

THE CARBON FOOTPRINT OF GLOBAL TRADE IMBALANCES

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Abstract

A large share of global carbon emissions arises in the production of goods that are consumed in a different country. The flow of carbon embodied in trade is highly asymmetrical. At the same time, trade is highly and persistently unbalanced in value terms, too. Prominently, the two countries with the largest net ex- and imports of carbon (China and the US) have at the same time consistently been among the countries with the largest trade surplus and deficit, respectively. We investigate the effects of global trade imbalances on carbon emissions around the world. To this end, we use a Ricardian quantitative trade model including sectoral input-output linkages, trade imbalances, and carbon emissions from fossil fuel combustion. For every individual country, the emission effect of removing its trade imbalance depends on the carbon intensities of its production and consumption patterns, as well as on its fossil resource abundance. The simultaneous removal of all global trade imbalances is found to lower world carbon emissions by 0.62 percent or 184 million tons of carbon dioxide. Out of all individual countries' imbalances, eliminating the Qatari trade surplus and the US trade deficit would lead to the largest environmental benefits in terms of lower global emissions.

JEL-Codes: F14; F18; Q56

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1 Introduction

In 2016, the two countries with the largest trade deficits in the world (the United States and the United Kingdom) were at the same time the countries with the largest (US) and third-largest (UK) net imports of carbon emissions. China, on the other hand, had both the largest trade surplus and by far the largest amount of net exports of carbon emissions. The second largest net carbon exporter (Russia) also had a large trade surplus (8th largest in the world). Of course, there are other examples, like Germany and Japan that have large trade surpluses and are strong net carbon importers, or India, that has a large trade deficit but exports way more carbon than it imports. Still, the question arises whether global trade imbalances allow specialization and consumption patterns that magnify the global carbon footprint.

The question is not straightforward to answer. First off, maybe the United States and China are net importer and net exporter of carbon *only because* they are net importers and exporter overall, respectively. The data can give an answer to this if we consider the embodied emissions *per dollar* of exports and per dollar of imports, i.e. the ex- and import carbon *intensities*. Focusing on the two most prominent examples for now, it turns out that Chinese exports are about twice as carbon-intensive as its imports, while US exports are only about half as carbon-intensive as its imports. This pattern magnifies these countries' imbalances in embodied emissions in comparison to their trade value imbalances. It further suggests that there may be scope for lower overall emissions if a trade re-balancing limited the United States' possibility to buy more of its "dirty" imports than it sells comparably "clean" exports and put a constraint on China to act as the world's supplier of carbon-intensive products. However, eliminating trade imbalances would reshuffle trade and production all around the world and we cannot rule out a-priori that some of China's "dirty" production will end up in countries that produce the same products with an even larger use of fossil fuels and hence higher emissions. Therefore, if we want to know the "carbon footprint of global trade imbalances", we need to simulate the balancing of all current accounts in a quantitative model.

Beyond the differences in production vs. consumption carbon intensity, the previously mentioned role of Russia as a large net exporter points to an additional important dimension: the role of trade in fossil fuels. A considerable share of Russian exports is the sale

of fossil fuels. The fact that the production of fossil fuels is itself carbon intensive shows up in the Russian carbon trade balance, the fact that the burning of these fossil fuels in their destination countries will cause additional emissions does not. The possibility to run a trade surplus enables fossil fuel exports like Russia to focus its production on fossil fuel extraction to a larger extent than they could if they had to align their production more strongly with their own consumption patterns. Global trade imbalances can therefore have important implications for fossil fuel *supply*, which also have to be taken into account in quantifying the imbalances' carbon footprint.

We use a Ricardian trade model along the lines of Eaton and Kortum (2002). In order to capture countries' full embedding into global value chains, we include a sectoral input-output structure as in Caliendo and Parro (2015). Additionally, we incorporate carbon emissions from fossil fuel combustion with varying carbon intensities for different types of fossil fuels. Together with the input-output structure, this allows a fine-grained consideration of embodied carbon flows and a clean distinction of countries' territorial emissions and carbon footprints. As an environmentally extended version of Caliendo and Parro (2015), the model is closely related to the contributions by Caron and Fally (2020) and Shapiro (2020), which in turn are the latest additions to a young, but growing literature incorporating emissions into structural gravity models (Egger and Nigai, 2015; Shapiro, 2016; Larch and Wanner, 2017, 2019; Shapiro and Walker, 2018).

We use the quantitative framework for two types of counterfactual analyses. First, we eliminate individual countries' trade imbalances, altering the rest of the world's surpluses and deficits only to the extent necessary to ensure that global supply equals global demand. We calculate both how the country's territorial emissions and footprint react to the elimination of the trade imbalance and how global emissions are affected. We use these country-level re-balancing exercises to identify patterns in countries' consumption habits and production specialization, as well as resource abundance that determine which imbalances are particularly problematic in terms of their effect on global emissions. Second, we simulate a global re-balancing in which all countries' surpluses and deficits are jointly erased. This allows us to assess whether the current pattern of trade imbalances around the world is in fact partly responsible for the high level of global carbon emissions. In addition to insights on the *level* of global emissions, this counterfactual is also informative

concerning the *distribution* of carbon emissions across the globe and how this is shaped by trade imbalances. Our exercises come with one important disclaimer. Unlike a growing literature on the *sources* of trade imbalances (cf. Davis and Weinstein, 2002; Barattieri, 2014; Reyes-Heroles, 2016; Eugster, Jaumotte, MacDonald, and Piazza, 2020; Felbermayr and Yotov, 2021), our paper purely examines the *consequences* of their removal, standing in the tradition of Dekle, Eaton, and Kortum (2007, 2008). To this respect, we do not point towards a policy that would eliminate the imbalance, but we can calculate the magnitudes of the long-run adjustments that such a policy would entail.

Until now, the role of trade imbalance in shaping global emission patterns has received little attention. In their recent handbook chapter, Copeland, Shapiro, and Taylor (2021) briefly refer to imbalances as one factor that could contribute to the outsourcing of emissions. Li et al. (2020) consider embodied energy in the US-Chinese *bilateral* trade imbalance, showing that the United States implicitly net import large amounts of energy from China.

The remainder of this paper is structured as follows. Section 2 presents a collection of stylized facts about global trade imbalances in terms of both values and embodied emissions, their interrelation with one another and with the countries' resource abundance. Section 3 lays out the quantitative model and Section 4 introduces the data used for the quantification. In Section 5, we present the results of the counterfactual exercises. Section 6 concludes.

