldsymbol{T_{mxi}}$	Technology parameters	Endogenously determined
$\boldsymbol{L_m}$	Industry employment	Estimated from output data and labor shares
$\boldsymbol{\alpha_{mi}}$	Demand share of industry in income	Production and trade data
$\boldsymbol{B_{mxi}}$	BCA tariff	Emissions data

Calculating Expenditure

In order to find $X_{mi} = Q_{mi} - EX_{mi} + IM_{mi}$, i.e. country m's expenditure on goods in industry i, we make use of X_{mmi}. X_{mmi} is country m's expenditure on industry i goods produced domestically and is calculated from the data by the following:

$$X_{mmi} = Q_{mi} - EX_{mi}. \tag{14}$$

EX_{mi} is total exports of goods from industry i in country m, to all other countries $EX_{mi} = \sum_{x=1,i\neq m}^{M} X_{mxi}$. Q_{mi} is country m's total production of goods in industry i. X_{mxi} is country m's expenditure on goods in industry i from country x.

Demand Share

The demand share α_{mi} is the proportion of country m's total income spent on final goods from industry i, i.e. $\alpha_{mi} = \frac{Y_{mi}}{GDP_m}$.

In order to calculate α_{mi} we make use of the following definitions. In any industry i, final spending equals total spending minus expenditures on intermediates, i.e. $Y_{mi} = X_{mi} - Z_{mi}$.

Thus for each country m, $Y_m = \sum_{i=1}^{I-1} X_{mi} - Z_{mi}$. Total expenditure in country m on goods in industry i is $X_{mi} = Q_{mi} - EX_{mi} + IM_{mi}$. Total expenditure in country m on intermediate goods in industry i is

$$Z_{mi} = \sum_j p_{mi} N_{mji} = \sum_j \rho_{mj} N_{mj} \eta_{ji} = \sum_j \eta_{ji}(1-\beta_j)Q_{mj} \tag{15}$$

where N_{mj} is country m's industry j's expenditure of on all intermediates.

These are combined to form the following definition of the parameter α_{mi}:

$$\alpha_{mi} = \frac{1}{GDP_m}\left(Q_{mi} - EX_{mi} + IM_{mi} - \sum_j^{J-1} \eta_{ji}\left(1-\beta_j\right)Q_{mj}\right). \tag{16}$$

The demand shares are first calculated separately for each country and industry, and then averaged across all countries to form the industry-specific demand share parameter α_i.

Gravity Equation

Bilateral trade costs, d_{mxi} where m is importing country, x is exporting country and i is industry, are found using Shikher's (2012b) extension of Eaton and Kortum (2002). Trade costs are of type Samuelson iceberg trade costs, as described above. Shikher (2012b) allows trade costs to vary across industries, which is of importance due to the extent to which our policy varies across industry. Further, he allows for asymmetric trade costs (i.e. where $d_{mxi} \neq d_{xmi}$), which is of significant importance in capturing features of world trade as studied by Waugh (2010).

Besides these extensions, trade costs are unobservable and are therefore, similar to what is standard in gravity literature, proxied by:

$$\log d_{mxi} = d_{ki} + b_i + l_i + f_i + m_{mi} + \delta_{mxi} \tag{17}$$

where all estimates are industry specific.

d_{ki} $(k = 1, \dots, 6)$ is the effect of physical distance lying in the kth interval where the intervals are [0,375), [375,750), [750,1500), [1500,3000), [3000,6000), and [6000,maximum) miles, as from Eaton and Kortum (2002). When estimating the equation, we drop d_{1i} for all industries i.

b_i, l_i and f_i are the effects of sharing a border, having the same official language and having a free trade agreement.

m_{mi} is the industry specific destination effect, which is Eaton and Kortum (2002)'s and Shikher (2012b,c)'s specification that makes asymmetric trade costs possible.

δ_{mxi} is the error term encompassing the remaining variation of trade costs. This error term includes a country-pair specific effect $({\delta^2}_{mxi})$ as well as a one-way effect $({\delta^1}_{mxi})$. I.e., $\delta_{mxi} = {\delta^1}_{mxi} + {\delta^2}_{mxi}$, where ${\delta^2}_{mxi} = {\delta^2}_{xmi}$, but ${\delta^1}_{mxi} \neq {\delta^1}_{xmi}$.

Estimating Trade Costs

We know from above (equation (9)) that $\pi_{mxi} \equiv X_{mxi}/X_{mi} = T_{xi}\left(\frac{c_{xi}d_{mxi}}{p_{mi}}\right)^{-\theta}$. This relationship can be used to solve for the technology parameters T_{xi} as well as for trade costs d_{mxi}. This is done in several steps, among one is to find the ratio between country m's spending on industry i goods from any other country x, and its spending on domestic goods:

$$\frac{\pi_{mxi}}{\pi_{mmi}} = \frac{X_{mxi}}{X_{mmi}} = \frac{T_{xi}}{T_{mi}} d_{mxi}^{-\theta} \left(\frac{c_{xi}}{c_{mi}}\right)^{-\theta}. \tag{18}$$

$T_{xi}c_{xi}^{-\theta}$ is a measure of international competitiveness of country x's industry i, taking both technology and production costs into account. It can be simplified as $S_{xi} = T_{xi}c_{xi}^{-\theta}$. Combining this with the logs of the above expression forms the following:

$$\log \frac{X_{mxi}}{X_{mmi}} = -\theta \log d_{mxi} + \log S_{xi} - \log S_{mi}. \tag{19}$$

Combining this expression with the approximation of $\log d_{mxi}$ from the above gravity equation forms the estimating equation for trade costs and the international competitiveness measure S_{xi}:

$$\log \frac{X_{mi}}{X_{mmi}} = -\theta(d_{ki} + b_i + l_i + f_i + m_{mi} + \delta_{mxi}) + \log S_{xi} - \log S_{mi}. \tag{20}$$

This estimation can be simplified with the use of importer and exporter dummies; in the following equation $D_{xi}^{exp} = \log S_{xi}$ is the exporter dummy and $D_{mi}^{imp} = -\log S_{mi} - \theta m_{mi}$ is the importer dummy. We follow Shikher (2012b) and normalize these estimates with respect to the U.S. such that $D_{us,i}^{exp} = D_{us,i}^{imp} = 0$.

$$\log \frac{X_{mxi}}{X_{mmi}} = -\theta d_{ki} - \theta b_i - \theta l_i - \theta f_i + D_{xi}^{exp} + D_{mi}^{imp} - \theta \delta_{mxi}. \tag{21}$$

The destination-industry specific import barriers can then be calculated as

$$m_{mi} = -\frac{1}{\theta}\left(D_{mi}^{exp} + D_{mi}^{imp}\right). \tag{22}$$

To obtain the fitted values and the estimates for D_{xi}^{exp} and D_{mi}^{imp} – the latter used in estimating technology parameters in below – we use ordinary least squares estimation of equation (21).

Once the estimates are obtained, we can then calculate trade costs $d_{mxi} = \exp(d_{ki} + b_i + l_i + f_i + m_{mi} + \delta_{mxi})$ by adding the constant with the fitted values. Finally, we divide by $-\theta$ and take the exponent to yield d_{mxi};

$$\begin{aligned} &\frac{-\theta d_{ki} - \theta b_i - \theta l_i - \theta f_i + D_{mi}^{exp} + D_{mi}^{imp} - \theta \delta_{mxi}}{-\theta} \\ &= \frac{-\theta d_{ki} - \theta b_i - \theta l_i - \theta f_i - \theta m_{mi} - \theta \delta_{mxi}}{-\theta} \\ &= d_{ki} + b_i + l_i + f_i + m_{mi} + \delta_{mxi} = \log d_{mxi}. \end{aligned} \tag{23}$$

Setting domestic trade costs, in conjunction with the iceberg specification, as $\log d_{mmi} = 0$, the minimum trade cost should intuitively be $e^0 = 1$. However, our minimum estimated trade cost lower than one, as found in Table 2, may reflect the development of a country's market; domestic geographical and institutional factors could in reality increase this number. If the importing country has a more developed, well-integrated market, trade costs may be comparatively lower. It can also be a consequence of subsidies directed at increasing trade in a specific industry. Thus, as a low trade cost may contain important information that influences trade flows we decide not to manipulate the data but to keep the estimated values. Manually adjusting trade costs smaller than one, as in both Shikher (2011) and Waugh (2010), leads to bias as criticized by Egger and Nigai (2012).

In further contrast to Shikher (2011), our average trade cost is 3.07. This is higher than what is estimated by Shikher (2011) and Anderson and van Wincoop (2004), who estimate 2.27 and 1.7 respectively. One reason is their choice of only including OECD countries that generally have a lower trade cost. Additionally, Shikher (2011) uses a higher value of the comparative advantage parameter θ, which further lowers trade costs.

Table 2: Trade Costs Summary Statistics

	Min	Average	Max
Total	0.22	3.07	9.18

Estimating Technology

Following the estimation of trade costs we estimate technology parameters T_{mi} that are endogenously determined by the model. To do this, we use the fact that $S_{mi}/S_{us,i}$ is a by-product of the above gravity equation estimation. In particular, we make use of the coefficients of D_{mi}^{exp}, which have been normalized with respect to the U.S., and of the equality $D_{mi}^{exp} = \log(S_{mi})$. Thus, the level $S_{mi} = T_{mi}c_{mi}^{-\theta}$ for any country m determines its level of international competitiveness in industry i relative to the U.S. where $S_{us,i} = 1$:

$$\log \frac{S_{mi}}{S_{us,i}} = \log \frac{T_{mi}}{T_{us,i}} - \theta \log \frac{c_{mi}}{c_{us,i}}. \qquad (24)$$

In order to get technology parameters T_{mi} we need to remove costs c_{mi} – consisting of input prices and wages – from S_{mi}. The first step in doing this will be to use that $\frac{X_{mmi}}{X_{mi}} = T_{mi}\left(\frac{c_{mi}}{p_{mi}}\right)^{-\theta}$. When we take logs and express this in relative terms to the U.S. we obtain

$$\log\frac{X_{mmi}}{X_{mi}} / \frac{X_{us,us,i}}{X_{us,i}} = \log\frac{T_{mi}}{T_{us,i}} - \theta\log\frac{c_{mi}}{c_{us,i}} + \theta\log\frac{p_{mi}}{p_{us,i}}. \tag{25}$$

We then obtain the expression for industry prices, by subtracting equation (24) from equation (25). Then this is combined with equation (3) to find the following expression for input prices

$$\log\frac{\rho_{mi}}{\rho_{us,i}} = \frac{1}{\theta}\sum_{j=1}^{I-1}\eta_{ij}\left(\log\frac{X_{mmj}}{X_{mj}} / \frac{X_{us,us,j}}{X_{us,j}} - \log\frac{S_{mj}}{S_{us,j}}\right). \tag{26}$$

If this is combined with equations (1) and (24) we get the following expression of the technology parameters

$$\log\frac{T_{mi}}{T_{us,i}} = \log\frac{S_{mi}}{S_{us,i}} + \theta\beta_i\log\frac{w_m}{w_{us}} + (1-\beta_i)\sum_{j=1}^{I-1}\eta_{ij}\left(\log\frac{X_{mmj}}{X_{mj}} / \frac{X_{us,us,j}}{X_{us,j}} - \log\frac{S_{mj}}{S_{us,j}}\right). \tag{27}$$

After the estimation of these parameters, they are used in simulating the baseline model. Since variables such as employment, trade levels and production levels are interdependent, these are determined through iterative procedures in MATLAB (see Appendix B).

3.3 Implementing BCA

To understand how we aim to incorporate BCA in the model, it is of use to first be familiar with the policy discussions and considered designs. No consensus has thus far been reached on the design of potential BCA policies and a variety of possibilities are under discussion. There are, however, some options that are more likely than others, as indicated by academic literature and policy briefings.

Design and Scope of BCA Policy

A BCA policy could be implemented either as plain import tariffs or as a combination of tariffs and export rebates. The magnitude of a possible tariff would be related to the level of CO_2 emissions of imports as well as stringency of domestic policy. Tariff levels could either be standardized depending on exporting countries and/or industries or to some extent be differentiated between individual producers. Standardized charges would be based on the carbon content of either the imported or the domestic good. In the case where export rebates would be implemented, these would entail an export rebate for goods with high CO_2 emissions (Persson, et al., 2010).

A wide range of BCA tariffs have been evaluated in the literature. In relation to other BCA studies, Burniaux, et al.'s (2010) tariff of \$63/MtCO_2 (metric ton carbon dioxide emissions) is located in the high end of the spectrum. It is for example above the highest estimate of McKibbin and Wilcoxen (2009) who choose tariff levels between \$20 and \$40. For the sake of comparison with most of the extant literature, we set our base level of the CO_2 tariff at $\tau = \$40/\mathrm{MtCO_2}$. This is within the range of social cost of carbon of 10-100€/MtCO_2 as suggested in (EEAG, 2012), and comprises one of the larger values in the \$4 - \$48 interval suggested by Elliott, et al. (2010). Bao, et al. (2011) implement a \$50/MtCO_2 tax in their analysis, as well as perform sensitivity checks of \$20/MtCO_2. We also evaluate tariff levels that are among the lower and higher bounds of the wide range of values being discussed – namely at the prevalent level \$20 and at \$63 as in Burniaux, et al. (2010).

We follow Burniaux, et al. (2010) in focusing on the introduction of tariffs rather than export rebates. Several studies have evaluated BCA in combination with a domestic tax, but we will restrict our focus to BCA implicitly assuming that the coalition countries already pursue a more stringent CO_2 policy than non-coalition countries, consistent with data from the World Bank (2008).

Coalition Countries

Most BCA studies have focused on EU implementation (e.g. Burniaux, et al., 2010; Winchester, et al., 2010). The predominant focus on the EU is explained by that "among larger industrialized countries, the European Union is pushing most vividly for stringent emission regulations" (Böhringer, Fischer and Rosendahl, 2011, p.25) and on the fact that the EU has taken what can be seen as a first step to BCA implementation, by including aviation – irrespective of carrier nationality – in its emissions trading scheme from the beginning of 2012 (Malina, et al., 2012).

There are however several other OECD countries such as the U.S., Japan and Australia that have considered BCA implementation (Persson, et al., 2010). Some previous studies have therefore examined scenarios where also other coalitions impose BCA on imported goods (Böhringer, et al., 2011; Burniaux, et al., 2010). As we aim to closely relate to both the policy debate and previous research, we follow Burniaux, et al. (2010) and simulate two coalition scenarios. In our base case, only the EU member states in year 2000 implement BCA tariffs. In the additional case we let BCA be imposed by all Annex I parties of the Kyoto protocol, as reported to UNFCCC in 1992 (Appendix B, Table B.1).

Industry Coverage – Energy Intensive Industries

In terms of the product scope, BCA could cover everything from a limited set of products to a more extensive list that also includes downstream products. Discussed by e.g. Persson, et al. (2010), there is a trade-off between the risk that a more limited list without downstream products leads to increased leakage, and the increased administration costs that could be the effect of a more extensive list. Current proposals "seek to address these concerns by limiting the scope of coverage to only those sectors most exposed to leakage," – i.e. energy intensive sectors exposed to trade (Sanctuary, 2012, p. 24). Consequently, most studies simulate BCA imposed on emission intensive products and inputs. We follow Burniaux, et al. (2010), as well as Fischer and Fox (2011) and simulate an implementation of BCA on the equivalent industries in our setting, i.e. Chemicals, Basic Metals, Fabricated, Paper and Minerals. As seen in Table 3 this is essentially comparable with the industries with large embodied CO_2 emissions factors, as indicated by Nakano, et al. (2009). The only anomaly is our industry "Other"[6]. Despite its rather high emission factor it will not be subject to BCA tariffs in our simulation, partly because we aim to follow the implementation of Burniaux, et al. (2010), and partly because it contains a wide range of sub-industries with varying emissions.

[6] The industry Other consists of e.g. rubber, plastics and furniture

Table 3: Average Embodied CO_2 Emission Factor by Sector (Base Case, kg-CO_2/\$, 2000)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textiles	Transport Equipment	Wood
Coalition	1.68	1.22	0.39	0.42	1.60	0.59	0.46	0.42	0.26	0.37
OECD, Non-Coalition	3.12	2.30	0.67	0.68	1.95	1.36	0.66	0.64	0.46	0.68
Non-OECD, Non-Coalition	5.07	4.41	1.79	1.24	4.77	3.19	1.70	1.42	1.37	1.41
All countries	3.16	2.52	0.89	0.75	2.63	1.61	0.89	0.78	0.57	0.78
EII	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No

BCA in the Model

To incorporate BCA in the model, a dummy variable B_{mxi} is first of all used to determine whether a tariff will be imposed. This will be the case only in EIIs, when the importer (and not the exporter) is part of the imposing bloc and when the exporter's emission level exceeds that of the importer, i.e.:

$$B_{mxi} = \begin{cases} 1, m \in \{Coalition\} \wedge x \notin \{Coalition\} \wedge i \in \{EII\} \\ 0, \qquad \text{otherwise} \end{cases} . \quad (28)$$

The tariff is then determined by first calculating the difference in emission levels between the two countries, in metric ton (Mt) CO_2/\$1,000 in output. These differences multiplied by the tariff level (\$40/MtCO_2 in the base case) are then used to find the tariff level bca_{mxi}.

$$bca_{mxi} = B_{mxi} * max\{emis_{xi} - emis_{mi}, 0\} * \tau \quad (29)$$

Total BCA revenues are found by multiplying the tariff level with the output value of these goods (i.e. excluding trade costs). This is consistent with the way emission levels are calculated by Burniaux, et al. (2010).

BCA can be thought of as an addition to the previously estimated trade costs.

$$dbca_{mxi} = d_{mxi} + bca_{mxi} \quad (30)$$

However, unlike the other trade costs, the BCA policy is assumed to give rise to tariff revenues in the importing country.

$$Revenue_{mxi} = \frac{trade_{mxi} * bca_{mxi}}{dbca_{mxi}} \quad (31)$$

The revenue is assumed to be added to the importing country's GDP and, similarly, be spent on a variety of final goods according to the demand shares α.

$$GDP_m = VAQ_m + VAQ_m^{nm} + Revenue_m \quad (32)$$

where $Revenue_m = \sum_{i=1}^{I} \sum_{x=1}^{M} \frac{trade_{mxi} * bca_{mxi}}{dbca_{mxi}}$.

Thus, the introduction of BCA affects the economy through various mechanisms; distortion of prices, increased production costs (both for EII and non-EII through the input channel) and increased revenues for coalition countries.

Again, due to the interdependence of revenues, trade levels and production levels, these are determined through iterative procedures in MATLAB.

Calculating Emissions

Apart from the economic variables, we simulate and estimate the effects of BCA on emission levels. There are two approaches to measuring the level of emissions; consumption based emissions (emissions embodied in a country's or industry's consumption of goods) vs. production based emissions (quantity emitted in a country's or industry's production process).

Consumption based emissions for country m and industry i are calculated as the total value spent on goods from each country $x = 1, \ldots, M$ in industry i multiplied by country $x's$ emission factor $emis_{xi}$ in that industry. The emission factor originates from calculations made by Nakano, et al. (2009), as described further in Section 4.4.

$$CO2_{mi}^{Consumption} = \sum_{x=1}^{M} emis_{xi} * X_{mxi} \quad (33)$$

Production based emissions are calculated by

$$CO2_{mi}^{Production} = emis_{mi} * Q_{mi} \quad (34)$$

Lastly it is of interest to evaluate the emissions embodied in trade, which as in Nakano, et al. (2009) is defined as consumption based emissions minus production based emissions and calculated as follows:

$$EEBT_{mi} = CO2_{mi}^{Consumption} - CO2_{mi}^{Production} = \left(\sum_{x=1}^{M} emis_{xi} * X_{mxi}\right) - \ emis_{mi} * Q_{mi}$$

$$= \left(emis_{mi}Q_{mi} - emis_{mi}EX_{mi} + \sum_{x=1, x\neq m}^{M} emis_{xi}\, IM_{mxi}\right) - \ emis_{mi} * Q_{mi} \qquad (35)$$

$$= emis_{mi}EX_{mi} + \sum_{x=1, x\neq m}^{M} emis_{xi}\, IM_{mxi}.$$

4. Data

4.1 Choice of Industries and Countries

Previous applications of the Eaton-Kortum model have largely been based on either few, mainly OECD countries (Erdogan, 2009; Shikher, 2011) or few sectors (Alvarez and Lucas, 2007; Waugh, 2010). However, policies aiming at reducing CO_2 emissions are likely to have very different impacts on countries depending on their level of development as well as on their industry specialization. To study implications and draw relevant conclusions, we therefore see the need to include industry level data from both OECD and non-OECD countries.

To use only consistent data from renowned sources, we restricted our analysis to 28 countries. Although not assumed to be a true representation of the world economy as a whole, these countries[7] cover different levels of industrialization, different specializations as well as different approaches to CO_2 mitigation policies. Together they account for a large share of world trade flows (CEPII, 2012).

Much of the extant literature examining bilateral trade flows uses manufacturing data. We analyze the following industries within the manufacturing sector: Food, Textiles, Basic Metals, Wood, Paper, Chemicals, Minerals, Fabricated Machinery (referred to as Fabricated), Transport Equipment, and Other. Petroleum refining was omitted due to limitations on both trade, production and emissions data.

4.2 Trade and Production Data

The data on bilateral trade, output, wages and employment is mainly derived from the TradeProd database (CEPII, 2012). It uses UN COMTRADE as primary source for trade data and the UNIDO database for variables related to production (Mayer, Paillacar and Zignago, 2008).

The database provides positive values for most of the countries and industries in our study. However, in certain cases, no data was reported for the base year 2000. As is often discussed in the trade literature (e.g. Santos Silva and Tenreyro, 2006; Helpman, Melitz and Rubinstein, 2008), this may depend either on incomplete data collection (missing values or below threshold reporting

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[7] Argentina, Australia, Austria, Brazil, Canada, China, Czech Republic, Germany, Finland, France, Great Britain, Greece, India, Indonesia, Israel, Italy, Japan, Korea, New Zealand, Norway, Poland, Portugal, Russia, South Africa, Spain, Sweden, Turkey, United States.

value), or on there being no trade/output (zero values). In the TradeProd dataset, it is not possible to distinguish between differing causes of zeros in the data. In these cases, we instead used the mean values reported for the years 1998-2002, which were inflation-adjusted with data from the World Bank (2012b). In some cases, production data was still missing and the dataset was complemented with data directly from UNIDO (2012).[8] Thereafter, the data was aggregated into 10 industries according to the scheme in Tables B.7 – B.15 in Appendix B. In certain instances however, there was still no trade data at the industry level.

Zeros in bilateral trade flows are of concern due to the log-linear specification of the gravity equation. Dealing with the problem inappropriately may lead to bias (Santos Silva and Tenreyro, 2006). Simply eliminating the observations with zeros or missing values is rather frequent in trade literature and applied by e.g. Waugh (2010) and Frankel and Romer (1999). Others, e.g. Shikher (2012b), have raised trade costs to infinity as a means of predicting zero flows. However, this would bring about the "stuck on zero trade" problem of the Armington model and also be an obstacle when estimating technology parameters and simulating policy. Instead we follow McCallum (1995), Raballand (2003) and others and substitute zero/missing trade flows with a small value ($1). The risk of substantial bias is not likely to be grave as the number of zeroes in our dataset is very small (0.61%). E.g. McCallum (1995) shows that with a corresponding number of 1% this procedure is not probable to be important for the estimation.

The data on total manufacturing wages was compiled in a similar method as output and trade data. In cases where no data was available for the base year, the inflation-adjusted mean during the period 1998-2002 was used.[9] GDP data for the base year was derived from the World Bank (2012a).

Labor Share

To calculate the labor share β_x by country we used data for countries with complete production, labor and wage data by ISIC code in 2000. However, we allowed for one code to be missing since

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[8] In the UNIDO database, data is available in ISIC Revision 3 only. We therefore followed conversion tables closely to convert to ISIC Revision 2. For product groups where the conversion was not evident, our method is described in Appendix B.

[9] For Australia, data on total manufacturing wages was still missing. We therefore proxied this with the mean labor share of the Australian industries where data was available. For China, no wage data was available in CEPII. We therefore used inflation-adjusted data on total manufacturing wages for year 2003 from UNIDO (2012). The derived levels seemed highly reasonable when compared with other countries in the dataset.

many countries aggregate e.g. ISIC industries 371 and 372 when reporting the data. The 15 countries are very diverse and include both OECD and non-OECD countries of very different income levels (see Table B.3 in Appendix B). Labor shares by industry were found for each of these countries by dividing labor compensation with output. For each of the industries an average labor share was found and allowed to represent all countries, similar to Shikher (2012b). When the values are compared with those obtained by Shikher (2012b), the inter-industrial pattern is very similar but labor shares are generally slightly lower, probably due to the inclusion of non-OECD countries.

Industry Share

Industry shares in intermediate goods, η, are found by the use of OECD input-output tables for year 2000 or neighboring years according to Table B.3 in Appendix B. Many economists, e.g. Chor (2010), and Shikher (2012b) have used matrices only for one country or for a minority of the sample. di Giovanni and Levchenko (2010) provide evidence that input-output tables are very similar across countries at a crude level of aggregation, and Levchenko and Zhang (2011) perform robustness tests which confirm this. In order to take into account the different development levels and specializations of the countries in our sample we however chose to calculate η on input-output matrices for all 28 countries instead of Shikher's (2011) seven countries. After finding individual η for each country, these were averaged across countries and used to estimate the model.

Table 4: Demand and Labor Shares

Industry	α_i (demand share of industry i in income)	β_i (labor share in industry i)
Basic Metals	0.009	0.103
Chemicals	0.058	0.103
Fabricated	0.237	0.158
Food	0.251	0.087
Minerals	0.050	0.187
Other	0.117	0.169
Paper	0.046	0.145
Textile	0.059	0.165
Transport Equipment	0.156	0.121
Wood	0.016	0.139

4.3 Geographical Data

Physical Distance

Following Chor (2010), Alvarez and Lucas (2007), Waugh (2010) and others we let the distance in miles between capitals be a determinant of geographic barriers. The data is derived from the CEPII (2012) GeoDist database, where it has been calculated by the great circle method. Although the data indicates distances in 2004, this should not have an impact on the values since none of the countries in the sample had a change of capital city between 2000 and 2004.

In their estimation, Eaton and Kortum (2002), Shikher (2011; 2012b) and other extensions assume that there are different trade barriers for six different distance intervals. These intervals are, in miles, set to [0, 350], [350, 750], [750, 1500], [1500, 3000], [3000, 6000], [6000, maximum). Eaton and Kortum (2002) also performed the estimation with a quadratic functional form, which is more standard in literature, but found no differences that are of significance. The step-wise method has the advantage of being flexible and imposing little structure on how barriers to trade vary with distance, which increases its robustness to specification errors (Anderson and van Wincoop, 2004). We will therefore follow the Eaton and Kortum (2002) approach and use the same distance intervals.

Language, Contiguity and FTAs

From the CEPII (2012) GeoDist database we also derive dummy variables for whether a country pair has a common official language or are contiguities. We further take into account whether the two countries have a free trade agreement (FTA). This dummy variable is based primarily on Rose (2004), where it equals one when both countries were members of the ASEAN, EEC/EC/EU, US-Israel FTA, NAFTA; ANZCERTA, SPARTECA or Mercosur in the end of 1999. To this, we included data from the WTO (2012) and EFTA (2012) webpages. Thus, the CEFTA, the EFTA (and their respective agreements) were included, as well as EU-Turkey, Canada-Israel and Turkey-Israel agreements.

4.4 Emissions Data

Emission factors by country and industry are needed to calculate aggregate emission levels and to calculate potential BCA tariffs. We derive this data from Nakano, et al. (2009), who in their turn use internationally comparable input-output tables, trade data and emissions data from OECD. They make use of interdependent relations between different trade partners and industries to solve for emissions. For example, emissions from utility, a CO_2 intensive intermediate sector, are allocated according to input output tables, and transportation emissions are allocated according to each sector's use of petroleum inputs. After this procedure, CO_2 emission factors are calculated by dividing emissions stemming from one sector by that sector's output. (The table of embodied emissions by country and industry can be found in Appendix B; Table B.16)

For a majority of the 28 countries, production and emissions data for Basic Metals is provided at an aggregate level, covering both ferrous and non-ferrous metals. However, certain countries provide only separate data for the two groups. Nine of these 13 countries (Appendix B) provide production data for both industries for the base year 2000. The average proportion between ferrous and non-ferrous metals in the production of metals in these countries is used to generate an aggregate estimate of emission levels in the Basic Metals industry when this is missing. In the Paper and Transport Equipment industries, emission factors for Russia are missing. We have used all other countries' average of the industry's share in the sum of all other industries to find these missing values.

5. Results

The following section presents the impact of the base case scenario of BCA implementation, i.e. when the EU countries impose a tariff of $40/Mt$CO_2$ on the difference in emission levels in energy intensive industries. The effects on trade flows, production, emissions and income will be evaluated. The changes are presented in real terms.

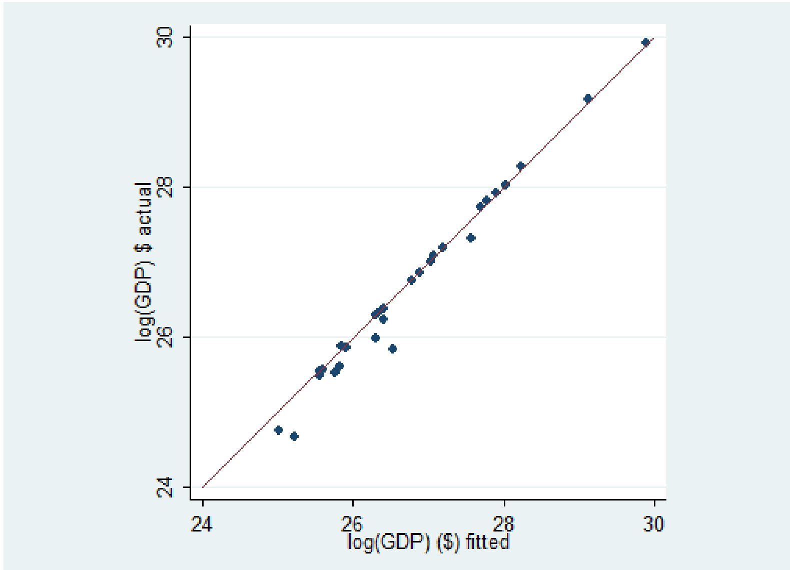

Figure 1: Fitted vs. Simulated log(GDP)

In order to calculate the before and after implementation effects, we simulate a reference case using the calibrated parameters in Section 3 and data described in Section 4. GDP in the reference case is highly correlated with actual GDP – approximately 0.996, where low-income countries are in general slightly overestimated as displayed in Figure 1.

The results are presented separately for three sub-groups of our 28 countries; coalition (EU member countries in year 2000), OECD non-coalition and non-OECD non-coalition countries.[10] The rationale behind the disaggregation is the significant differences between the countries of each group that may have important influences on policy implications. Table 5 summarizes baseline key figures from the reference simulation to illustrate the large differences between the groups at the outset.

[10] Coalition (EU): Austria, Finland, France, Germany, Great Britain, Greece, Italy, Portugal, Spain, Sweden. OECD, non-coalition: Australia, Canada, Czech Republic, Japan, Korea, New Zealand, Norway, Poland, Turkey, United States.
Non-OECD, non-coalition: Argentina, Brazil, China, India, Indonesia, Israel, Russia, South Africa

Table 5: Summary Table for Baseline Values

	GDP per capita (in $1,000)	Consumption Emissions per capita (in $MtCO_2$)	Production Emissions per capita (in $MtCO_2$)	Exports per capita (in $1,000)
Coalition	17.33	6.84	5.89	4.52
OECD, Non-Coalition	22.38	11.62	8.90	3.93
Non-OECD, Non-Coalition	0.94	1.64	2.34	0.37
All countries	5.87	3.72	3.72	1.32

Table 6 summarizes the impact of BCA implementation on key variables where changes are calculated with respect to the baseline simulation. The results are further described in the rest of this section, while complete tables are found in Appendix A.