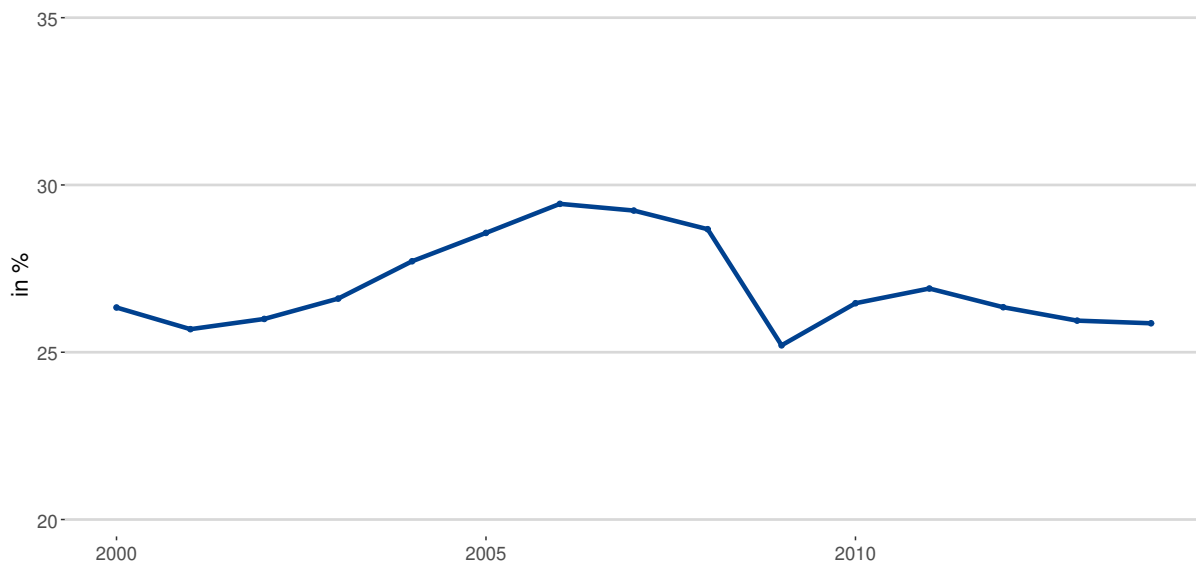
2 Trade Imbalances and Embodied Emissions:

A Look at the Data

In this section, we take a look at the data and establish seven stylized facts about value and embodied emission trade imbalances across countries and time. While not novel individually and in part very straightforward, the aim of this *collection* of stylized facts is to motivate that trade imbalances have the potential to play an important role in shaping the level and distribution of global carbon emissions.

Stylized fact 1: A considerable share of global emissions is embodied in products that are traded internationally.

Figure 1: Share of Global CO2 Emissions Embodied in Trade, by Year

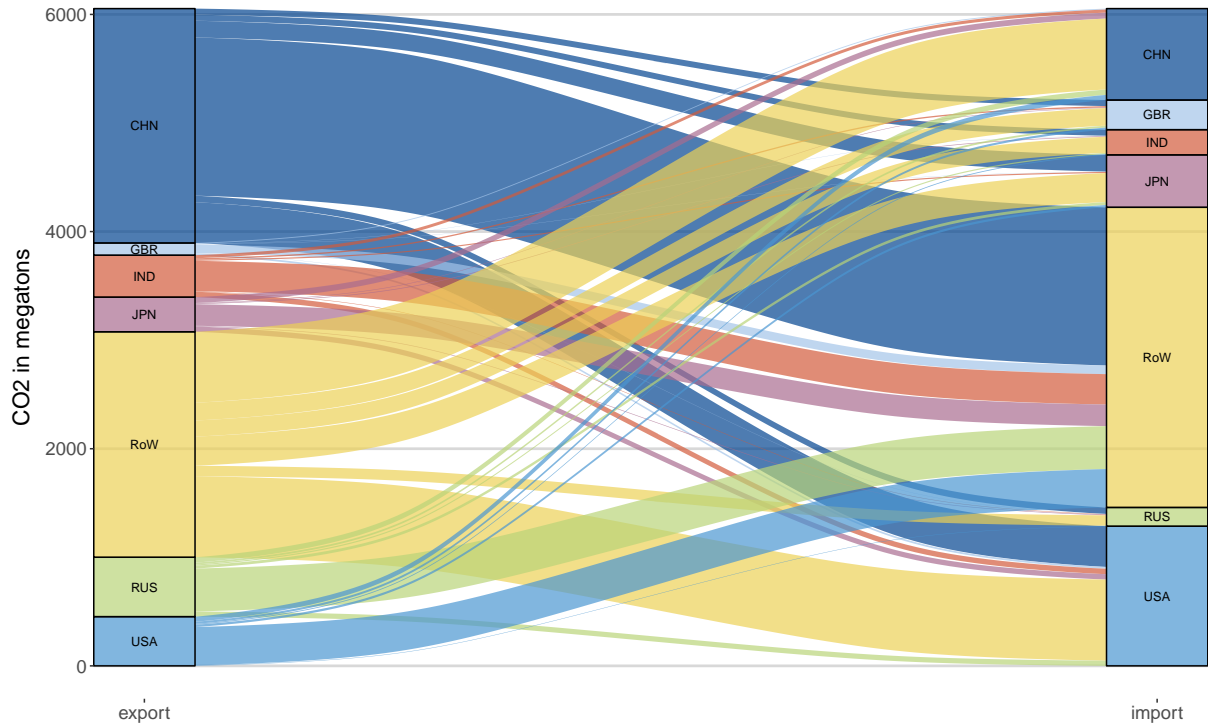


The first fact is important to establish the relevance of international trade in determining emission patterns around the world. If carbon emissions were overwhelmingly associated with products that are produced and consumed in the same countries, this would limit the role trade imbalances can play for carbon emissions. Figure 1 shows the share of carbon emissions embodied in international trade over time. It is calculated by dividing the embodied emissions in products that are traded internationally by global carbon emissions. The embodied emissions of traded goods include the emissions of their entire global value chain, including electricity and other intermediates, as well as their inputs and inputs to inputs, etc. Each dot represents one year for a period from 2000 to 2014.

As Figure 1 shows, 25 to 29 percent of global CO2 emissions are embodied in international trade. While some important sources of carbon emissions such as heating are necessarily local, a considerable share of emissions is embodied in products that are shipped internationally. Note that the range of values slightly deviates from Copeland, Shapiro, and Taylor (2021), who already establish this stylized fact and report a range from 24 to 35 percent between 1995 and 2009. This deviation is not surprising because we use a newer WIOD release (Timmer, Los, Stehrer, and De Vries, 2016).¹ In 2014 (i.e. the last year covered in this data set), the share of global CO2 emissions that were embodied in international trade was 26 percent.

¹WIOD is also the data source of all stylized facts in Section 2, despite Stylized Fact 7.

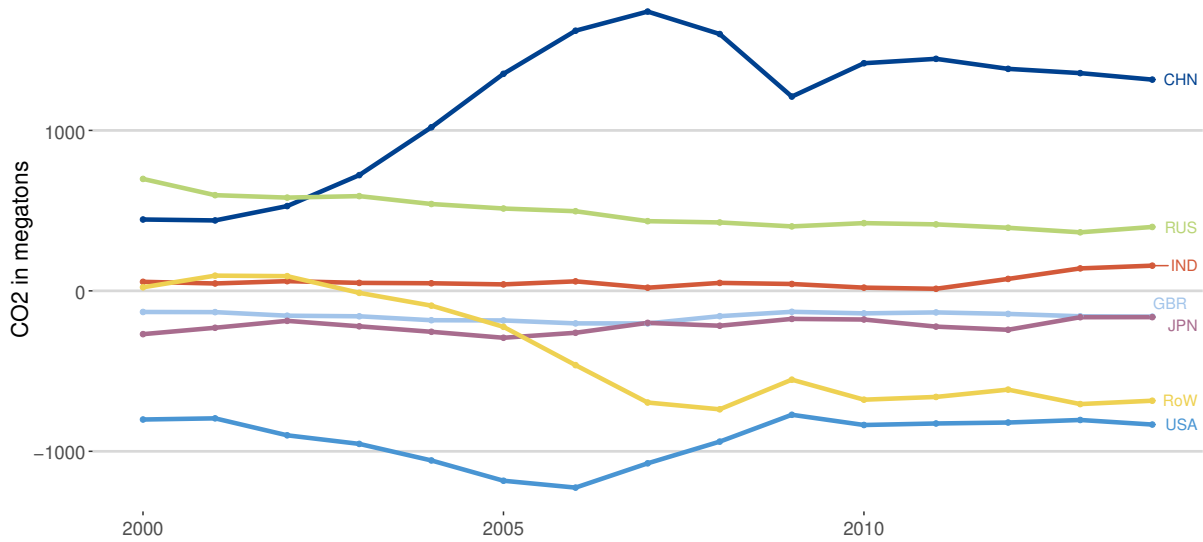
Figure 2: Bilateral Flows of Embodied CO2 Emissions in International Trade, 2014



Stylized fact 2: Embodied emissions in international trade are highly asymmetric.