Table 6: Summary Table (% Change)

	Manufacturing Output (Q)	Manufacturing Employment (L)	Exports (EX)	Imports (IM)	GDP	Production-Based Emissions	Consumption-Based Emissions
Coalition	1.09%	1.17%	0.71%	0.29%	0.89%	1.56%	-1.69%
OECD, Non-Coalition	-0.07%	-0.37%	-0.20%	-0.08%	0.00%	-0.31%	-0.07%
Non-OECD, Non-Coalition	-0.53%	-0.43%	-0.66%	-0.65%	-0.06%	-1.67%	-1.15%
All countries	0.17%	-0.32%	-0.02%	-0.02%	0.22%	-0.69%	-0.69%

5.1 BCA Effects on Emissions

Changes in emission levels due to the introduction of BCA tariffs vary considerably with the method of measurement. It is, for example, evident in Figure 2 that coalition countries as a group increase their production based emissions while their consumption based emissions decrease. Both changes are consequences of the higher prices on imported goods with high embodied carbon content from non-coalition

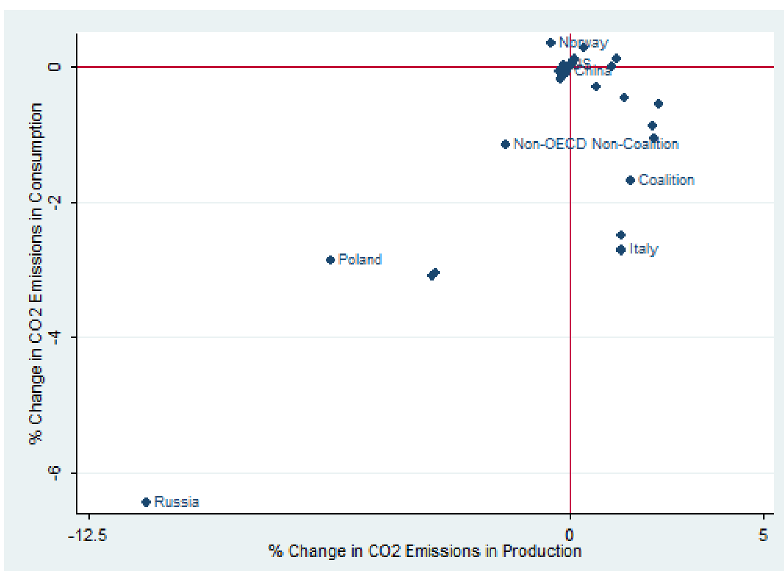

Figure 2: % Change in CO_2 Emissions

countries. Higher prices result in making low polluting imports and domestic production more competitive. For both groups of non-coalition countries (OECD and non-OECD) on the other hand, consumption as well as production emissions decrease. The changes are largest for non-OECD countries, following their generally higher emission factors (as seen in Section 3.3), in turn causing larger tariffs and decreased competitiveness. Decreased competitiveness means that production (manufacturing output) diminishes, which is followed by a contraction in labor income and therefore consumption. Ultimately this lowers both emission level measurements.

The density graph in Figure 3 illustrates emissions embodied in trade (EEBT) per capita for coalition and non-coalition, non-OECD countries before and after BCA implementation. Contrasting these groups is of main interest as one of the main purposes of imposing BCA is to reduce carbon leakage to emerging countries. The difference in EEBT before the BCA policy, when coalition countries are net-importers and non-OECD countries are net-exporters of CO_2 gives certain weight to carbon leakage. It thus indicates that there exist incentives for emission intensive production activities to take place in lower-income countries to then be consumed as inputs or final goods in coalition countries. These incentives can be in form of more lenient regulation, lower pollution taxes or fossil fuel subsidies. After the BCA policy is introduced, however, the density graphs show a more coherent pattern. The incentives to allocate high-emitting production activities to non-coalition countries are reduced.

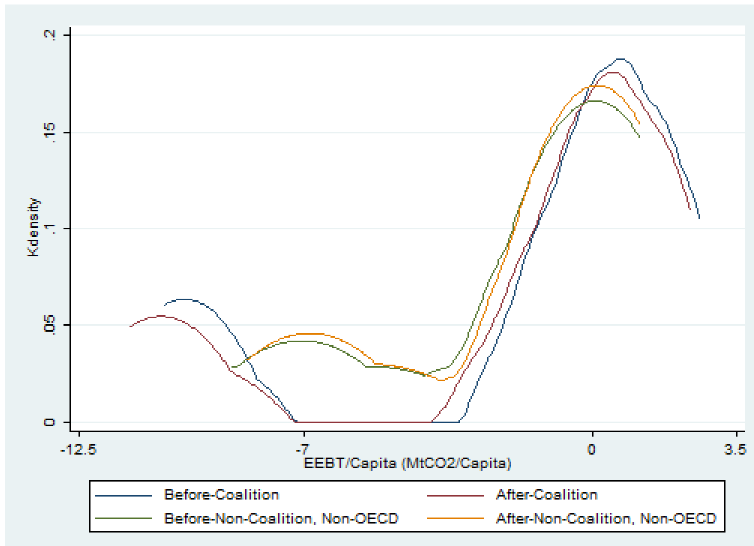

Figure 3: Emissions Embodied in Trade ($MtCO_2$/Capita)

The following summary tables indicate a similar pattern as described above, yet the effects on energy intensive and non-energy intensive industries are now distinguished. It is evident that the large changes are driven by coalition countries and non-OECD, non-coalition countries. It is also clear that the big differences occur in the energy intensive industries (EII), where the total reduction in emissions is 1.27%, compared with a slight increase in emissions of 0.01% in other industries.

The change in coalition countries' emissions is worth noticing. Due to the relocation of polluting industries after BCA, consumption based emissions from EII decrease whereas production based emissions from the same industries increase. In non-EII on the other hand, which are not subject to BCA, both production and consumption emissions increase. This increase in production emissions could seem counterintuitive as coalition countries find their EII's input prices rise more relative to other countries and hence they should lose competitiveness. However, the tariff revenues generated from BCA will lead to higher expenditure on manufactured goods in coalition countries. Due to the specifications of the gravity equation most countries spend a relatively large share of their income on domestic goods or goods from neighboring countries (that in this case are also likely to be in the coalition). Therefore it follows that the increase in expenditure has a positive effect on both production and consumption, and in turn production and consumption emissions increase for coalition countries.

Burniaux, et al. (2010) do not disaggregate into different groups when estimating greenhouse gas effects of BCA (using CO_2 equivalents), but find that world emissions decrease by approximately 0.20%. Although our estimated values stand for different things, the circumstance that manufacturing contribute with 38% of global CO_2 emissions (IEA, 2008) indicate that our reduction of 0.69% in the manufacturing sector could imply a slightly greater impact of BCA in our framework. This is especially convincing when considering that we impose a lower value of BCA tariff – \$40/$MtCO_2$ instead of Burniaux, et al.'s (2010) value of \$63/$MtCO_2$. Sensitivity analysis conducted in Section 6.1 suggests a reduction of -0.87% when the tariff is \$63/$MtCO_2$.

Table 7: Consumption Based Emissions by Group and EII vs. non-EII (% Change)

Group	EII	Non-EII	Total
Coalition	-3.84%	1.07%	-1.69%
OECD, Non-Coalition	-0.10%	-0.03%	-0.07%
Non-OECD, Non-Coalition	-1.80%	-0.42%	-1.15%
All countries	-1.27%	0.01%	-0.69%

Table 8: Production Based Emissions by Group and EII vs. non-EII (% Change)

Group	EII	Non-EII	Total
Coalition	2.19%	0.79%	1.56%
OECD, Non-Coalition	-0.48%	-0.02%	-0.31%
Non-OECD, Non-Coalition	-3.35%	-0.17%	-1.67%
All countries	-1.27%	0.01%	-0.69%

5.2 BCA Effects on Trade Flows

As can be expected, an increase in trade costs through the implementation of BCA has a dampening effect on world trade – yet only by 0.02% in our simulation. The reductions are largest in energy intensive industries and for the group of non-OECD, non-coalition countries. In all non-EII on the other hand, trade is actually positively affected by BCA as a result of an overall increasing income level (to be discussed in Section 5.4) and due to shifts in relative price levels of goods.

Table 9: World Trade by EII vs. Non-EII (% Change)

Group	EII	Non-EII	Total
Coalition Exports	1.05%	0.46%	0.71%
Coalition Imports	-0.61%	1.06%	0.29%
OECD, Non-Coalition Exports	-0.45%	0.11%	-0.20%
OECD, Non-Coalition Imports	-0.18%	0.00%	-0.08%
Non-OECD, Non-Coalition Exports	-3.04%	0.17%	-0.66%
Non-OECD, Non-Coalition Imports	-0.72%	-0.53%	-0.65%
Total Trade, All countries	-0.33%	0.24%	-0.02%

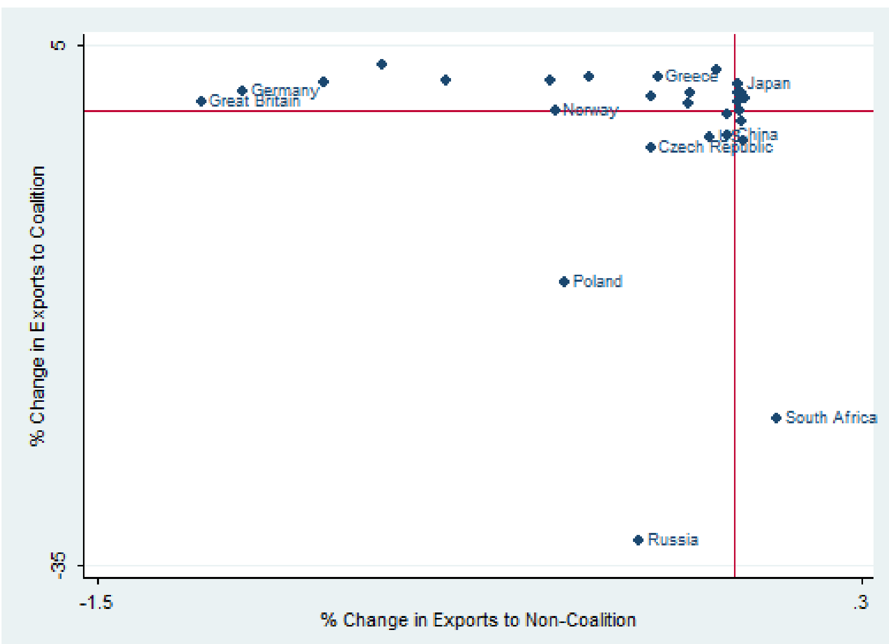

Figure 4: % Change in Exports to Coalition and Non-Coalition.

Figure 4 illustrates changes in exports to non-coalition and coalition countries respectively.

A few of the observations are worth further discussion. The by-far largest effect is the 33% reduction of Russia's exports to the coalition, a result of its considerably higher emission levels. The impact on South Africa's exports is similar but less substantial. There is however a slight increase in South Africa's exports to other non-coalition countries, despite these countries' reduced income level (to be discussed in Section 5.4). This increase in market share can be explained by increased competitiveness against countries where prices of intermediate goods increase more. Such countries are mostly the coalition countries, as exemplified by Great Britain and Germany.

One can also note a reduction in Czech Republic's and Poland's (not EU countries in year 2000) exports to both the coalition and non-coalition countries. This is a result of both their relatively higher emission levels and proximity to the EU countries, which make them important trading partners. Thus, as the increase in input prices make these trading partners' final products more expensive, combined with their high emissions factors, they find it more difficult to export EII goods to the coalition countries, ultimately decreasing their international competitiveness. Non-coalition countries with lower emission factors, e.g. Japan, Korea and Brazil, show the opposite pattern. Although the EU member countries are important trade partners for them as well, the results show that they gain more from their improved competitiveness, than they lose from the higher price of intermediates.

It is of interest to relate the competitiveness aspect to carbon leakage. As indicated in Table 10 coalition countries are in general net exporters of EII goods. However, the World Bank (2008) use a gravity equation regression to show that high-income countries have increased their energy intensive net imports over time, while the opposite is true for low-income countries. This pattern is assumed to be at least partly due to carbon leakage. With the implementation of BCA, the EII Import-Export ratio decreases for coalition countries, whereas it increases for both groups of non-coalition countries – a slight reversal of the leakage. Using this qualitative definition, we are also able to compare our results to Burniaux, et al. (2010), where the international trade channel (market shares) is one of the channels of carbon leakage. They find that leakage decreases significantly in the presence of BCA; the leakage rate due to EU emission-reduction measures decrease from 7.9% to 1.0% when BCA is used as a complement. The gain in market share for coalition countries' EII in trade for both our case and Burniaux, et al.'s (2010) sheds further light to BCA's effect on competitiveness, as well as averts carbon leakage.

Table 10: EII Import-Export Ratio

Group	EII Import-Export Ratio Before BCA	EII Import-Export Ratio After BCA	Change in Import-Export Ratio in EII
Coalition	0.90	0.88	-0.01
OECD, Non-Coalition	1.04	1.05	0.01
Non-OECD, Non-Coalition	1.11	1.11	0.00

5.3 BCA Effects on Production and Employment

The effects of BCA on competitiveness are also evident in the results on manufacturing production and employment. Due to the specification of fixed labor shares in production, changes in manufacturing output and employment are closely aligned at country levels but differ at the aggregated level. In terms of manufacturing employment, coalition countries are as a group better off in all industries under the implementation of BCA. In non-coalition countries on the other hand, employment decreases in all industries except in manufacturing of Textiles and Wood.

A more pronounced negative effect is found in non-coalition non-OECD countries, while several OECD countries such as Japan and Korea actually gain jobs in all industries (0.05% and 0.09% respectively) due to their increased competitiveness against countries with higher emission factors. Overall, world employment decreases, a result of the significantly large negative effect on employment in mainly non-OECD countries but also in other countries with high emissions. Knowing the close link between employment and production, the simultaneous decrease in the number of jobs and the increase in global manufacturing output may appear as a contradiction. This stems from the relatively lower per unit worker requirement in countries where output increases. A given change in output will thus produce a bigger impact on employment in lower-income countries due to their lower wage levels (that are rigid in our framework). This is especially evident in the energy intensive industries Basic Metals and Chemicals (see Table A.1 and Table A.2 in Appendix A), where there is a large migration of industries to coalition countries. The substantial loss of jobs in non-coalition countries is not completely offset by job gains in coalition countries. Thus, global EII employment falls despite the increase in output. In non-EII, the pattern is less clear and BCA implementation thus has the impact of a slight shift towards less polluting industries.

Table 11: Manufacturing Employment by Group, EII vs. Non-EII (% Change)

Group	EII	Non-EII	Total
Coalition	1.62%	0.80%	1.17%
OECD, Non-Coalition	-0.69%	-0.08%	-0.37%
Non-OECD, Non-Coalition	-1.23%	-0.02%	-0.43%
All countries	-0.93%	0.02%	-0.32%

Burniaux, et al. (2010) do not predict outcomes for employment or wage levels, but estimate output changes in energy intensive industries. Contrary to our results, EII output in Burniaux, et al. (2010) reduces for the world as a whole and for both coalition and non-coalition countries, but more so for coalition countries. Considering their chosen modeling framework, the fact that "EIIs in industrialized countries make important use of carbon intensive intermediate inputs produced by EIIs in other geographical areas" (p. 7) is a valid explanation for their results. However, the true story may be hidden behind the specifics of CGE models such as ENV-Linkages. In our case, output in coalition countries may increase as a result of several factors. The increased comparative advantage in energy intensive industries, combined with the altered trade and production costs with BCA, may shift the cheapest producer of a good from being a non-coalition member to being an EU member.

Our specification of the Eaton-Kortum model therefore accounts for that the original exporter may stop exporting that good to another country completely. For the ENV-Linkages model with Armington assumption, there is no such extensive margin choice; they still need to buy all categories of goods from all suppliers. If there are significant cost increases for these inputs and/or goods due to BCA, this would drive bigger real output losses. The implication of the distinction between this result and ours is that BCA supports the competitiveness of the domestic industries that BCA aimed to protect in the first place. A complementary explanation is the positive change in income in the coalition. Since these are in close proximity to one another and according to the gravity model, trade costs are therefore likely to be low and bilateral trade high.

Table 12: Manufacturing Output by Group, EII vs. Non-EII (% Change)

	EII	Non-EII	Total
Coalition	1.51%	0.79%	1.09%
OECD, Non-Coalition	-0.16%	0.02%	-0.07%
Non-OECD, Non-Coalition	-1.46%	-0.07%	-0.53%
All countries	0.09%	0.23%	0.17%

5.4 BCA Effects on Income

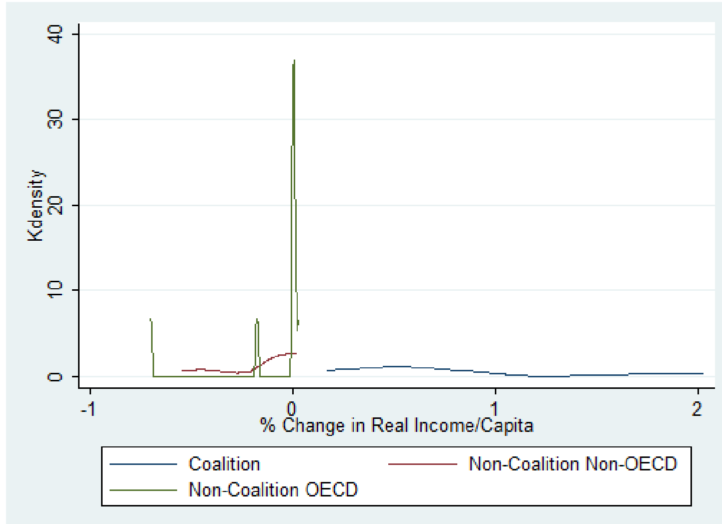

Figure 5: % Change in Real Income/Capita

As shown in Figure 5 the density graph over changes in per capita income clearly illustrates the impact on countries in each of the different groups. With a few exceptions, non-coalition OECD countries are not substantially affected. All coalition countries find their income per capita increase and almost all non-coalition non-OECD find it decrease on total manufacturing level. The income increases in coalition countries are driven by BCA tariff revenues (see Table 13) and increased labor income attributed to improved competitiveness within the coalition market. Although there is a slight increase in prices, this is not enough to counteract the positive impacts on GDP. For non-coalition countries, the change in income per capita is driven by mostly negative changes in labor income combined with the slight increase in price level.

Overall, on a global level, change in income is positive. This could be seen as counterintuitive given that increased tariffs according to the trade literature leads to deadweight losses and welfare costs. However, these models often assume perfect competition. When wages are rigid as in our simulation, the standard results do not necessarily hold. Cuts in tariff levels may in fact be welfare reducing, as shown by e.g. Brecher (1974) and Kreickemeier (2005). In any case however, the increase in income reflects a primary impact and should be interpreted with caution.

Table 13: Coalition Tariff Revenues

Group	Coalition Revenue as Share of Group's Baseline GDP	Share of Coalition Revenue's Contribution to Group's Gain in GDP
Coalition	0.04%	4.65%
OECD, Non-Coalition	0.02%	
Non-OECD, Non-Coalition	0.09%	
All countries	0.01%	4.81%

Burniaux, et al. (2010) use an alternative income measure, namely Hicksian equivalent variation (EV) in income. Using a consumer utility-based measurement may be more appropriate for CGE models that depend on the Armington assumptions, as their main force driving trade is consumers' preferences and love for variety. Since our modeling framework is focused on the production side of trade volumes and no detailed specifications on consumer utility are needed, "more" is "better." Thus we follow Eaton and Kortum (2002) and Shikher (2012b) and let changes in GDP give us the information needed to determine if a country is better or worse off. Hence, this difference in specifications and measurement makes comparing exact magnitudes of welfare changes to Burniaux, et al. (2010) less insightful or even erroneous.

What we can compare, however, is the general direction of the results. For example, they find no change in total world income due to the introduction of a BCA policy whereas we see an increase in global income. In both modeling frameworks, the EU gains with BCA, whereas the costs are incurred by non-EU members. The main difference to Burniaux, et al. (2010) is that these effects do not balance each other out in our model, i.e. coalition countries' income gains are larger than non-coalition countries' costs.

The channels that drive these results are necessary to highlight, as it seems questionable that output losses occur simultaneously as income reductions for coalition countries in Burniaux, et al. (2010). Further, they do not account for non-EII output but it does not seem likely that a sector that is affected by higher input costs but not of reduced competition will contribute substantially to the increase in income – rather the reverse. Thus, tariff revenues need to account for much of the difference.

In our case, revenues only account for 4.65% of the increase in coalition countries' income, with the rest attributed to manufacturing output increasing. This is a result of migration of production being preferred to paying the increased trade cost, as consumers do not care about the origin of the good. In the ENV-Linkages framework on the other hand, the tariff revenues' impact is probably much stronger. This should be related to Brown's (1987) finding that in Armington models, the terms of trade effect is overestimated due to the implied monopoly power of each country on their goods. Strong terms of trade effects will positively bias welfare estimates of tariffs, which is consistent with the above description of Burniaux, et al.'s (2010) results.

6. Alternative Specifications

6.1 Different Levels of BCA Tariff

As previously discussed, the design and scope of the BCA policy remain to be finalized. Therefore, in accordance with the literature on BCA and potential values of the tariff, we conduct sensitivity analysis with different tariff levels. As an upper bound, we follow Burniaux, et al. (2010) who yield a carbon tax of $63/Mt$CO_2$ when EU countries impose BCA tariffs both on indirect and direct carbon contents. As the lower bound, we use $20 as suggested by McKibbin and Wilcoxen (2009). The results presented in Table 14 indicate that increasing the level of the tariff on carbon dioxide emissions would result in increased output, decreased employment, and lower trade. However, aggregate income increases due to the increase in labor income and tariff revenues in coalition countries. The opposite is true for the lower tariff level but it can be noticed that trade increases slightly under this scenario compared with the baseline without BCA. Output increases more than trade, however, implying that the BCA tariff still has a dampening effect on world trade if calculated as a percentage of GDP. Furthermore, the indication that the increased value-per-unit of traded goods outweighs the decrease in units may be a result of fixed wages.

Table 14: % Change for Different Levels of BCA

	$\tau = \$20/Mtco2$	$\tau = \$40/Mtco2$	$\tau = \$63/Mtco2$
Manufacturing Output	0.11%	0.17%	0.22%
Manufacturing Employment	-0.19%	-0.32%	-0.42%
Trade	0.00%	-0.02%	-0.05%
Income	0.14%	0.22%	0.30%
Emissions	-0.44%	-0.69%	-0.87%

When increasing the tariff level the effect on two variables, income and emissions, are possible to compare with Burniaux, et al. (2010). Although using different measurements of emissions, it follows from the discussion in Section 5.1 that our estimate may indicate a larger effect. The effect on income indicates a similar but more significant effect as before which confirms the discussion in Section 5.4.

6.2 Different Coalition

Aside from evaluating the effect of BCA implementation by the EU countries, Burniaux, et al. (2010) study the effect of implementation by all Kyoto Annex I countries. Although this is not the most probable design in the near future, we make a similar evaluation in order to improve the possibilities of comparison. Thus, instead of letting only the EU countries implement BCA, we also include the other Annex I countries in the imposing coalition to enable comparison. Table 15 illustrates the effects on main variables.

Table 15: EU vs. Annex 1 Coalition

	Manufacturing Output (Q)	Manufacturing Employment (L)	Exports (EX)	Imports (IM)	GDP	Production-Based Emissions	Consumption-Based Emissions
EU: Coalition	1.09%	1.17%	0.71%	0.29%	0.89%	1.56%	-1.69%
EU: OECD, Non-Coalition	-0.07%	-0.37%	-0.20%	-0.08%	0.00%	-0.31%	-0.07%
EU: Non-OECD, Non-Coalition	-0.53%	-0.43%	-0.66%	-0.65%	-0.06%	-1.67%	-1.15%
EU: All countries	0.17%	-0.32%	-0.02%	-0.02%	0.22%	-0.69%	-0.69%
Annex: Coalition	1.52%	1.51%	1.44%	0.32%	0.72%	2.11%	-1.08%
Annex: OECD, Non-Coalition	-0.60%	-0.37%	-1.18%	-2.80%	-0.06%	-1.87%	-0.90%
Annex: Non-OECD, Non-Coalition	-3.24%	-2.95%	-4.36%	-2.36%	-0.45%	-7.34%	-4.36%
Annex: All countries	0.47%	-2.01%	0.13%	0.13%	0.58%	-2.04%	-2.04%

Overall, in the Annex I scenario, non-coalition countries are more adversely affected compared to when only EU members are in the coalition. Manufacturing output decreases significantly for non-coalition countries but increases in the coalition as a result of non-coalition countries losing competitiveness on a larger market. Further, the countries that are not parties to the Kyoto protocol Annex I could be believed to have comparatively higher emission factors than non-EU countries in general, thus being a sample of some of the most emission intensive nations. These effects are especially strong for the non-OECD countries.

OECD employment remains unaffected. Coalition exports increase, whereas non-coalition exports decrease vastly. Although GDP decreases for coalition and non-coalition, the effect on non-coalition is slightly larger. Production based and consumption based emissions increase in coalition, which partly can be attributed to increased competitiveness and income, and partly to the addition of the new members Russia and Japan. In general, emissions decrease significantly; a reduction of 2.04% after BCA implementation, which can be compared with the reduction of 0.69% in the base scenario.

The direction of results for both imposing and non-imposing countries coincide with that of Burniaux, et al.'s (2010) when they increase the coalition from EU member countries to Annex I members. The increase in total world output in our case is the only deviation from the similarity between the two studies' sensitivity analysis on the size of coalition. A lower degree of output reductions and EV income increases of coalition (Annex I) countries substantiates our concerns that the terms of trade effects of tariffs are strong and positively bias welfare effects in Armington assumption models.

6.3 Different Values of θ

As discussed in Footnote 5, various estimates of the comparative advantage parameter θ exist in the applications of the Eaton and Kortum (2002) model. We motivated our choice of 6.67, in contrast to Eaton and Kortum (2002)'s and Shikher's (2011; 2012b) 8.28, by the inclusion of non-OECD countries that usually have a lower value of θ. In order to test the sensitivity of our results to this choice, we simulated the model with $\theta = 8.28$ and $\theta = 4.12$ with the latter as suggested by Simonovska and Waugh (2011).

As expected, the impact of BCA on production, emissions and trade flows is slightly larger when $\theta = 8.28$ and smaller when $\theta = 4.12$. This is due to the interpretation of θ, where a lower value implies stronger effects of comparative advantage and higher trade costs, and therefore less sensitivity to adjustments in tariffs. However, the choice of θ does not alter the interpretation of the results, and barely the magnitude. The exception of an increase in trade flows when $\theta = 4.12$ can be explained by the same reasoning as when a lower BCA tariff is imposed, i.e. possibly due to the effect of rigid wages and increasing GDP.

Table 16: Sensitivity Analysis to Comparative Advantage Parameter

	$\boldsymbol{\theta = 4.12}$	$\boldsymbol{\theta = 6.67}$	$\boldsymbol{\theta = 8.28}$
Manufacturing Output	0.19%	0.17%	0.16%
Manufacturing Employment	-0.09%	-0.32%	-0.44%
Trade	0.06%	-0.02%	-0.07%
Income	0.26%	0.22%	0.21%
Emissions	-0.34%	-0.69%	-0.85%

7. Discussion

7.1 Validity of Results

Choosing a model to accurately reproduce characteristics of actual data and with a high fit is not the simplest task. Add the dimension of simulation and combine it with that the accuracy of results obtained matters for policy makers' future decisions, and the task becomes even more intricate. The problem at hand is that most economic models' results and calibrations rely on a set of core assumptions and parameters. One such is the value of the comparative advantage parameter θ, another is the set of Armington assumption elasticities that CGE models so often and incessantly depend upon. It is therefore useful when a majority of the model's predictions are barely dependent on these values, as in our case. The value of θ is only of significance for the magnitude but not the direction of the results, and mainly so for employment, output and indirectly emissions. The fact that these outcome variables are most sensible to the value of θ is likely to be a consequence of the rigid wages assumption and our focus on primary short term impacts. If wages were flexible, the choice of parameter would have a lower impact on employment, industry output and thus also emissions. Therefore, the results are considered robust to the choice of θ.

Nevertheless, the value of θ should still be chosen carefully. As discussed in Footnote 5, θ may vary depending on the group of countries. Hence it is recommended to select or calculate θ on the basis of the countries in the studied sample. However, the estimation results when estimating at various levels of θ indicate that the effects follow a rather intuitive pattern. Thus, any possible insecurity that may exist about the exact impact estimations may be overcome if tariff levels are allowed to be changed dynamically depending on how well e.g. emissions and leakage relate to target levels.

Of greater importance is as suggested the assumption of rigid wages. Although this enables modeling of economic features vital for trade policy formation, it also means that the estimated effects on employment-related variables should be seen as a higher bound. The sometimes dramatic effects will smoothen in the long run when wages are allowed to adjust. A related aspect is the assumed fixed price of energy inputs (part of the nonmanufacturing sector). As energy intensive industries migrate to countries where emission factors and fossil fuel requirements are lower, a dampening effect on fossil fuel prices would be probable. This emphasizes the importance of interpreting our results not as long run equilibrium predictions but rather as short run impacts.

When it comes to accounting for zeros or missing values in the bilateral trade data, using a more technically intricate estimation technique could possibly have produced a better prediction of the data, although no consensus in the literature on the proper estimation methodology exists. The quantitative differences and thus the validity of the results are however likely to be small. This is mostly attributed to our low number of zero or missing observation – the effect would likely be different had it not been for this small percentage.

Finally, the importance and benefit of splitting up our model of 28 countries into three separate groups depending on coalition membership, and economic development, is highlighted in the majority of result tables as effects of the policy vary substantially. Results for individual countries are presented in Appendix A. Nearly all other studies, including Burniaux, et al. (2010) only present aggregate effects or impacts on coalition and non-coalition countries. Our deviation in this aspect contributes in transparency and improves the foundation for policy makers, for whom it is important to consider the implications of the considered policy on different distributions of the world.

7.2 Policy Implications

Economic and Environmental Effects

When prospects for a global first-best solution, at least in the near term, seem grim, our simulations indicate that a second-best solution such as border carbon adjustment may be a conceivable alternative. While the simulated policy certainly does not come without economically undesirable consequences, there are substantial positive effects to be gained on a global level.

Our intention is not to weigh changes in environmental and economic variables against each other. Yet we find that income is only marginally affected (and even positively so in the short run) when aggregating all countries' GDP, at the same time as global CO_2 emissions from manufacturing decrease. There is no doubt that a reduction of emissions by 0.69% may seem trivial, given that for example the EU has committed to reduce emissions by 20% between 1990 and 2020 (European Commission, 2012). As will be discussed here, however, the policy may bring about other environmental gains in the long run given that it is appropriately designed and implemented.

Related to this and to the externality aspect of CO_2 emissions, several researchers have evaluated the social cost of carbon. The mean estimate of marginal damages of emissions is \$48 per $MtCO_2$ (Tol, 2011). The failure to internalize these costs indicates that reducing greenhouse gas emissions to mitigate global warming will not come without a price. However, taking no action against polluting emissions is also costly, as revealed by e.g. Muller, Mendelsohn and Nordhaus (2011). They find that manufacturing is responsible for a large portion of total air pollution (even when only considering other pollutants than CO_2) and that the gross external damages from air pollution in some U.S. industries strongly outweigh the value added. Current national regulations and international agreements are clearly not coping with the externalities of greenhouse gases and other pollutants satisfactorily – leading to what has been described as the "greatest market failure the world has seen;" climate change (Stern, 2007, p. viii).

If BCA, as our results suggest, can reduce manufacturing CO_2 emissions with 0.69% at a low cost in terms of global income, it could be economically efficient and should at least remain a viable option. The essence of the BCA policy's candidacy is that it has the possibility to be implemented even before a potential global climate agreement is reached, given that the legal and practical aspects are resolved. Evidence shows that the cost of limiting global warming will increase the longer it takes before sufficient action is taken. This immediacy is emphasized by Stern (2007) and many others. Despite the long run impacts of climate change, the short run perspective we apply in this thesis is essential. This is due to the urgency of introducing efficient policies, in combination with a potential unwillingness among politicians and policy makers to impose policies with adverse short term effects.