Bilateral flows of embodied CO2 emissions for the six countries with the largest absolute imbalance of embodied carbon emissions in trade, plus an aggregated “Rest of the World”, are depicted in Figure 2. The height of a country’s box on the vertical axis relates to the corresponding total embodied emissions in their exports (left) and imports (right) in 2014. China, Great Britain, India, Japan, Russia and the USA account together for 66 percent of total embodied carbon emissions in exports and for 53 percent of total embodied carbon emissions in imports. For individual countries, the contrast can be very stark: while China exports 2158 megatons, it only imports 842 megatons of embodied CO2. For the US, the pattern is similarly extreme, but in the opposite direction. Their exports embody 453 megatons, while the embodied emissions in their imports amount to 1286 megatons of CO2. As the US, Great Britain and Japan are both net importers of embodied CO2, while India and Russia are net exporters. Russia is also the country with the largest share of net exports to total exports in embodied emissions, which amount to 68 percent, followed by China with 60 percent. Figure 2 implies large gaps between

Figure 3: Embodied CO2 Emissions Imbalance in International Trade, by Year



territorial emissions, which stem from the production of goods, and carbon footprints, which account for the embodied emissions in consumed goods.

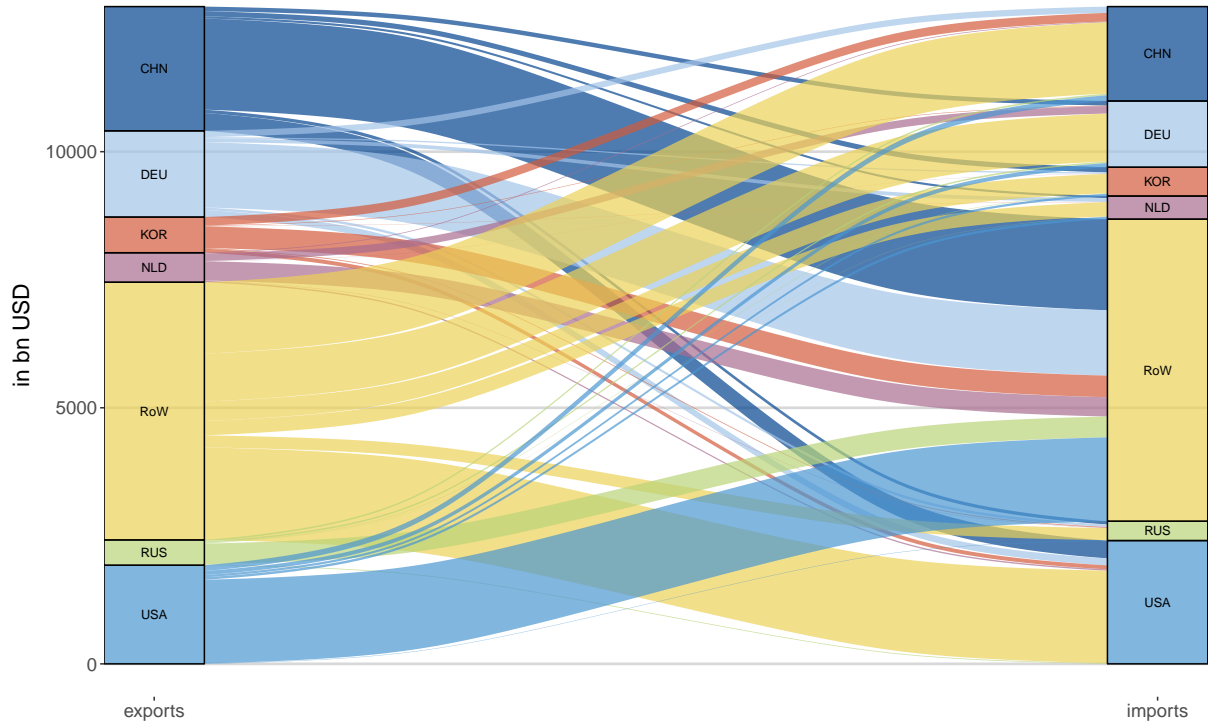
Stylized fact 3: The asymmetry in traded emissions is highly persistent.

Figure 3 depicts the imbalance of traded CO2 emissions embodied in exports and imports for the same countries as in Figure 2, but for the whole period from 2000 to 2014 rather than for just one point in time. All individual countries keep their role as a net ex- or importer of embodied emissions throughout the period. The United States are by far the largest net importer of emissions in all years and China overtakes Russia as the main net carbon exporter in 2003 and then takes a clear lead for all later years. This persistence magnifies the importance of understanding the role that the trade imbalances play in shaping global emissions. If trade imbalances contribute to a production and consumption pattern around the world that goes in hand with higher carbon emissions and this pattern persists over time, the resulting additional emissions will add up over time.

Stylized fact 4: Trade is highly asymmetric in value terms, too.

Figure 4 shows bilateral trade flows of goods and services of the six countries with the world's largest absolute trade imbalances. The height of a country's box on the vertical