A positive correlation of 0.89 between the simulated baseline GDP and country consumption emissions levels before introducing BCA further accentuates the importance of appropriate policy formulations. The present high GDP growth rates of emerging economies and the pace of economic development necessary to reach the income levels of OECD countries indicate that emissions levels could continue to increase rapidly if insufficient action is taken. Combining this with the high share of domestic consumption (due to the specifications of the gravity equation) that is often emission intensive, stresses the imminent importance of designing incentives for increasing investments into energy efficient production processes. The implementation of BCA could provide one such incentive.

The Impact on Lower-Income Countries

Additionally, the vast differences in income levels highlight the distributional problems of introducing a BCA policy. The negative impact on the countries with the lowest income makes the policy questionable in ethical terms and could reduce its appeal in global climate negotiations. Relatedly, it is worth mentioning that both production and consumption emissions are considerably lower per capita than in either group of OECD countries despite the non-OECD countries' high emission factors. To implement a policy that makes lower-income countries bear the largest burden for reducing global emissions that are in the first place produced and consumed by citizens in OECD-countries, further fuels the moral quandary.

The drastically adverse effects on a number of countries are likely not to pass without notice. The strong negative impact on e.g. Russian and South African employment and output, as well as the comparatively minor but still negative impact on U.S. income could validate the fear that BCA implementation could lead to political conflicts. This confirms that any action taken must be evaluated carefully to not trigger trade wars or create mistrust in international negotiations on climate change mitigation and related issues. The other side of the coin is that the prospect of negative impacts may constitute a sufficiently important "leverage" to make the most polluting countries engage in international climate negotiations to find another solution or to adopt national policies to reduce emissions.

Optimal Design of a Potential BCA Policy

Admittedly, the dual effects on coalition and the lower-income non-OECD countries, make the latters' resistance to BCA implementation understandable. A mechanism is needed to even out the economic losses and further reduce emissions in a dynamic framework. One solution would be to reinvest the tariff revenues in research and development as well as in improvements in energy efficiency where emission factors are high. To increase legitimacy this could possibly be done via a global environment fund such as the Clean Development Mechanism or the UNEP-Environment fund. Such a procedure has much in spirit with Davies, Shi and Whalley's (2011) article where it is found that partial redistribution of potential carbon pricing income can have substantial impacts on simultaneous reductions of poverty and emissions.

With this alternative design of BCA, naturally a source of income for imposing countries would be removed and their income would be lower. However, a strong benefit would be its innate legitimacy as not distributing resources from lower-income to higher-income countries, which could lead to a higher acceptance among other countries and could lower the risk of sparking a trade war. In demonstrating environmental motivation rather than protectionism and self-interest, this framework could also be more likely to be compatible with WTO regulations. Further, our results illustrate that while the tariff revenues only make up a small part of the coalition's income gains (approximately 5%, the rest being attributed to increased labor income), they would completely offset the losses incurred by the non-OECD countries if redistributed. This relation could contribute to increasing both higher-income and lower-income countries willingness to accept such a framework.

In a dynamic framework, even stronger emission reductions could be likely as industries in affected countries adjust by reducing their emissions factors. However, carbon import tariffs are most likely based on industry-average measures of carbon embodied in imported goods. Thus, they will not give a direct incentive for individual producers in non-coalition countries to adjust their emissions intensity so they can pay a lower import tax. This could be counteracted through strong coordinating agents such as governments and industry organizations, or by allowing for reduced tariffs for individual exporters that use significantly less CO_2-emitting production methods than the industry average. If this were the case and exporters thus were to reduce their intensity, emissions would decline compared to what we find here.

Also of importance for the formation of a potential BCA policy is the size of the coalition of countries. When all Annex I countries apply BCA, emissions decrease substantially while the impact on economic variables is not that severe for the world as a whole, but even worse than the base simulation for non-OECD countries. Thus, a broader coalition would be preferred but only provided that considerations are taken to the effect on lower-income countries. Further, tariff levels could be allowed to be altered too, and should go hand in hand with domestic emissions-reducing policies. It is thus important not to see BCA implementation as an isolated policy but as a complement to enforcing stringent environmental policies in coalition countries. Our results indicate that BCA tariffs could be used to compensate energy intensive industries if strict regulations that may lead to reduced competitiveness are introduced. Potentially this could lower the risk of strong industrial objections and lead to CO_2 mitigation policies gaining a wider acceptance, something that may reduce emissions also in coalition countries.

8. Concluding Remarks

8.1 Conclusion

In this thesis, we have analyzed the impacts of a border carbon adjustment policy on emissions, trade flows, income and production, as well as provided a connection to an ongoing policy discussion. More specifically, we have done so by applying an extension of the Eaton and Kortum (2002) model – Shikher's (2012b) industry level extension – instead of the predominantly used CGE models that rely on Armington (1969) assumptions.

In using the Eaton-Kortum framework we avoid relying on the much-debated Armington elasticities and manage to capture important features of world trade, such as the important extensive margin of trade and production based competition. We also find that the difference in theoretical specification ultimately influences the results. The countries imposing BCA seem to have a revenue-driven increase in income in the CGE model we use as a comparison, whereas in our framework, the same result predominantly comes from the relocation of production. Additionally, there are indications of emission reductions being stronger in our framework.

While our results should be interpreted with caution as they illustrate a primary, static impact rather than dynamic effect, they demonstrate that a BCA policy is at least worth considering as one component of sub-global climate policy. Global income is only marginally affected (and even positively so in the short run), at the same time as global CO_2 emissions decrease. Whereas the emission reduction of 0.69% may seem trivial, we discuss potential dynamic effects that could lead to larger reductions. These may be strengthened if tariff revenues are reinvested in research and improvements in energy efficiency in lower-income countries.

The redistribution of revenues is called upon due to the large impact differences on countries at different stages of economic development – an important aspect that previous evaluations have not sufficiently addressed. The generally strong and adverse impacts on lower-income countries in our simulation also call for further evaluation of BCA policy. We expect that our thesis has brought attention to a new framework for such analysis.

8.2 Suggestions for Further Research

With a model as well-cited as Eaton and Kortum (2002) there is a wide array of extensions to draw upon when constructing a model aiming to capture additional features of global trade and production with an even better fit. These possibilities include incorporating capital (Shikher, 2011), other sources of comparative advantage, e.g. institutions (Chor, 2010) as well as modeling the agricultural sector (Tombe, 2012).

Although one of the most attractive features of our model is its simplicity, an investigation as to whether the Eaton-Kortum specifications rather than the Armington assumptions could form a base for more elaborate simulations would be insightful. The extensions could range from incorporating fossil fuels as a factor of production or modeling several time periods, all the way to constructing a dynamic CGE model explaining world trade by technology and geography rather than by product differentiation and consumers' love of variety. Such extensions will provide us further insights as to whether the Eaton-Kortum framework is more appropriate than the Armington CGE models.

Of key interest for policy evaluation purposes – when results are interpreted cautiously – would be to internalize emissions-related technology in a dynamic framework. First of all, this would enable industries in affected countries to react by investing in order to lower their emission factors and thus also their costs. Such a framework would also enable modeling an international green energy fund to improve technology. Using the Eaton-Kortum instead of the Armington model would in this case be an advantage attributed to that endogenous effects on technology are perhaps more realistic in a producer based rather than a consumer based framework. An improvement in the ability to make policy recommendations would be to formally include a domestic carbon tax, which is frequently done in the current supply of BCA simulations, incorporate export rebates and/or lastly include least developed countries that would be exempt from tariffs into the simulation framework.

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Appendix A - Results

Table A.1: Manufacturing Output by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	0.26%	0.10%	0.15%	0.05%	0.05%	0.05%	0.04%	0.03%	0.05%	0.07%	0.07%
Australia	-0.48%	0.06%	0.01%	0.04%	0.01%	0.03%	0.02%	0.07%	0.02%	0.03%	0.02%
Austria	5.58%	3.59%	1.44%	0.72%	1.02%	0.85%	1.27%	0.75%	0.61%	1.04%	0.81%
Brazil	0.31%	0.07%	0.15%	0.04%	0.05%	0.06%	0.04%	0.03%	0.07%	0.22%	0.09%
Canada	0.21%	-0.14%	0.19%	0.01%	0.00%	-0.01%	-0.12%	-0.03%	0.09%	0.03%	0.00%
China	-0.09%	-0.04%	-0.46%	-0.02%	-0.14%	0.07%	-0.07%	0.00%	-0.10%	-0.06%	-0.10%
Czech Republic	-8.73%	-39.54%	-4.91%	-1.34%	-3.52%	-1.77%	-3.51%	0.08%	-0.25%	-2.42%	-2.11%
Finland	5.04%	6.25%	1.16%	1.04%	1.91%	1.71%	1.72%	1.74%	0.75%	1.58%	1.51%
France	6.12%	5.28%	0.91%	0.50%	1.27%	1.14%	1.78%	1.09%	0.65%	1.32%	1.42%
Germany	4.90%	0.87%	0.75%	0.59%	1.28%	0.56%	1.05%	0.64%	0.51%	0.82%	0.88%
Great Britain	4.60%	-0.79%	0.44%	1.75%	1.83%	0.98%	2.17%	1.25%	0.63%	1.11%	1.09%
Greece	4.27%	3.38%	0.67%	0.24%	0.62%	0.53%	0.73%	0.55%	0.47%	0.69%	0.70%
India	-0.03%	-2.78%	-0.10%	0.00%	-0.12%	0.01%	0.00%	0.10%	0.00%	0.05%	0.01%
Indonesia	-0.26%	-0.23%	-0.59%	-0.01%	-0.92%	0.13%	-0.24%	0.09%	-0.26%	0.22%	-0.11%
Israel	1.88%	0.69%	0.45%	0.05%	0.22%	0.22%	0.17%	0.17%	0.26%	0.31%	0.34%
Italy	6.25%	2.75%	0.72%	0.71%	1.07%	0.86%	1.30%	0.90%	0.65%	1.07%	1.03%
Japan	0.22%	0.05%	0.06%	0.01%	0.02%	0.03%	0.03%	0.01%	0.03%	0.03%	0.04%
Korea	0.25%	0.02%	0.10%	0.02%	0.06%	0.09%	0.05%	0.07%	0.07%	0.08%	0.08%
New Zealand	-0.90%	0.05%	-0.10%	0.07%	-0.06%	-0.05%	0.02%	0.10%	-0.09%	-0.02%	0.03%
Norway	5.57%	-10.99%	1.01%	0.03%	0.05%	-0.15%	0.06%	-0.60%	0.67%	-0.20%	0.31%
Poland	-23.46%	-37.45%	-3.58%	-0.30%	-2.50%	-1.58%	-1.63%	-0.69%	-0.76%	-1.99%	-3.03%
Portugal	3.77%	4.73%	0.63%	0.33%	0.40%	0.46%	0.77%	0.52%	0.39%	0.79%	0.58%
Russia	-27.63%	-33.51%	-4.48%	-0.65%	-3.39%	-3.44%	-7.79%	-1.30%	-3.23%	-0.73%	-6.52%
South Africa	-4.89%	-7.44%	-2.56%	-0.47%	-2.19%	-2.42%	-1.85%	-0.13%	-2.17%	-2.43%	-2.44%
Spain	5.32%	5.44%	0.79%	0.45%	0.95%	0.85%	1.11%	0.85%	0.57%	1.09%	0.99%
Sweden	5.07%	1.03%	1.09%	1.47%	1.45%	1.10%	1.47%	1.01%	1.04%	1.25%	1.42%
Turkey	-0.24%	-1.55%	0.11%	0.03%	-0.05%	0.12%	0.11%	0.37%	0.19%	0.11%	0.12%
United States	0.23%	-0.61%	0.19%	0.01%	0.04%	0.03%	-0.01%	-0.01%	0.11%	0.04%	-0.04%
Coalition	5.16%	2.62%	0.81%	0.86%	1.32%	0.92%	1.49%	0.93%	0.64%	1.10%	1.09%
OECD, Non-Coalition	-0.07%	-0.51%	-0.02%	0.01%	-0.07%	-0.03%	-0.12%	0.02%	0.05%	-0.08%	-0.07%
Non-OECD, Non-Coalition	-5.15%	-6.30%	-0.68%	-0.04%	-0.71%	-0.08%	-0.68%	0.02%	-0.43%	0.13%	-0.53%
All countries	-0.11%	-0.11%	0.14%	0.23%	0.21%	0.21%	0.20%	0.23%	0.23%	0.24%	0.17%

Table A.2: Manufacturing Employment by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	0.30%	0.11%	0.18%	0.05%	0.05%	0.05%	0.05%	0.03%	0.06%	0.07%	0.08%
Australia	-0.44%	0.10%	0.03%	0.04%	0.01%	0.04%	0.03%	0.07%	0.02%	0.03%	0.03%
Austria	6.42%	4.39%	1.66%	0.73%	1.06%	0.90%	1.35%	0.76%	0.62%	1.04%	0.86%
Brazil	0.37%	0.08%	0.18%	0.04%	0.05%	0.06%	0.04%	0.03%	0.07%	0.22%	0.10%
Canada	0.26%	-0.12%	0.23%	0.01%	0.00%	0.00%	-0.12%	-0.03%	0.10%	0.04%	0.01%
China	-0.05%	-0.03%	-0.44%	-0.02%	-0.14%	0.08%	-0.06%	0.00%	-0.10%	-0.06%	-0.10%
Czech Republic	-8.50%	-39.13%	-4.77%	-1.33%	-3.50%	-1.74%	-3.47%	0.09%	-0.24%	-2.42%	-2.15%
Finland	5.72%	7.36%	1.31%	1.05%	1.95%	1.75%	1.82%	1.75%	0.76%	1.59%	1.59%
France	7.26%	6.62%	1.14%	0.52%	1.34%	1.21%	1.98%	1.11%	0.66%	1.32%	1.57%
Germany	6.12%	1.54%	1.03%	0.61%	1.41%	0.63%	1.18%	0.65%	0.52%	0.83%	1.03%
Great Britain	5.83%	0.21%	0.70%	1.81%	1.98%	1.09%	2.49%	1.27%	0.64%	1.12%	1.26%
Greece	4.89%	4.04%	0.80%	0.25%	0.65%	0.56%	0.80%	0.56%	0.48%	0.70%	0.77%
India	0.02%	-2.70%	-0.08%	0.00%	-0.12%	0.02%	0.01%	0.11%	0.00%	0.05%	0.02%
Indonesia	-0.24%	-0.22%	-0.55%	-0.01%	-0.92%	0.14%	-0.23%	0.10%	-0.25%	0.22%	-0.12%
Israel	2.05%	0.86%	0.50%	0.05%	0.22%	0.23%	0.19%	0.17%	0.27%	0.31%	0.36%
Italy	7.81%	3.62%	0.97%	0.73%	1.14%	0.94%	1.44%	0.91%	0.66%	1.07%	1.16%
Japan	0.26%	0.07%	0.08%	0.01%	0.02%	0.03%	0.03%	0.01%	0.03%	0.04%	0.05%
Korea	0.29%	0.03%	0.13%	0.02%	0.06%	0.10%	0.05%	0.07%	0.07%	0.08%	0.09%
New Zealand	-0.82%	0.06%	-0.09%	0.07%	-0.06%	-0.04%	0.02%	0.10%	-0.09%	-0.02%	0.03%
Norway	6.10%	-10.10%	1.09%	0.03%	0.05%	-0.12%	0.10%	-0.59%	0.68%	-0.20%	0.44%
Poland	-23.15%	-37.06%	-3.46%	-0.29%	-2.49%	-1.55%	-1.60%	-0.68%	-0.76%	-1.99%	-2.84%
Portugal	4.54%	5.37%	0.76%	0.34%	0.41%	0.49%	0.81%	0.52%	0.39%	0.79%	0.62%
Russia	-27.55%	-33.33%	-4.42%	-0.65%	-3.39%	-3.43%	-7.76%	-1.29%	-3.22%	-0.73%	-5.90%
South Africa	-4.82%	-7.34%	-2.53%	-0.47%	-2.18%	-2.42%	-1.85%	-0.12%	-2.16%	-2.43%	-2.18%
Spain	6.36%	6.51%	0.98%	0.47%	1.01%	0.91%	1.19%	0.86%	0.58%	1.09%	1.08%
Sweden	5.72%	1.64%	1.25%	1.50%	1.49%	1.16%	1.56%	1.02%	1.04%	1.26%	1.46%
Turkey	-0.03%	-1.17%	0.19%	0.03%	-0.04%	0.14%	0.14%	0.38%	0.19%	0.11%	0.16%
United States	0.29%	-0.20%	0.24%	0.01%	0.04%	0.04%	0.00%	-0.01%	0.11%	0.04%	0.08%
Coalition	6.21%	3.93%	1.03%	0.82%	1.31%	0.97%	1.56%	0.89%	0.64%	1.00%	1.17%
OECD, Non-	-1.97%	-0.54%	-0.78%	-0.03%	-0.47%	-0.23%	-0.33%	0.05%	-0.03%	-0.51%	-0.37%
Non-OECD, Non-	-7.41%	-6.54%	-0.71%	-0.06%	-0.82%	0.00%	-0.82%	0.04%	-0.44%	0.17%	-0.43%
All countries	-5.83%	-0.59%	-0.57%	0.01%	-0.65%	0.02%	-0.59%	0.07%	-0.20%	0.17%	-0.32%

Table A.3: Specialization by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood
Argentina	0.22%	0.04%	0.10%	-0.03%	-0.03%	-0.03%	-0.03%	-0.04%	-0.02%	-0.01%
Australia	-0.47%	0.06%	0.00%	0.01%	-0.02%	0.00%	-0.01%	0.04%	-0.01%	0.00%
Austria	5.51%	3.50%	0.79%	-0.13%	0.20%	0.04%	0.48%	-0.10%	-0.24%	0.18%
Brazil	0.27%	-0.02%	0.08%	-0.06%	-0.05%	-0.03%	-0.06%	-0.06%	-0.03%	0.12%
Canada	0.25%	-0.14%	0.21%	-0.01%	-0.01%	-0.02%	-0.13%	-0.04%	0.08%	0.02%
China	0.04%	0.07%	-0.34%	0.08%	-0.04%	0.18%	0.03%	0.10%	0.00%	0.04%
Czech Republic	-6.48%	-37.79%	-2.67%	0.84%	-1.38%	0.42%	-1.35%	2.29%	1.96%	-0.27%
Finland	4.06%	5.68%	-0.28%	-0.53%	0.35%	0.16%	0.22%	0.16%	-0.82%	0.00%
France	5.60%	4.97%	-0.42%	-1.03%	-0.22%	-0.35%	0.41%	-0.46%	-0.89%	-0.24%
Germany	5.03%	0.50%	0.00%	-0.42%	0.37%	-0.40%	0.14%	-0.37%	-0.51%	-0.20%
Great Britain	4.51%	-1.04%	-0.55%	0.55%	0.71%	-0.16%	1.21%	0.01%	-0.61%	-0.14%
Greece	4.10%	3.25%	0.03%	-0.51%	-0.12%	-0.20%	0.03%	-0.21%	-0.29%	-0.07%
India	0.00%	-2.72%	-0.10%	-0.02%	-0.14%	0.00%	-0.01%	0.09%	-0.01%	0.03%
Indonesia	-0.13%	-0.10%	-0.44%	0.11%	-0.80%	0.26%	-0.11%	0.21%	-0.14%	0.33%
Israel	1.68%	0.50%	0.14%	-0.30%	-0.14%	-0.13%	-0.17%	-0.19%	-0.09%	-0.05%
Italy	6.58%	2.44%	-0.18%	-0.42%	-0.02%	-0.21%	0.27%	-0.24%	-0.49%	-0.09%
Japan	0.21%	0.02%	0.03%	-0.04%	-0.03%	-0.02%	-0.02%	-0.04%	-0.02%	-0.02%
Korea	0.20%	-0.05%	0.04%	-0.06%	-0.03%	0.01%	-0.03%	-0.02%	-0.02%	0.00%
New Zealand	-0.85%	0.04%	-0.11%	0.05%	-0.09%	-0.07%	0.00%	0.07%	-0.12%	-0.04%
Norway	5.63%	-10.49%	0.65%	-0.41%	-0.39%	-0.56%	-0.34%	-1.03%	0.24%	-0.64%
Poland	-20.90%	-35.22%	-0.64%	2.63%	0.36%	1.32%	1.28%	2.23%	2.14%	0.88%
Portugal	3.89%	4.72%	0.14%	-0.28%	-0.20%	-0.13%	0.19%	-0.09%	-0.22%	0.17%
Russia	-23.01%	-29.15%	1.57%	5.58%	2.67%	2.63%	-1.98%	4.89%	2.84%	5.49%
South Africa	-2.69%	-5.27%	-0.36%	1.76%	0.00%	-0.24%	0.35%	2.10%	0.02%	-0.26%
Spain	5.23%	5.37%	-0.10%	-0.61%	-0.07%	-0.17%	0.11%	-0.22%	-0.50%	0.01%
Sweden	4.19%	0.17%	-0.21%	0.04%	0.03%	-0.30%	0.10%	-0.43%	-0.41%	-0.20%
Turkey	-0.19%	-1.32%	0.03%	-0.13%	-0.20%	-0.02%	-0.02%	0.22%	0.03%	-0.05%
United States	0.21%	-0.28%	0.16%	-0.06%	-0.03%	-0.03%	-0.08%	-0.09%	0.03%	-0.03%
Coalition	4.99%	2.73%	-0.13%	-0.35%	0.14%	-0.20%	0.39%	-0.28%	-0.52%	-0.16%
OECD, Non-Coalition	-1.61%	-0.17%	-0.41%	0.34%	-0.11%	0.13%	0.04%	0.42%	0.34%	-0.15%
Non-OECD, Non-Coalition	-7.02%	-6.14%	-0.29%	0.37%	-0.39%	0.42%	-0.40%	0.47%	-0.01%	0.60%
All countries	-5.53%	-0.27%	-0.25%	0.33%	-0.33%	0.34%	-0.28%	0.39%	0.12%	0.49%

Table A.4: Exports by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	1.03%	0.15%	0.25%	0.07%	-0.01%	0.23%	0.31%	0.14%	0.11%	0.40%	0.08%
Australia	-3.39%	0.09%	-0.65%	0.07%	-0.26%	0.20%	0.08%	0.12%	0.11%	0.25%	0.01%
Austria	7.89%	4.06%	1.19%	0.55%	0.87%	0.69%	1.45%	0.68%	0.57%	0.84%	0.69%
Brazil	0.47%	0.13%	0.14%	0.07%	-0.10%	0.23%	0.03%	0.14%	0.12%	0.34%	0.14%
Canada	0.19%	-0.14%	0.23%	0.01%	0.04%	0.06%	-0.15%	-0.01%	0.09%	0.06%	-0.02%
China	-0.44%	-0.05%	-1.91%	0.02%	-0.67%	0.15%	-0.19%	0.08%	0.03%	0.16%	-0.19%
Czech Republic	-43.41%	-49.17%	-5.84%	0.51%	-4.17%	0.72%	-5.95%	0.69%	0.54%	0.93%	-1.94%
Finland	5.14%	6.60%	0.82%	0.32%	0.15%	0.37%	1.61%	0.66%	0.59%	0.94%	1.32%
France	5.53%	5.28%	0.54%	0.52%	0.42%	0.31%	1.34%	0.70%	0.48%	0.89%	2.20%
Germany	2.22%	0.74%	-0.27%	0.23%	0.15%	0.20%	1.36%	0.64%	0.44%	0.80%	0.32%
Great Britain	1.30%	-0.85%	-1.34%	-0.29%	-0.38%	-0.83%	0.02%	0.11%	-0.01%	0.48%	-0.60%
Greece	5.68%	3.65%	0.86%	0.27%	0.25%	0.40%	1.48%	0.65%	0.48%	0.83%	1.01%
India	-3.39%	-5.23%	-3.78%	0.05%	-1.73%	0.22%	-2.38%	0.13%	0.10%	0.31%	-0.05%
Indonesia	-1.18%	-0.44%	-0.83%	0.04%	-1.27%	0.23%	-0.41%	0.13%	0.09%	0.26%	-0.09%
Israel	4.03%	1.87%	0.94%	0.18%	-0.07%	0.52%	0.95%	0.22%	0.37%	0.76%	0.95%
Italy	2.76%	2.69%	-0.03%	0.25%	0.26%	0.18%	1.44%	0.65%	0.46%	0.96%	0.94%
Japan	0.48%	0.05%	0.48%	0.11%	0.11%	0.25%	0.19%	0.14%	0.07%	0.19%	0.16%
Korea	0.23%	0.02%	0.11%	0.02%	-0.12%	0.18%	0.01%	0.08%	0.06%	0.07%	0.08%
New Zealand	-1.21%	-0.76%	0.21%	0.07%	-0.07%	0.21%	0.10%	0.12%	0.11%	0.24%	0.04%
Norway	6.88%	-12.55%	1.11%	0.39%	-0.21%	0.58%	1.80%	0.72%	0.46%	0.99%	-0.20%
Poland	-41.93%	-50.36%	-8.87%	0.49%	-9.54%	0.68%	-7.24%	0.69%	0.47%	0.87%	-8.75%
Portugal	4.64%	5.45%	0.54%	0.25%	0.13%	0.25%	1.71%	0.56%	0.30%	0.82%	0.55%
Russia	-34.70%	-55.40%	-19.58%	0.29%	-10.05%	0.71%	-22.63%	0.55%	0.45%	0.84%	-19.06%
South Africa	-5.14%	-8.15%	-1.41%	0.07%	-0.50%	0.23%	-1.14%	0.12%	0.17%	0.32%	-2.57%
Spain	4.68%	5.48%	0.53%	0.33%	0.33%	0.42%	1.80%	0.70%	0.49%	1.04%	1.33%
Sweden	5.87%	0.61%	0.62%	0.20%	0.33%	0.26%	1.46%	0.61%	0.46%	0.81%	0.91%
Turkey	-5.48%	-5.13%	-0.44%	0.29%	-0.22%	0.51%	-0.32%	0.67%	0.53%	0.81%	0.20%
United States	0.25%	-0.61%	0.30%	0.08%	-0.20%	0.14%	-0.01%	-0.02%	0.20%	0.05%	-0.39%
Coalition	3.80%	2.52%	0.00%	0.27%	0.26%	0.24%	1.52%	0.60%	0.48%	0.85%	0.71%
OECD, Non-Coalition	-0.15%	-0.51%	-0.58%	0.06%	-0.69%	0.25%	-0.15%	0.16%	0.14%	0.07%	-0.20%
Non-OECD, Non-Coalition	-8.26%	-8.37%	-1.16%	0.05%	-1.22%	0.19%	-1.83%	0.13%	0.14%	0.28%	-0.66%
All countries	-1.30%	-0.14%	-0.39%	0.08%	-0.64%	0.21%	0.05%	0.23%	0.33%	0.29%	-0.02%

Table A.5: Imports by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	0.02%	0.02%	-0.36%	0.02%	-0.01%	-0.03%	0.01%	0.02%	0.02%	0.07%	-0.08%
Australia	-0.22%	0.00%	-0.34%	0.02%	-0.02%	-0.04%	-0.02%	0.04%	-0.03%	0.02%	-0.08%
Austria	-1.24%	0.42%	-0.16%	0.76%	-3.18%	0.95%	0.25%	0.80%	0.67%	1.12%	0.33%
Brazil	-0.17%	0.02%	-0.37%	0.01%	-0.01%	-0.02%	-0.06%	0.02%	0.02%	0.14%	-0.11%
Canada	0.02%	-0.10%	-0.13%	-0.01%	-0.09%	-0.11%	-0.11%	-0.05%	0.06%	0.00%	-0.06%
China	-0.37%	-0.06%	-0.41%	-0.03%	-0.13%	-0.09%	-0.11%	-0.03%	-0.13%	-0.14%	-0.17%
Czech Republic	-6.71%	-4.70%	-4.48%	-1.42%	-3.42%	-3.08%	-3.26%	-0.66%	-1.38%	-3.33%	-3.51%
Finland	-3.44%	2.44%	0.47%	1.05%	-2.75%	2.05%	0.64%	1.99%	0.95%	1.88%	1.00%
France	-2.83%	1.36%	-0.14%	0.55%	-3.81%	1.44%	0.11%	1.21%	0.81%	1.55%	0.60%
Germany	-5.37%	-0.14%	-1.19%	0.66%	-3.50%	0.96%	0.19%	0.70%	0.76%	0.91%	0.00%
Great Britain	-7.11%	-1.92%	0.81%	2.30%	-8.08%	2.20%	0.58%	1.69%	1.48%	1.32%	0.33%
Greece	-6.67%	0.47%	-0.26%	0.22%	-2.52%	0.56%	-0.20%	0.50%	0.45%	0.72%	0.08%
India	-0.44%	-0.06%	-0.41%	-0.01%	-0.08%	-0.04%	-0.08%	0.07%	-0.04%	0.00%	-0.15%
Indonesia	-0.69%	-0.16%	-0.89%	-0.08%	-0.59%	-0.11%	-0.28%	0.04%	-0.29%	0.10%	-0.27%
Israel	0.12%	-0.04%	-0.54%	0.04%	0.10%	0.05%	0.02%	0.12%	0.21%	0.30%	0.05%
Italy	-4.03%	0.38%	-0.21%	0.83%	-5.37%	1.39%	0.27%	1.05%	0.86%	1.19%	0.32%
Japan	-0.12%	0.00%	-0.19%	0.00%	0.00%	0.00%	-0.02%	0.01%	0.00%	0.04%	-0.02%
Korea	-0.14%	0.04%	-0.23%	0.01%	0.04%	0.04%	0.01%	0.05%	0.03%	0.08%	0.00%
New Zealand	-1.02%	0.02%	-0.68%	0.06%	-0.13%	-0.15%	-0.06%	0.07%	-0.15%	-0.03%	-0.08%
Norway	2.55%	-3.59%	0.24%	-0.03%	-0.08%	-0.51%	-0.54%	-0.88%	0.69%	-0.25%	-0.56%
Poland	-13.57%	-3.02%	-2.57%	-0.37%	-2.01%	-2.03%	-1.55%	-0.99%	-1.44%	-2.37%	-2.52%
Portugal	-3.42%	0.41%	-0.91%	0.29%	-3.81%	0.48%	-0.33%	0.46%	0.44%	0.76%	-0.11%
Russia	-22.22%	-3.50%	-4.57%	-0.68%	-3.50%	-3.57%	-4.53%	-1.51%	-3.41%	-2.46%	-3.55%
South Africa	-5.64%	-3.23%	-3.29%	-0.76%	-2.54%	-2.63%	-2.04%	-0.45%	-2.46%	-2.49%	-2.92%
Spain	-3.21%	1.14%	-0.18%	0.49%	-5.16%	1.10%	0.47%	0.91%	0.65%	1.16%	0.40%
Sweden	-4.93%	-0.17%	-0.10%	1.73%	-6.63%	1.80%	1.53%	1.31%	1.44%	1.44%	0.37%
Turkey	-0.77%	-0.19%	-0.56%	-0.01%	-0.09%	-0.06%	-0.03%	0.18%	0.06%	0.11%	-0.18%
United States	0.06%	-0.08%	-0.40%	0.00%	-0.04%	-0.06%	-0.01%	-0.02%	0.04%	0.03%	-0.06%
Coalition	-4.63%	0.04%	-0.21%	1.06%	-4.79%	1.42%	0.35%	1.12%	0.95%	1.22%	0.29%
OECD, Non-Coalition	-0.11%	-0.14%	-0.38%	0.00%	-0.04%	-0.06%	-0.02%	-0.03%	0.03%	0.01%	-0.08%
Non-OECD, Non-Coalition	-0.64%	-0.50%	-1.16%	-0.31%	-1.01%	-1.11%	-0.32%	-0.20%	-0.53%	-0.38%	-0.65%
All countries	-1.30%	-0.14%	-0.39%	0.08%	-0.64%	0.21%	0.05%	0.23%	0.33%	0.29%	-0.02%