Figure 4: Bilateral Trade Flows, 2014

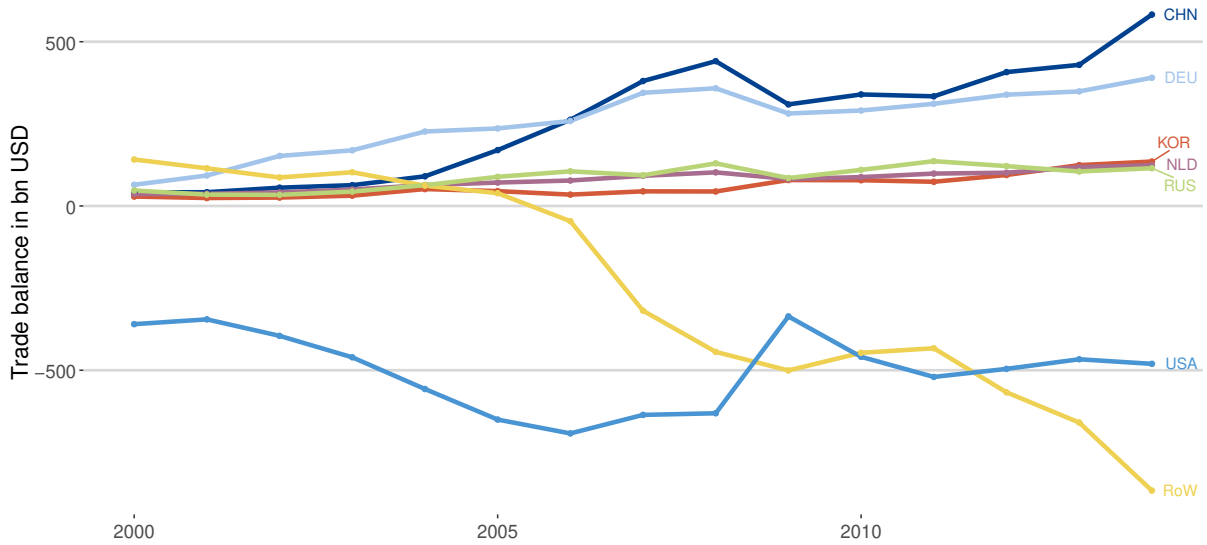


axis relates to their total exports (left) and imports (right) in billions of USD in 2014. It hence reproduces Figure 2, substituting embodied emissions for values. Even though the asymmetry in value trade is not as drastic as in embodied emissions trade, the value imbalances are substantial, too. China, Germany, South Korea, Netherlands, Russia and USA account together for 60.8 percent of total exports and 54 percent of total imports. China has a trade surplus of 583 bn USD, followed by Germany (390 bn), South Korea (135 bn), the Netherlands (124 bn), and Russia (114 bn). The USA have the largest trade deficit with 481 bn USD. Even though this stylized fact is well-established, we restate it here because it takes center-stage in our analysis which asks whether these well-known imbalances have an additional, so far overlooked environmental implication to them.

Stylized fact 5: Value trade imbalances are persistent, too.

Figure 5 shows the annual trade imbalance in value terms of the same countries as in Figure 4 for the period 2000-2014. Similarly to the embodied emissions imbalances over time shown in Figure 3, a highly persistent pattern emerges. Though the fluctuations are somewhat larger, again none of the individual countries considered switches between net

Figure 5: Trade Imbalance, by Year



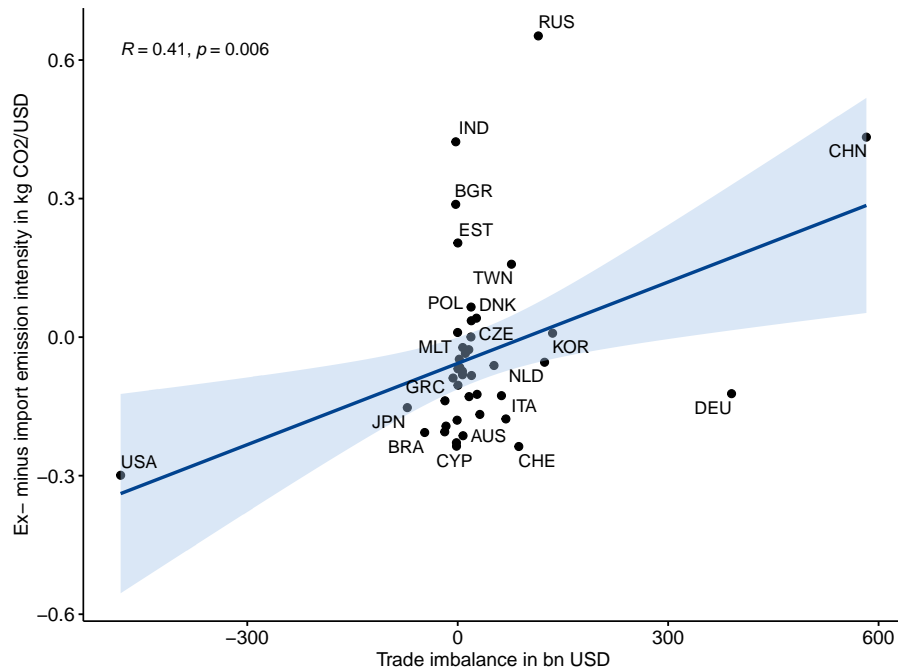
ex- and net importer status. The United States consistently run the by far largest trade deficit. China overtakes Germany as the world's largest net exporter in 2006 and keeps this first rank throughout the remaining period, though the gap to other countries is not as large in net value exports as in net carbon exports. If trade imbalances were a short-lived phenomenon, potential emission implications would be of little concern. This year's surpluses would turn into next year's deficits and a specialization pattern made possible in one year that leads to particularly high carbon emissions would be followed by a different pattern that would imply comparably low emissions. The persistence implies, however, that a high-emission global imbalance distribution could be a sustained phenomenon.

Stylized fact 6: The value trade imbalances and the relative carbon intensities of exports vs. imports are correlated.

In order to assess whether global trade imbalances are likely to drive world emissions up or down, we need to know which countries are running the deficits and which countries are running the surpluses. If countries that sell less carbon-intensive products internationally than they buy were the surplus countries, imbalances might actually be environmentally beneficial. As Figure 6 makes clear, however, the opposite is true: the imbalances are positively correlated with the relative carbon-intensity of exports.² Countries supplying

²The relative carbon-intensity of exports is calculated by subtracting the country's carbon intensity per imported USD from its carbon intensity per exported USD.

Figure 6: Correlation of Trade Imbalances and Carbon Intensities of Exports vs. Imports, 2014

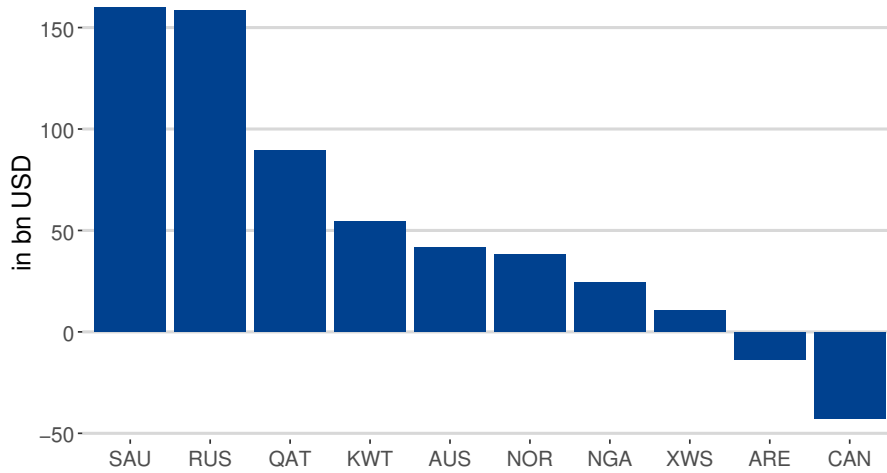


“dirty” goods to the rest of world, while importing comparably clean products, tend to run surpluses. On the other hand, the countries exporting relatively “cleanly” tend to run deficits. Most clearly and most importantly, this pattern is evident for the United States and China, as we already briefly discussed in the introduction. The (imperfect) separation into clean deficit and dirty surplus countries strongly suggests that today’s global trade imbalances contribute to upholding a trade pattern that implies higher carbon emissions than would prevail in a world of balanced trade.

Stylized fact 7: Many large fossil resource exporters are consistently running strong trade surpluses.