Table A.6: Production Based Emissions by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	0.26%	0.10%	0.15%	0.05%	0.05%	0.05%	0.04%	0.03%	0.05%	0.07%	0.07%
Australia	-0.48%	0.06%	0.01%	0.04%	0.01%	0.03%	0.02%	0.07%	0.02%	0.03%	-0.02%
Austria	5.58%	3.59%	1.44%	0.72%	1.02%	0.85%	1.27%	0.75%	0.61%	1.04%	1.20%
Brazil	0.31%	0.07%	0.15%	0.04%	0.05%	0.06%	0.04%	0.03%	0.07%	0.22%	0.10%
Canada	0.21%	-0.14%	0.19%	0.01%	0.00%	-0.01%	-0.12%	-0.03%	0.09%	0.03%	-0.03%
China	-0.09%	-0.04%	-0.46%	-0.02%	-0.14%	0.07%	-0.07%	0.00%	-0.10%	-0.06%	-0.11%
Czech Republic	-8.73%	-39.54%	-4.91%	-1.34%	-3.52%	-1.77%	-3.51%	0.08%	-0.25%	-2.42%	-3.51%
Finland	5.04%	6.25%	1.16%	1.04%	1.91%	1.71%	1.72%	1.74%	0.75%	1.58%	2.29%
France	6.12%	5.28%	0.91%	0.50%	1.27%	1.14%	1.78%	1.09%	0.65%	1.32%	2.15%
Germany	4.90%	0.87%	0.75%	0.59%	1.28%	0.56%	1.05%	0.64%	0.51%	0.82%	1.33%
Great Britain	4.60%	-0.79%	0.44%	1.75%	1.83%	0.98%	2.17%	1.25%	0.63%	1.11%	1.31%
Greece	4.27%	3.38%	0.67%	0.24%	0.62%	0.53%	0.73%	0.55%	0.47%	0.69%	1.10%
India	-0.03%	-2.78%	-0.10%	0.00%	-0.12%	0.01%	0.00%	0.10%	0.00%	0.05%	0.00%
Indonesia	-0.26%	-0.23%	-0.59%	-0.01%	-0.92%	0.13%	-0.24%	0.09%	-0.26%	0.22%	-0.24%
Israel	1.88%	0.69%	0.45%	0.05%	0.22%	0.22%	0.17%	0.17%	0.26%	0.31%	0.35%
Italy	6.25%	2.75%	0.72%	0.71%	1.07%	0.86%	1.30%	0.90%	0.65%	1.07%	1.34%
Japan	0.22%	0.05%	0.06%	0.01%	0.02%	0.03%	0.03%	0.01%	0.03%	0.03%	0.05%
Korea	0.25%	0.02%	0.10%	0.02%	0.06%	0.09%	0.05%	0.07%	0.07%	0.08%	0.08%
New Zealand	-0.90%	0.05%	-0.10%	0.07%	-0.06%	-0.05%	0.02%	0.10%	-0.09%	-0.02%	-0.13%
Norway	5.57%	-10.99%	1.01%	0.03%	0.05%	-0.15%	0.06%	-0.60%	0.67%	-0.20%	-0.48%
Poland	-23.46%	-37.45%	-3.58%	-0.30%	-2.50%	-1.58%	-1.63%	-0.69%	-0.76%	-1.99%	-6.21%
Portugal	3.77%	4.73%	0.63%	0.33%	0.40%	0.46%	0.77%	0.52%	0.39%	0.79%	0.66%
Russia	-27.63%	-33.51%	-4.48%	-0.65%	-3.39%	-3.44%	-7.79%	-1.30%	-3.23%	-0.73%	-10.98%
South Africa	-4.89%	-7.44%	-2.56%	-0.47%	-2.19%	-2.42%	-1.85%	-0.13%	-2.17%	-2.43%	-3.59%
Spain	5.32%	5.44%	0.79%	0.45%	0.95%	0.85%	1.11%	0.85%	0.57%	1.09%	1.41%
Sweden	5.07%	1.03%	1.09%	1.47%	1.45%	1.10%	1.47%	1.01%	1.04%	1.25%	2.16%
Turkey	-0.24%	-1.55%	0.11%	0.03%	-0.05%	0.12%	0.11%	0.37%	0.19%	0.11%	0.09%
United States	0.23%	-0.61%	0.19%	0.01%	0.04%	0.03%	-0.01%	-0.01%	0.11%	0.04%	-0.16%
Coalition	5.16%	3.14%	0.80%	0.78%	1.20%	0.91%	1.49%	0.90%	0.63%	1.07%	1.56%
OECD, Non-Coalition	-1.23%	-0.54%	-0.26%	0.00%	-0.13%	-0.07%	-0.16%	0.03%	0.03%	-0.17%	-0.31%
Non-OECD, Non-Coalition	-8.22%	-9.64%	-1.03%	-0.13%	-0.84%	-0.19%	-1.20%	0.01%	-0.50%	-0.05%	-1.67%
All countries	-4.43%	-0.53%	-0.43%	0.09%	-0.30%	-0.05%	-0.31%	0.10%	-0.04%	0.01%	-0.69%

Table A.7: Consumption Based Emissions by Country and Industry (% Change)

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood	Total
Argentina	0.16%	0.03%	0.08%	0.02%	0.04%	0.04%	0.03%	0.03%	0.05%	0.07%	0.05%
Australia	-0.09%	0.01%	0.04%	0.02%	0.01%	0.01%	0.02%	0.04%	0.01%	0.02%	0.01%
Austria	-2.67%	-0.68%	0.19%	0.78%	0.87%	1.05%	0.92%	0.82%	0.69%	1.12%	0.12%
Brazil	0.24%	0.04%	0.10%	0.02%	0.05%	0.06%	0.04%	0.03%	0.06%	0.14%	0.07%
Canada	0.21%	-0.10%	0.10%	0.00%	-0.01%	-0.02%	-0.09%	-0.04%	0.08%	0.00%	0.00%
China	-0.10%	-0.06%	-0.14%	-0.02%	-0.11%	-0.04%	-0.06%	-0.02%	-0.10%	-0.14%	-0.09%
Czech Republic	-4.93%	-4.30%	-3.66%	-1.39%	-3.29%	-2.91%	-3.09%	-0.63%	-1.34%	-3.33%	-3.06%
Finland	-7.57%	-3.32%	0.90%	1.09%	1.19%	2.15%	1.79%	2.02%	0.97%	1.88%	-0.55%
France	-12.05%	0.31%	-0.38%	0.50%	0.02%	1.37%	-1.10%	1.20%	0.80%	1.53%	-0.88%
Germany	-15.78%	-3.84%	-1.36%	0.61%	-1.11%	0.88%	-1.00%	0.69%	0.75%	0.90%	-2.49%
Great Britain	-19.68%	-2.76%	-0.28%	1.95%	-3.18%	1.86%	-2.14%	1.64%	1.46%	1.32%	-2.72%
Greece	-1.61%	-1.44%	0.22%	0.23%	0.45%	0.57%	-0.13%	0.50%	0.46%	0.71%	-0.01%
India	0.06%	0.00%	0.03%	0.00%	-0.03%	0.00%	0.01%	0.07%	0.00%	0.00%	0.02%
Indonesia	-0.26%	-0.15%	-0.36%	-0.07%	-0.46%	-0.04%	-0.16%	0.05%	-0.26%	0.11%	-0.19%
Israel	1.08%	0.37%	0.25%	0.05%	0.22%	0.21%	0.15%	0.14%	0.24%	0.30%	0.28%
Italy	-24.16%	-2.60%	-0.54%	0.74%	0.02%	1.20%	-0.74%	1.03%	0.85%	1.18%	-2.71%
Japan	0.16%	0.02%	0.02%	0.00%	0.02%	0.02%	0.02%	0.01%	0.02%	0.04%	0.03%
Korea	0.21%	0.04%	0.08%	0.02%	0.07%	0.06%	0.05%	0.06%	0.07%	0.08%	0.08%
New Zealand	-0.60%	0.03%	-0.14%	0.07%	-0.06%	-0.06%	0.02%	0.08%	-0.11%	-0.02%	-0.12%
Norway	3.86%	-2.65%	0.87%	0.02%	0.05%	-0.31%	-0.39%	-0.84%	0.71%	-0.24%	0.33%
Poland	-11.82%	-2.36%	-1.90%	-0.33%	-1.87%	-1.86%	-1.41%	-0.97%	-1.41%	-2.37%	-2.86%
Portugal	-6.88%	0.39%	-0.02%	0.34%	0.43%	0.53%	0.57%	0.48%	0.46%	0.73%	-0.31%
Russia	-21.00%	-2.78%	-3.93%	-0.66%	-3.38%	-3.50%	-4.39%	-1.50%	-3.37%	-2.46%	-6.42%
South Africa	-4.56%	-3.21%	-2.74%	-0.75%	-2.47%	-2.55%	-1.96%	-0.44%	-2.41%	-2.49%	-3.09%
Spain	-10.43%	-0.01%	-0.03%	0.46%	0.35%	1.02%	0.69%	0.90%	0.64%	1.16%	-0.48%
Sweden	-6.20%	-2.71%	0.78%	1.60%	1.29%	1.62%	1.35%	1.25%	1.44%	1.41%	-1.06%
Turkey	0.28%	0.31%	0.08%	0.02%	0.03%	0.06%	0.07%	0.21%	0.08%	0.10%	0.10%
United States	0.19%	-0.08%	0.09%	0.01%	0.04%	0.03%	-0.01%	-0.01%	0.05%	0.03%	0.03%
Coalition	-13.61%	-2.18%	-0.45%	0.85%	-0.36%	1.30%	-0.26%	1.09%	0.91%	1.22%	-1.69%
OECD, Non-Coalition	-0.22%	-0.11%	-0.05%	-0.02%	-0.04%	-0.03%	-0.08%	-0.03%	-0.01%	-0.10%	-0.07%
Non-OECD, Non-Coalition	-4.78%	-0.52%	-0.86%	-0.18%	-0.63%	-0.60%	-0.68%	-0.10%	-0.51%	-0.59%	-1.15%
All countries	-4.43%	-0.53%	-0.43%	0.09%	-0.30%	-0.05%	-0.31%	0.10%	-0.04%	0.01%	-0.69%

Table A.8: GDP by country (% Change)

Country	GDP
Argentina	0.00%
Australia	0.00%
Austria	0.72%
Brazil	0.00%
Canada	0.00%
China	-0.01%
Czech Republic	-0.70%
Finland	0.81%
France	0.40%
Germany	0.56%
Great Britain	2.03%
Greece	0.17%
India	0.00%
Indonesia	-0.06%
Israel	0.02%
Italy	0.69%
Japan	0.00%
Korea	0.01%
New Zealand	0.01%
Norway	0.03%
Poland	-0.18%
Portugal	0.30%
Russia	-0.36%
South Africa	-0.54%
Spain	0.40%
Sweden	1.71%
Turkey	0.00%
United States	0.00%
Coalition	0.89%
Non-Coalition	-0.01%
OECD, Non-Coalition	0.00%
Non-OECD, Non-Coalition	-0.06%
All countries	0.22%

Appendix B - Data

Table B.1: List of Coalition Countries

	European Union	Annex I	Neither Coalition	Non-EU, OECD	Non-EU, Non-OECD
Argentina			x		x
Australia		x		x	
Austria	x	x			
Brazil			x		x
Canada		x		x	
China			x		x
Czech Republic		x		x	
Finland	x	x			
France	x	x			
Germany	x	x			
Great Britain	x	x			
Greece	x	x			
India			x		x
Indonesia			x		x
Israel			x		x
Italy	x	x			
Japan		x		x	
Korea			x	x	
New Zealand		x		x	
Norway		x		x	
Poland		x		x	
Portugal	x	x			
Russia		x			x
South Africa			x		x
Spain	x	x			
Sweden	x	x			
Turkey		x		x	
United States		x		x	
Total	**11**	**20**	**8**		
% of Total	**39%**	**71%**	**29%**		

Table B.2: Technology Parameters

	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textile	Transport Equipment	Wood
Argentina	1.11	0.15	0.23	2.11	0.04	0.15	0.08	0.48	0.11	0.13
Australia	1.05	0.09	0.46	2.12	0.24	0.64	0.23	1.48	0.25	0.29
Austria	0.59	0.03	0.41	0.89	1.66	1.52	1.01	1.28	1.67	0.52
Brazil	0.94	0.02	0.08	1.17	0.12	0.08	0.30	0.18	0.19	0.90
Canada	1.19	0.21	0.43	0.86	0.42	0.36	2.20	0.75	0.79	1.24
China	0.08	0.01	0.05	0.15	0.03	0.18	0.04	0.08	0.03	0.08
Czech Republic	0.11	0.01	0.10	0.08	0.11	0.10	0.09	0.17	0.21	0.09
Finland	0.89	0.19	0.69	0.56	0.46	1.02	2.32	0.94	1.12	1.17
France	1.00	0.16	0.59	1.08	1.19	0.76	0.55	0.93	0.72	0.62
Germany	1.18	0.10	0.91	0.9	1.65	1.46	0.98	1.52	1.28	0.76
Great Britain	1.32	0.18	0.84	1.06	1.36	1.07	0.59	1.18	0.84	0.24
Greece	0.65	0.13	0.22	0.89	0.23	0.46	0.20	0.70	0.10	0.13
India	0.10	0.01	0.02	0.09	0.02	0.03	0.02	0.13	0.02	0.08
Indonesia	0.06	0.01	0.04	0.35	0.07	0.11	0.08	0.11	0.02	0.38
Israel	1.66	0.02	1.19	0.37	0.35	0.27	0.56	1.61	0.11	0.30
Italy	0.61	0.19	0.44	0.82	1.16	0.78	0.44	0.94	0.62	0.45
Japan	0.93	0.33	0.98	0.07	0.71	1.36	0.44	0.74	1.37	0.06
Korea	0.63	0.08	0.58	0.27	0.39	0.89	0.40	1.57	1.02	0.17
New Zealand	1.67	0.01	0.25	4.08	0.23	0.23	0.41	1.53	0.19	0.26
Norway	1.60	0.24	0.80	0.34	0.45	1.11	1.11	0.82	0.43	0.33
Poland	0.29	0.02	0.10	0.14	0.08	0.09	0.08	0.11	0.14	0.09
Portugal	0.13	0.01	0.13	0.28	0.21	0.17	0.21	0.36	0.19	0.71
Russia	0.31	0.01	0.01	0.04	0.00	0.01	0.04	0.02	0.02	0.08
South Africa	2.13	0.32	0.15	0.70	0.23	0.12	0.40	0.81	0.20	0.15
Spain	0.60	0.15	0.30	0.76	0.82	0.61	0.40	0.68	0.65	0.37
Sweden	1.20	0.10	1.00	0.81	1.36	1.69	1.38	1.46	0.99	1.14
Turkey	0.29	0.02	0.13	0.30	0.38	0.26	0.04	0.44	0.17	0.09
United States	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table B.3: Countries Used to Calculate β and Years of Availability of Input-output Tables

Country	ISICs with wage data	ISICs with production data	ISICs with employment data	Included when calculating beta?	Year(s) of availability of input-output tables
Argentina	24	24	24	No	1997
Australia	19	19	19	No	2001/02
Austria	24	24	24	No	2000
Brazil	20	20	20	No	2000
Canada	26	26	26	Yes	2000
China	0	0	0	No	2000
Czech Republic	13	13	13	No	2001
Finland	26	26	26	Yes	2000
France	25	25	25	Yes	2000
Germany	26	26	26	Yes	2000
Great Britain	26	26	26	Yes	2000
Greece	0	0	0	No	2000
India	23	23	23	No	1998/99 and 2003/04
Indonesia	26	26	26	Yes	2000
Israel	22	22	22	No	1995 and 2004
Italy	26	26	26	Yes	2000
Japan	26	26	26	Yes	2000
Korea	26	26	26	Yes	2000
New Zealand	0	0	0	No	1995/96 and 2002/03
Norway	25	25	25	Yes	2000
Poland	10	10	10	No	2000
Portugal	26	26	26	Yes	2000
Russia	25	25	25	Yes	2000
South Africa	9	9	9	No	2000
Spain	26	26	26	Yes	2000
Sweden	23	23	23	No	2000
Turkey	26	26	26	Yes	1998 and 2002
United States	25	25	25	Yes	2000

Table B.4: Industry Shares in Intermediate Goods (Input - output Table)

Industry	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textiles	Transport Equipment	Wood
Basic Metals	0.426	0.011	0.183	0.002	0.026	0.068	0.007	0.003	0.088	0.010
Chemicals	0.027	0.391	0.033	0.016	0.055	0.189	0.068	0.097	0.021	0.048
Fabricated	0.070	0.032	0.379	0.024	0.056	0.089	0.027	0.024	0.175	0.048
Food	0.002	0.016	0.003	0.223	0.003	0.006	0.006	0.025	0.002	0.003
Minerals	0.013	0.010	0.012	0.008	0.194	0.011	0.002	0.003	0.011	0.009
Other	0.031	0.031	0.044	0.025	0.022	0.153	0.026	0.026	0.068	0.020
Paper	0.006	0.027	0.015	0.030	0.030	0.028	0.418	0.018	0.006	0.020
Textiles	0.002	0.006	0.004	0.003	0.006	0.037	0.009	0.445	0.012	0.010
Transport Equipment	0.004	0.003	0.010	0.002	0.005	0.006	0.002	0.002	0.359	0.004
Wood	0.003	0.003	0.005	0.003	0.010	0.066	0.017	0.002	0.004	0.293
Nonmanufactures	0.417	0.470	0.314	0.664	0.595	0.348	0.417	0.355	0.253	0.536
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table B.5: Labor Share (Based on 15/28 Countries)

Industry	Total Compensation	Total Output	Labor Share
Basic Metals	68,118,626	589,474,675	0.103
Chemicals	131,379,826	1,271,085,065	0.103
Fabricated	537,492,681	3,407,723,789	0.158
Food	140,191,402	1,519,380,017	0.087
Minerals	55,926,173	365,819,996	0.187
Other	213,318,851	1,166,385,932	0.169
Paper	104,607,173	700,718,929	0.145
Textile	76,978,204	514,414,556	0.165
Transport Equipment	212,262,721	1,747,555,619	0.121
Wood	32,155,331	217,738,663	0.139

Production Data from UNIDO

Table B.6: Food Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa	Israel	Norway
Years	2002	2000	2000	1998-2002 average
1511-1514	151A	151C	151	151
1520	151A	151C	1520	1520
1531-1533	151A	151C	153	153
1541-1544, 1549	151A	151C	154	154
1551-1554	151A	155A	155A	155
1600	Missing	155A	155A	Missing

Table B.7: Paper Production Data from UNIDO

ISIC Rev. 2	South Africa
Years	1998-2002 average
1920	Not used because used in Textiles instead
2021	Not used because used in Wood instead
2101-2102, 2109	210
2211-2212, 2219, 2221-2222	221B
2699	Missing
2899	Missing

Table B.8: Wood Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa
Years	2000	2000
1920	Not used because used in Textiles instead	Not used because used in Textiles instead
2010, 2021-2023, 2029	2010A	2010A
3699	Not used because used in Other instead	Not used because used in Other instead

Table B.9: Textiles Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa	Brazil	China
Years	2003	1998-2002 average	2000	2003
140	Not in trade data	Not in trade data	Not in trade data	Not in trade data
1711	171F	171G	171	1711
1712	171F	171G	171	1712
1721	171F	171G	172	1721
1722	171F	171G	172	1722
1723	171F	171G	172	1723
1729	171F	171G	172	1729
1730	171F	171G	1730	1730
1810	171F	171G	1810A	1810
1820	171F	171G	1810A	1820
1911	Missing	171G	191	1911
1912	Missing	171G	191	1912
1920	Missing	171G	1920	1920
2029	Missing for all countries with no values for ISIC Rev. 2 industry 321	Missing for all countries with no values for ISIC Rev. 2 industry 321	Missing for all countries with no values for ISIC Rev. 2 industry 321	Missing for all countries with no values for ISIC Rev. 2 industry 321
2430	Missing	Missing or aggregated (2310G for year 1998)	2430	2430
2520, 3699, 3720	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead
2610	2610	2610	2610	2610
2899	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead

Table B.10: Chemicals Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa	Australia	China
Years	NA	2000	1998-2002 average	2003
2330	Missing	2330A	Missing	Missing
2411	Missing	2330A	2411	2411
2412	Missing	2330A	2412	2412
2413	Missing	2330A	2413	2413
2421	Missing	242	2421	2421
2422	Missing	242	2422	2422
2423	Missing	242	2423	2423
2424	Missing	242	2424	2424
2429	Missing	242	2429	2429
2430	Missing	Missing or aggregated (2310G)	2430	2430
2519, 2520, 3699	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead
2927	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead

Table B.11: Basic Metals Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa	Australia	Greece	Israel	Brazil
Years	2000	2000	1998-2002 average	Use CEPII	Use CEPII	2000
2710	2710A	2710G	2710	2710	2710	2710
2720	2710A	2720	2720	2720	2720	2720
2731	2710A	2710G	2731	273	273	273
2732	2710A	2710G	2732	273	273	273
2891, 2892	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead
3520	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead
3710	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead

Table B.12: Minerals Production Data from UNIDO

ISIC Rev. 2	Argentina	Brazil	India	Israel	New Zealand	South Africa
Years	2000	2000	2003	2000	2000	2000
1030, 5239	Missing from UNIDO IndStat	Missing from UNIDO IndStat	Missing from UNIDO IndStat	Missing from UNIDO IndStat	Missing from UNIDO IndStat	Missing from UNIDO IndStat
2610	2610	2610	2610	2691C	2610A	2610
2691	269	269	269	2691C	2610A	269
2692	269	269	269	Missing	2610A	269
2693	269	269	269	2691C	2610A	269
2694	269	269	269	2694A	2610A	269
2695	269	269	269	2694A	2610A	269
2696	269	269	269	2696A	2610A	269
2699	269	269	269	2696A	2610A	269
2720	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead
3190	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead
3320, 3699	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead	Not used because used in Other instead
Comments	Use CEPII because same	Use CEPII because same		Use CEPII because same		Use CEPII because same

Table B.13: Fabricated Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa
Years	2003 values	2000
2213, 2230	Not used because used in Paper instead	Not used because used in Paper instead
2710, 2720	Not used because used in Basic Metals instead	Not used because used in Basic Metals instead
2811- 2813, 2891-2893, 2899	281A	281A
2911-2915, 2919, 2921-2927, 2929, 2930	291A	291A
3000	3000B (includes irrelevant 4-digit ISICs from Other)	Missing
3110, 3120, 3140, 3150, 3190	3000B (includes irrelevant 4-digit ISICs from Other)	3110A
3130	3110A	
3210, 3220, 3230	3000B (includes irrelevant 4-digit ISICs from Other)	3210A
3311-3312, 3610, 3694, 2699	Not used because used in Other instead	Not used because used in Other instead
3420, 3511, 3520, 3530, 3599	Not used because used in Transport Equipment instead	Not used because used in Transport Equipment instead
7250	Not in trade data	Not in trade data

Table B.14: Transport Equipment Production Data from UNIDO

ISIC Rev. 2	New Zealand	South Africa
Years	2003	2000
2911-2912, 2915, 3190	Not used because used in Fabricated instead	Not used because used in Fabricated instead
3410, 3420, 3430	3410A	3410B
3511-3512, 3520, 3530, 3591-3592, 3599	3410A	351A
3694, 3699	Not used because used in Other instead	Not used because used in Other instead

Table B.15: Other Production Data from UNIDO

ISIC Rev. 2	Brazil	New Zealand	South Africa
Years	2000	2000	2000
1721, 1729, 1810, 1912,1920	Not used because used in Textiles instead	Not used because used in Textiles instead	Not used because used in Textiles instead
2029	Not used because used in Wood instead	Not used because used in Wood instead	Not used because used in Wood instead
2101, 2109, 2221	Not used because used in Paper instead	Not used because used in Paper instead	Not used because used in Paper instead
2422, 2423, 2429	Not used because used in Chemicals instead	Not used because used in Chemicals instead	Not used because used in Chemicals instead
2511, 2519	251	251A	251
2520	2520	251A	2520
2892, 2899, 2914, 2919, 2926, 2929, 3000, 3140, 3150, 3190	Not used because used in Fabricated instead	Not used because used in Fabricated instead	Not used because used in Fabricated instead

Table B.16: Embodied CO_2 Emissions in Trade (kg/$)

Country	Basic Metals	Chemicals	Fabricated	Food	Minerals	Other	Paper	Textiles	Transport Equipment	Wood
Argentina	1.56	0.81	0.51	0.50	1.71	1.31	0.37	0.29	0.26	0.40
Australia	4.74	1.44	1.13	0.77	2.92	1.00	0.64	0.72	0.70	0.59
Austria	1.99	1.07	0.31	0.35	0.92	0.59	0.38	0.31	0.23	0.27
Brazil	2.01	1.50	0.59	0.51	1.91	1.17	0.62	0.44	0.45	0.37
Canada	2.32	1.79	0.51	0.49	1.56	1.22	0.85	0.41	0.27	0.55
China	5.73	3.94	2.34	1.39	5.73	2.75	2.46	1.44	2.19	2.02
Czech Republic	6.49	3.35	0.95	1.07	2.28	1.81	1.00	0.95	0.46	0.93
Finland	1.77	1.45	0.34	0.48	1.02	0.51	0.71	0.42	0.27	0.43
France	1.50	1.12	0.38	0.35	1.14	0.90	0.37	0.39	0.25	0.32
Germany	1.76	1.23	0.38	0.43	1.33	0.69	0.41	0.50	0.30	0.49
Great Britain	1.06	0.76	0.29	0.29	0.61	0.49	0.23	0.31	0.24	0.28
Greece	3.19	1.67	0.86	0.65	3.98	0.97	0.75	0.62	0.31	0.63
India	6.58	4.23	2.86	1.62	7.23	4.23	3.49	2.91	3.16	1.42
Indonesia	5.29	5.06	1.06	0.42	6.81	3.83	1.24	1.41	0.94	0.67
Israel	0.79	1.35	0.30	0.59	1.38	1.10	0.33	0.46	0.29	0.41
Italy	1.07	0.93	0.30	0.40	1.32	0.35	0.41	0.35	0.25	0.25
Japan	1.06	0.98	0.26	0.20	0.60	0.55	0.27	0.33	0.24	0.47
Korea	1.91	2.14	0.54	0.61	2.54	1.19	0.80	0.86	0.60	0.91
New Zealand	3.07	4.43	0.56	0.39	1.85	2.05	0.49	0.44	0.42	0.45
Norway	0.96	1.52	0.29	0.35	1.28	0.52	0.20	0.34	0.25	0.31
Poland	5.91	3.86	1.46	1.67	3.33	1.43	1.20	1.06	0.89	1.47
Portugal	1.73	1.89	0.32	0.46	2.51	0.51	0.59	0.45	0.27	0.45
Russia	12.52	13.54	4.97	3.33	9.62	6.79	3.83	3.01	2.68	4.74
South Africa	6.06	4.87	1.65	1.57	3.74	4.34	1.25	1.40	0.95	1.28
Spain	1.48	1.41	0.53	0.51	2.05	0.49	0.54	0.47	0.36	0.38
Sweden	1.26	0.63	0.20	0.25	1.15	0.35	0.25	0.35	0.15	0.20
Turkey	2.77	1.91	0.58	0.63	1.33	3.21	0.67	0.64	0.38	0.51
United States	1.96	1.54	0.43	0.59	1.78	0.62	0.47	0.62	0.40	0.60

Source: Own calculations and Nakano, et al. (2009, p. 34)

Table B.17: Emissions for Countries with Separate Data on Ferrous (371) and Non-Ferrous (372) Metals

Country	371 Production ($1,000)	372 Production ($1,000)	Total Production ($1,000)	371/Total	372/Total	371 Emissions ($MtCO_2$/$1,000)	372 Emissions ($MtCO_2$/$1,000)	Basic Metals Emissions ($MtCO_2$/$1,000)
Argentina	4,061,031	.	.	.	.	1.57	1.54	1.56
Australia	.	.	.	.	.	4.48	5.33	4.74
Brazil	.	.	.	.	.	2.16	1.67	2.01
Canada	11,244,325	14,150,858	25,395,183	0.44	0.56	3.03	0.70	2.32
China	57,170,984	26,336,052	83,507,036	0.69	0.32	6.40	4.20	5.73
India	2,629,879	1,038,359	3,668,238	0.72	0.28	5.89	3.92	5.29
Indonesia	16,715,537	4,266,137	20,981,674	0.80	0.20	7.25	5.03	6.58
Israel	947,924	333,206	1,281,130	0.74	0.26	0.93	0.48	0.79
Japan	104,074,792	36,269,152	140,343,944	0.74	0.26	1.24	0.65	1.06
Korea	30,364,204	9,063,194	39,427,398	0.77	0.23	1.99	1.72	1.91
Russia	18,704,122	8,680,837	27,384,959	0.68	0.32	15.51	5.66	12.52
South Africa	.	.	.	.	.	6.19	5.75	6.06
Turkey	6,586,322	1,542,121	8,128,443	0.81	0.19	2.74	2.83	2.77
Average	.	.	.	0.70	0.30	.	.	.

Table B.18: Industry ISIC Codes

Industry	ISICs
Food	311,313,314
Textiles	321-324
Wood	331
Paper	341,342
Chemicals	351,352
Minerals	361,362,369
Basic Metals	371,372
Fabricated	381-383
Transport Equipment	384
Other	332,355,356,385,390

Appendix C - Equations

Our calculation of real income is performed as follows: $W_m = \frac{GDP_m}{\prod_{i=1}^{I} p_{mi}^{\alpha_i}} = \frac{VAQ_m + VAQ_m^{nm} + Revenue_m}{\prod_{i=1}^{I} p_{mi}^{\alpha_i}}$

Where $Revenue_{mi} = \sum_{x=1}^{M} \frac{trade_{mxi} * bca_{mxi}}{d_{mxi} + bca_{mxi}}$ and $Revenue_m = \sum_{i=1}^{I} \sum_{x=1}^{M} \frac{trade_{mxi} * bca_{mxi}}{d_{mxi} + bca_{mxi}}$

Per country real income % change is calculated as follows: $\frac{W_m^{BCA} - W_m^{BASE}}{W_m^{BASE}} * 100\% = \frac{\frac{GDP_m^{BCA}}{\prod_{i=1}^{I} p_{mi}^{\alpha_i}{}^{BCA}} - \frac{GDP_m^{BASE}}{\prod_{i=1}^{I} p_{mi}^{\alpha_i}{}^{BASE}}}{\frac{GDP_m^{BASE}}{\prod_{i=1}^{I} p_{mi}^{\alpha_i}{}^{BASE}}} * 100\%$

Coalition real income % change $\frac{\sum_{m \in \{Coalition\}}^{M} W_m^{BCA} - \sum_{m \in \{Coalition\}}^{M} W_m^{BASE}}{\sum_{m \in \{Coalition\}}^{M} W_m^{BASE}} * 100\%$

% change in exports to non-coalition: $\frac{\sum_{m, m \notin \{Coalition\}}^{M} EX_{xmi}^{BCA} - \sum_{m, m \notin \{Coalition\}}^{M} EX_{xmi}^{BASE}}{\sum_{m, m \notin \{Coalition\}}^{M} EX_{xmi}^{BASE}} * 100\%$

% change in exports to coalition: $\frac{\sum_{m, m \in \{Coalition\}}^{M} EX_{xmi}^{BCA} - \sum_{m, m \in \{Coalition\}}^{M} EX_{xmi}^{BASE}}{\sum_{m, m \in \{Coalition\}}^{M} EX_{xmi}^{BASE}} * 100\%$

Change in EEBT shares in total CO_2 emissions in production: $\left(\frac{CO2_{mi}^{Consumption,BCA} - CO2_{mi}^{Production,BCA}}{CO2_m^{Production,BCA}}\right) - \left(\frac{CO2_{mi}^{Consumption,BASE} - CO2_{mi}^{Production,BASE}}{CO2_m^{Production,BASE}}\right)$