The relative carbon intensity of a country’s production vs. consumption is not the only dimension that determines how the country’s trade surplus or deficit impacts carbon emissions. Importantly, international trade is not only about products of varying carbon intensities, but it’s also about the products use of which *causes* carbon emissions, namely fossil fuels. If countries that are rich in fossil resources run trade surpluses, this has the potential to drive up the global supply of fossil fuels and in turn the global level of emissions. As Figure 7 shows, this is exactly the case for many of the world’s largest

Figure 7: Trade Imbalance of the 10 Largest Fossil Exporters, 2014



fossil fuel exporters.³ Out of the top ten, eight countries have a trade surplus in 2014, which are partly huge in relation to these countries' overall GDPs.⁴ It seems, therefore, that current global trade imbalances contribute to high carbon emissions in a second way, namely by fostering the global supply of fossil fuels.

To sum up, we have shown that international trade is highly unbalanced both in value and in embodied emissions terms. While this need not be bad news for global emission levels, the fact that there are positive associations between running a trade surplus and both exporting fossil-fuel intensive products and exporting fossil fuels, there is strong reason to suspect that the today's global imbalances are indeed driving up global carbon emissions and — given the persistence of the observed imbalances — will continue to do so. To quantitatively assess *the carbon footprint of global trade imbalances*, however, we need to take into account the equilibrium adjustments that would result from a global rebalancing. In the following section, we present a model that will allow us to simulate such a rebalancing.

³Based on GTAP 10. Fossil exports are calculating by summing up the export values of the *coal*, *oil* and *gas* sectors.

⁴Qatar's trade surplus is as high as 42 percent of their GDP, followed by Kuwait (33 percent), Saudi Arabia (21 percent) and Russia (9 percent).

3 Model

We use a Ricardian quantitative trade model a la Eaton and Kortum (2002, henceforth EK), which incorporates a sectoral structure with input-output linkages, trade imbalances, and carbon emissions from fossil fuel combustion. It closely follows the sectoral extension of EK by Caliendo and Parro (2015, henceforth CP), but additionally includes carbon emissions from fossil fuel combustion in the production of other goods or for final consumption. As an environmental extension of the framework by CP, the model is also closely related to Shapiro (2020) and Caron and Fally (2020).

As our focus is on the effect of changes in trade imbalances (as in Dekle, Eaton, and Kortum, 2007, 2008), we will keep the expressions as simple as possible by not considering tariffs as in CP or other policy variables that would allow explicit climate policies (such as a carbon tax).

3.1 Preferences

There is a set of countries \mathcal{N} , denoted by i and n , one set of fossil fuel sectors, denoted by $f \in \mathcal{F}$ and $g \in \mathcal{F}$, and J other sectors, denoted by $j \in \mathcal{J}$ and $k \in \mathcal{J}$. In each sector, there is a continuum of goods $\omega^{f/j} \in [0, 1]$. Households in n obtain utility from consumption C according to the following two-tier Cobb-Douglas utility function:

$$u_n = \prod_{f \in \mathcal{F}} \left(\exp \int_0^1 \ln C_n(\omega^f) d\omega^f \right)^{\alpha_n^f} \prod_{j \in \mathcal{J}} \left(\exp \int_0^1 \ln C_n(\omega^j) d\omega^j \right)^{\alpha_n^j},$$

where α is the constant sectoral expenditure share and $\alpha_n^f + \sum_{j \in \mathcal{J}} \alpha_n^j = 1$. Note that the choice of a lower-tier Cobb-Douglas instead of a more general CES utility function does not affect any results and is solely motivated by the attempt to keep parameters to the necessary minimum (see Eaton and Kortum, 2012, for the corresponding comparison in the one-sector EK framework). While the aggregation of utility from different varieties *within* one sector is the same for all countries, expenditures shares *across* sectors vary between countries, allowing for differently emission-intensive consumption patterns. This flexibility is crucial as the trade deficit or surplus of a country that consumes a lot of fossil fuels or products that require high fuel input in production will have different emission

implications than the deficit or surplus of a country with a high share of clean services expenditure.

3.2 Production

Goods are produced using labour l and composite intermediate input bundles m from the fossil fuel sectors and from all other sectors. Countries differ in their productivity for different goods from the continua, inversely captured by the input requirement a , and the input cost shares γ . The production technology is Cobb-Douglas:

$$\begin{aligned} q_n(\omega^j) &= [a_n(\omega^j)]^{-1} [l_n(\omega^j)]^{\gamma_n^j} \prod_{f \in \mathcal{F}} [m_n^f(\omega^j)]^{\gamma_n^{f,j}} \prod_{k \in \mathcal{J}} [m_n^k(\omega^j)]^{\gamma_n^{k,j}}, \\ q_n(\omega^f) &= [a_n(\omega^f)]^{-1} [l_n(\omega^f)]^{\gamma_n^f} \prod_{g \in \mathcal{F}} [m_n^g(\omega^f)]^{\gamma_n^{g,f}} \prod_{j \in \mathcal{J}} [m_n^j(\omega^f)]^{\gamma_n^{j,f}}, \end{aligned}$$

with $\gamma_n^j + \sum_{f \in \mathcal{F}} \gamma_n^{f,j} + \sum_{k \in \mathcal{J}} \gamma_n^{k,j} = 1$ and $\gamma_n^f + \sum_{g \in \mathcal{F}} \gamma_n^{g,f} + \sum_{j \in \mathcal{J}} \gamma_n^{j,f} = 1$ and the intermediate input bundles are themselves Cobb-Douglas composites⁵:

$$m_n^f = \exp \int_0^1 \ln d_n(\omega^f) d\omega^f \quad \text{and} \quad m_n^j = \exp \int_0^1 \ln d_n(\omega^j) d\omega^j,$$

where $d_n(\omega^f)$ and $d_n(\omega^j)$ are the demand for the specific varieties ω^f and ω^j as intermediate inputs. Unit costs (which equal the price due to perfect competition and constant returns to scale) in the regular and the fossil fuel sectors are given by $c_n^j a_n(\omega^j)$ and $c_n^f a_n(\omega^f)$, where the cost of the input bundles are given by

$$c_n^j = \Upsilon_n^j [w_n]^{\gamma_n^j} \prod_{f \in \mathcal{F}} [P_n^f]^{\gamma_n^{f,j}} \prod_{k \in \mathcal{J}} [P_n^k]^{\gamma_n^{k,j}}, \quad (1)$$

$$c_n^f = \Upsilon_n^f [w_n]^{\gamma_n^f} \prod_{g \in \mathcal{F}} [P_n^g]^{\gamma_n^{g,f}} \prod_{j \in \mathcal{J}} [P_n^j]^{\gamma_n^{j,f}}, \quad (2)$$

where $\Upsilon_n^j = (\gamma_n^j)^{-\gamma_n^j} \prod_{f \in \mathcal{F}} (\gamma_n^{f,j})^{-\gamma_n^{f,j}} \prod_{k \in \mathcal{J}} (\gamma_n^{k,j})^{-\gamma_n^{k,j}}$, w denotes the wage, P the price of a composite intermediate bundle, and $\Upsilon_n^f = (\gamma_n^f)^{-\gamma_n^f} \prod_{g \in \mathcal{F}} (\gamma_n^{g,f})^{-\gamma_n^{g,f}} \prod_{j \in \mathcal{J}} (\gamma_n^{j,f})^{-\gamma_n^{j,f}}$. Input requirement coefficients are assumed to be drawn from a type-III extreme value

⁵Note that just as in the utility function, this could be generalized to a CES composite without changing any of the final results.

(Weibull) distribution, i.e. $Pr[a_i(\omega^j) \leq a] = 1 - \exp(-(A_i^j a)^{\theta_j})$ (and accordingly in the fossil fuel sectors), where A is a location parameter capturing the absolute advantage and θ is a dispersion parameter (inversely) capturing the extent of comparative advantage differences.⁶

Importantly, the production structure implies that countries not only differ in their productivities, but also in the extent to which they rely on fossil fuel inputs in producing different goods. Just as the differences in the “greenness” of consumption, this can have important implications for how a country’s trade surplus/deficit affects global emissions: it can enable “dirty” (i.e. fossil fuel intensive) producers to serve a larger share of global demand or it can help them cover more of their own demand with cleaner products from abroad. Note also the two-layer structure of comparative advantage: the probabilistic EK notion of comparative advantage determines which countries produce which products *within* sectors and additionally, comparative advantage *across* sectors as determined by sectoral productivities and input costs determines which countries specialize into production in which sectors. In one important dimension, countries can specialize in producing fossil fuel intensive goods vs. products that rely on less fossil fuel inputs — with different implications for the consequences of the countries’ trade imbalances on emissions. In a second dimension, countries can specialize in ordinary goods or in the *production* of fossil fuels. If countries of this latter (fossil resource abundant) type run a trade surplus, this increases global fossil fuel supply and hence drives up global emissions, pointing to a potentially problematic role of imbalances of fossil fuel exporters.

3.3 International Trade

3.3.1 Gravity

Both consumers and producers source the goods they buy from the lowest-cost supplier. International trade faces iceberg trade costs t_{ni}^j and t_{ni}^f , i.e. t units have to be shipped to deliver one unit from i to n . The cost distributions for country i delivering goods to country n depend on i ’s productivity and input costs, as well as on bilateral frictions

⁶Note that both EK and CP equivalently have countries draw productivities from a type-II extreme value (Frechet) distribution instead. We follow Eaton and Kortum (2012) here and use the original Ricardian technology measure of input requirements.

between i and n and are given by

$$Pr[c_{ni}(\omega^j) \leq c] = 1 - e^{-(A_{ni}^j c)^{\theta^j}} \quad \text{and} \quad Pr[c_{ni}(\omega^f) \leq c] = 1 - e^{-(A_{ni}^f c)^{\theta^f}},$$

with $A_{ni}^j = A_i^j / (t_{ni}^j c_i^j)$ and $A_{ni}^f = A_i^f / (t_{ni}^f c_i^f)$. Country i is hence likelier to be able to provide goods at a low price to n if (i) its overall productivity in the respective sector is high (large A), (ii) its input costs are low (small c), and/or (iii) its trade costs with n are low (small t).

Under perfect competition, producers price at their costs. The price at which consumers and producers in country n end up buying a good ω is the minimum price across the bilateral cost distributions just shown. The resulting price distributions inherit the Weibull form from the technology and cost distributions and are given by:

$$F_n^j(p) = 1 - e^{-(\bar{A}_n^j p)^{\theta^j}} \quad \text{and} \quad F_n^f(p) = 1 - e^{-(\bar{A}_n^f p)^{\theta^f}},$$

with

$$\bar{A}_n^j = \left[\sum_{i \in \mathcal{N}} (A_{ni}^j)^{\theta^j} \right]^{1/\theta^j} \quad \text{and} \quad \bar{A}_n^f = \left[\sum_{i \in \mathcal{N}} (A_{ni}^f)^{\theta^f} \right]^{1/\theta^f}$$

The \bar{A} s summarize how the three price influences (technology, input costs, and geography as captured by the trade costs) *all around the world* shape the price level in a country. Specifically, we can obtain sectoral price indices by integrating over the price distributions:

$$P_n^j = \exp \left(\int_0^\infty \ln(p) dF_n^j(p) \right) = \frac{\exp(-\varepsilon/\theta^j)}{\bar{A}_n^j} \quad \text{and} \quad P_n^f = \frac{\exp(-\varepsilon/\theta^f)}{\bar{A}_n^f}, \quad (3)$$

where $\varepsilon = 0.5772 \dots$ is Euler's constant. Note that the possibility of non-tradable sectors is implicitly also captured. In these non-tradable sectors, trade costs are prohibitively high ($t_{ni}^j = \infty$) and the price hence simplifies to $P_n^j = \exp(-\varepsilon/\theta^j) / A_{nn}^j$.

Country n 's total spending on goods from sector j and on fossil fuels are X_n^j and X_n^f . The shares of these expenditures that are spent on goods and fossil fuels from country i equals the share in which i is the lowest supplier and is given by a sectoral version of the

EK gravity expression⁷:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \left(\frac{A_{ni}^j}{\bar{A}_n^j} \right)^{\theta^j} \quad \text{and} \quad \pi_{ni}^f = \frac{X_{ni}^f}{X_n^f} = \left(\frac{A_{ni}^f}{\bar{A}_n^f} \right)^{\theta^f}. \quad (4)$$

International trade links carbon emissions across countries in a direct and an indirect way. Directly, countries with a comparative advantage in fossil fuel intensive goods will specialize in the production of these goods, emit more CO₂, and tend to implicitly export more emissions to other countries than importing from them. Indirectly, emissions in different countries are additionally linked because the fossil fuels causing them are themselves traded. Lower (higher) demand for fossil fuels in one country will drive down (up) the price for fossil fuels and hence incentivize other countries to produce more (less) fossil fuel intensively.

3.3.2 Trade balance

Total expenditures for sector j and for fossil fuels f combine expenditure on intermediate bundles and for final consumption:

$$\begin{aligned} X_n^j &= \sum_{f \in \mathcal{F}} \gamma_n^{j,f} \sum_{i \in \mathcal{N}} X_i^f \pi_{in}^f + \sum_{k \in \mathcal{J}} \gamma_n^{j,k} \sum_{i \in \mathcal{N}} X_i^k \pi_{in}^k + \alpha_n^j I_n \quad \text{and} \\ X_n^f &= \sum_{g \in \mathcal{F}} \gamma_n^{f,g} \sum_{i \in \mathcal{N}} X_i^g \pi_{in}^g + \sum_{j \in \mathcal{J}} \gamma_n^{f,j} \sum_{i \in \mathcal{N}} X_i^j \pi_{in}^j + \alpha_n^f I_n, \end{aligned} \quad (5)$$

where the final absorption I_n consists of labour income (given by the total labour endowment L_n times the wage) and the trade deficit (D_n):

$$I_n = w_n L_n + D_n. \quad (6)$$

⁷As described in EK, this share can be calculated as the probability that i has the lowest costs of delivering a good ω to n : $Pr[c_{ni}(\omega^j) \leq \min\{c_{ns}(\omega^j); s \neq i\}] = \int_0^\infty \prod_{s \neq i} [\exp(-(A_{ns}^j c)^{\theta^j})] d(\exp(-(A_{ni}^j c)^{\theta^j}))$ (and in the fossil fuel sectors accordingly). To move to EK's explicit gravity equation for trade *flows*, multiply the trade shares with the destination country's total sectoral expenditure, solve the market clearing condition for $(A_{ni}^j/c_i^j)^\theta$, substitute the expression into (4) and simplify using (3)

Trade is multilaterally balanced up to the exogenously given trade deficit:

$$\sum_{i \in \mathcal{N}} \left(\sum_{f \in \mathcal{F}} X_n^f \pi_{ni}^f + \sum_{j \in \mathcal{J}} X_n^j \pi_{ni}^j \right) - D_n = \sum_{i \in \mathcal{N}} \left(\sum_{f \in \mathcal{F}} X_i^f \pi_{in}^f + \sum_{j \in \mathcal{J}} X_i^j \pi_{in}^j \right). \quad (7)$$

International trade allows countries to decouple their production and consumption patterns. They can specialize in producing certain varieties and they can focus their production on the sectors in which they have a comparative advantage. At the same time, they are free to still consume a product basket that is determined by their preferences rather than their comparative advantage. Just because a country produces a lot of fossil fuels, it does not have to spend a large share of its income on these fuels. Trade balance puts a limit to the decoupling: the overall value of produced goods has to equal the overall value of the purchased ones. If a country wants to export another dollar worth of its products, it has to also import an additional dollar worth from elsewhere. With trade imbalances, the limit is softened. Up to the level of the deficit or surplus, they decouple not only *what* a country produces and buys, but also *how much*. The equilibrium effects of this further decoupling on carbon emissions are ambiguous. One country's surplus necessarily is another country's deficit. A deficit [surplus] will increase [lower] the respective country's carbon footprint. Globally, deficits in countries with "green" preferences, relatively "brown" production technologies, and large fossil resource endowments will tend to lower emissions, while deficits in countries demanding fossil-intensive products that produce with small fossil input shares will tend to increase them.

3.4 Equilibrium

The definition of an equilibrium closely mimics the expression by CP, slightly expanded by the presence of the fossil fuel sector.

Definition 1. *For given labour endowments L_n , technology parameters A_n^j and A_n^f , trade costs t_{ni}^j and t_{ni}^f , and trade imbalances D_n , an equilibrium is a set of wages w_n , composite intermediate goods prices P_n^j , and composite fossil fuel prices P_n^f that satisfy conditions (1)–(7).*

3.4.1 Equilibrium in relative changes

Just as in CP, the determination of an equilibrium for a given policy change simplifies if, following Dekle, Eaton, and Kortum (2007, 2008), equilibrium conditions are re-expressed in terms of relative changes where possible. Denote values of any variable or parameter in the baseline equilibrium by x , under the counterfactual scenario by x' , and its relative change by $\hat{x} = x'/x$. Then, the equilibrium can be defined in relative changes as follows:

Definition 2. Let $\{w_n, P_n^j, P_n^f\}$ be a baseline equilibrium for global trade imbalances D_n and $\{w'_n, P_n^{j'}, P_n^{f'}\}$ be a counterfactual equilibrium for global trade imbalances D'_n . Then, $\{\hat{w}_n, \hat{P}_n^j, \hat{P}_n^f\}$ satisfy the following equilibrium conditions (8)–(13):

Cost of the input bundles:

$$\hat{c}_n^j = [\hat{w}_n]^{\gamma_n^j} [\hat{P}_n^f]^{\gamma_n^{f,j}} \prod_{k=1}^J [\hat{P}_n^k]^{\gamma_n^{k,j}} \quad \text{and} \quad \hat{c}_n^f = [\hat{w}_n]^{\gamma_n^f} [\hat{p}_n^r]^{\gamma_n^{r,f}} [\hat{P}_n^f]^{\gamma_n^{f,f}} \prod_{j=1}^J [\hat{P}_n^j]^{\gamma_n^{j,f}} \quad (8)$$

Price indices:

$$\hat{P}_n^j = \left[\sum_{i=1}^N \pi_{ni}^j (\hat{c}_i^j)^{-\theta^j} \right]^{\frac{-1}{\theta^j}} \quad \text{and} \quad \hat{P}_n^f = \left[\sum_{i=1}^N \pi_{ni}^f (\hat{c}_i^f)^{-\theta^f} \right]^{\frac{-1}{\theta^f}} \quad (9)$$

Bilateral trade shares:

$$\hat{\pi}_{ni}^j = \left[\frac{\hat{c}_i^j}{\hat{P}_n^j} \right]^{-\theta^j} \quad \text{and} \quad \hat{\pi}_{ni}^f = \left[\frac{\hat{c}_i^f}{\hat{P}_n^f} \right]^{-\theta^f} \quad (10)$$

Total expenditure by country and sector:

$$\begin{aligned} X_n^{j'} &= \gamma_n^{j,f} \sum_{i=1}^N X_i^{f'} \pi_{in}^{f'} + \sum_{k=1}^J \gamma_n^{j,k} \sum_{i=1}^N X_i^{k'} \pi_{in}^{k'} + \alpha_n^j I_n' \quad \text{and} \\ X_n^{f'} &= \gamma_n^{f,f} \sum_{i=1}^N X_i^{f'} \pi_{in}^{f'} + \sum_{k=1}^J \gamma_n^{f,k} \sum_{i=1}^N X_i^{k'} \pi_{in}^{k'} + \alpha_n^f I_n' \end{aligned} \quad (11)$$

Final absorption:

$$I_n' = w'_n L_n + p_n^{r'} R_n' + D_n' \quad (12)$$

Trade balance:

$$\sum_{i=1}^N X_n^{f'} \pi_{ni}^{f'} + \sum_{j=1}^J \sum_{i=1}^N X_n^{j'} \pi_{ni}^{j'} - D'_n = \sum_{i=1}^N X_i^{f'} \pi_{in}^{f'} + \sum_{j=1}^J \sum_{i=1}^N X_i^{j'} \pi_{in}^{j'} \quad (13)$$

3.5 Carbon Emissions

Carbon emissions stem from fossil fuel combustion and are therefore modeled to be proportional to the usage of the fossil fuel composite, either as an intermediate in production or in final consumption, weighted by the varying carbon intensities ι^f of the different fossil fuel types. National emissions are hence given by

$$E_n = \sum_{f \in F} \iota^f \left(\int_0^1 \left(C_n(\omega^f) + \sum_{g \in \mathcal{F}} m_n^f(\omega^f) + \sum_{j \in \mathcal{J}} m_n^f(\omega^j) \right) d\omega^j \right) = \sum_{f \in \mathcal{F}} \frac{\iota^f X_n^f}{P_n^f}. \quad (14)$$

Note the difference to Shapiro (2020) who models emissions as being proportional to the *extraction* of fossil fuels. Linking emissions to the fossil fuel *usage* instead allows us to precisely track the emergence of emissions along the whole value chain.

3.6 Counterfactual Scenarios

The primary counterfactual analysis will consider the complete elimination of trade imbalances, i.e. a scenario in which $D'_n = 0 \forall n$. Additionally, we will also consider what happens if only a specific individual country n eliminates its deficit or surplus. In this case, we need to make sure that world trade remains balanced. Specifically, if n was a surplus country initially, we calculate its share in the surpluses over all surplus countries. In the counterfactual scenario, we put its surplus to zero and lower all deficit countries' deficit by n 's baseline share of the global surpluses. If n was a deficit country, we obtain its deficit share out of all trade deficits and proceed accordingly.

4 Data

To simulate the effects of a (simultaneous) removal of trade imbalances in general equilibrium, we need to identify the model parameters. Consumption shares and input coefficients (α , β , and γ), as well as bilateral trade shares (π), value added (wL), and initial

trade imbalances (D) are obtained from input-output tables. Sectoral dispersion parameters (θ) are taken from the online database of Fontagné et al. (2018).⁸ For the service sectors we rely on estimates of Egger et al. (2012).

Data Source

The main input for our simulation comes from the GTAP 10 database (Aguilar, Chepeliev, Corong, McDougall, and van der Mensbrugghe, 2019). The data supplies the model with all information that is needed from input-output tables (α , β , γ , π , wL , D) for the year 2014.⁹ We also calculate carbon intensities of different fossil fuel types (ι) from the database. We choose GTAP because of its rich geographical (121 countries and 20 aggregated regions) and sectoral (65 sectors) coverage. It includes 5 fossil sectors (coal, oil, gas, petroleum and coal products, gas manufacture and distribution). For a full list of all countries see Appendix A.

5 Results

Quantitative trade models à la Eaton and Kortum (2002) allow the investigation of counterfactual scenarios, taking into account full general equilibrium effects. We use the model presented in Section 3 to conduct scenarios in which we — partly or fully — re-balance global trade. We first simulate the elimination of an individual country’s imbalance for each country separately in turn. Afterwards, we analyze the case of globally balanced trade, i.e. of a simultaneous elimination of all trade imbalances.

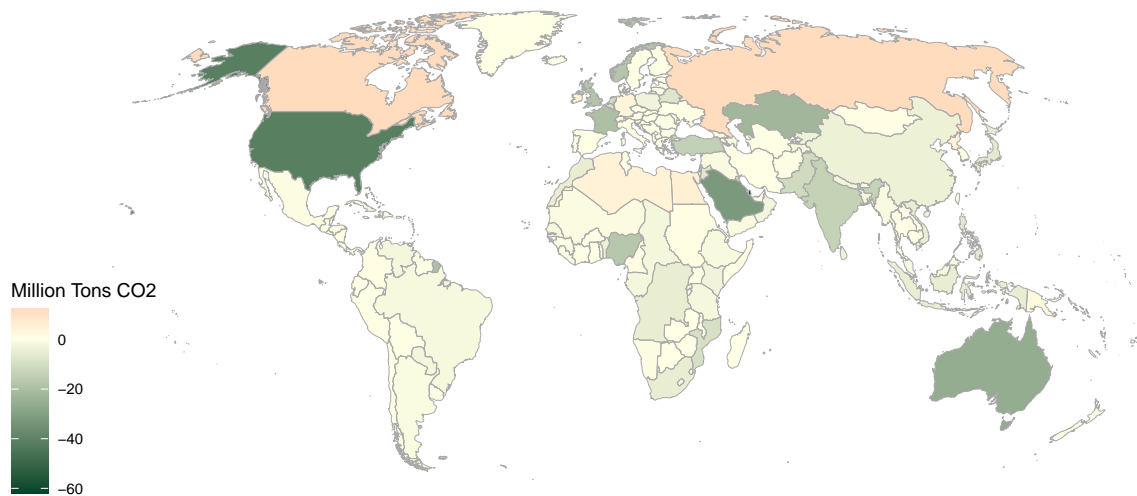
5.1 Balancing Individual Country’s Trade Separately

In this section, we conduct a set of counterfactual experiments, in which we always set *one* country’s trade imbalance to zero. For the removed trade imbalance of a single country the value of their imbalance is subtracted from the imbalances of the remaining 140 countries to ensure that world supply still equals world demand. If the single country has a trade

⁸Their GTAP 10 estimates are from October 2020 and can be found on their homepage.

⁹This is the most recent year for which input-output data for 141 countries/regions is available. We do not predict baseline values for some future year since this would introduce additional margins of error.

Figure 8: Change in Global Carbon Emissions from the Removal of the Corresponding Country's Trade Imbalance, Each Country Balanced Separately



surplus the imbalances of trade deficit countries are reduced proportionally,¹⁰ leaving the values of the other trade surplus countries unchanged. This is done vice versa if the single country has a trade deficit. As each country's individual trade re-balancing is separately considered here, this leads to 141 different counterfactuals.

Figure 8 shows the change of global carbon emissions for all 141 counterfactuals. The value of each country represents the change in global carbon emission in the scenario where the respective country's imbalance is removed.¹¹ One thing that becomes apparent right away is the large effect on global emissions resulting from an elimination of the huge US trade deficit. As discussed in Section 2, the US not only import *more* than they export, but they also import clearly *more carbon-intensive* products. In line with the expectations, taking away the United States' possibility to sustain parts of their immense carbon footprint by consistently running a deficit indeed leads to a lower-emission new global production and consumption pattern. Specifically, global CO2 emissions would go down by 41.4 mln tons or 0.14 percent.¹² This is roughly equivalent to Bulgaria's total annual emissions. Note that the global emission reduction in response to a US re-balancing

¹⁰If the trade surplus of a single country accounts for 2 percent of all trade deficits, the trade imbalance of each deficit country is reduced by 2 percent.

¹¹For the exact values of the change in global carbon emissions see the second column of Table B1 in the Appendix.

¹²All emission quantities refer to CO2 emissions only and to the model base year 2014.

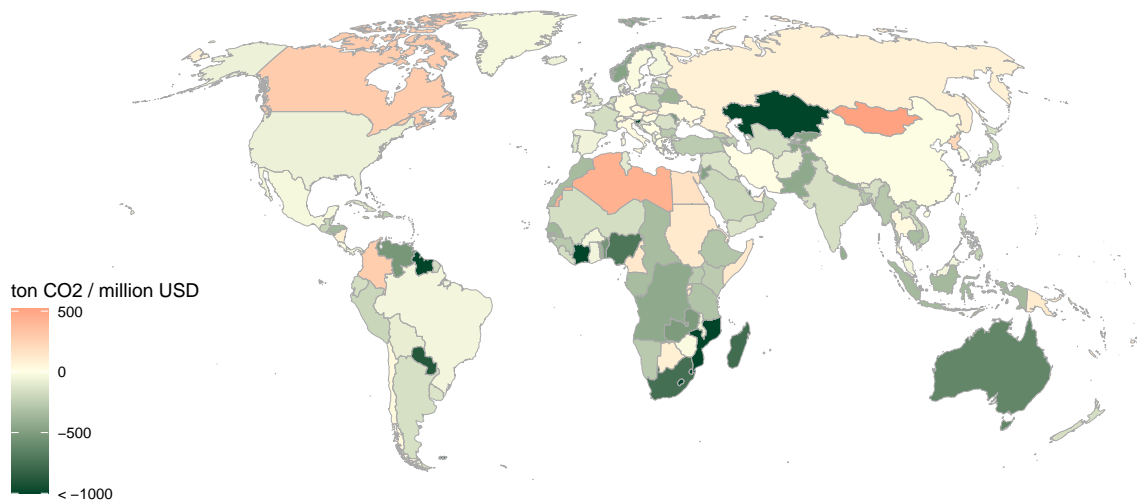
does *not* stem from lower US emissions. The US in fact slightly increases their emissions by 0.36 percent, while the overall reduction comes from countries that previously served the US market with carbon-intensive products to larger extents or from countries that are indirectly affected from the global reshuffling of the international trade network resulting from the elimination of the world's largest trade deficit.

The largest drop in global emissions, however, results from the elimination of the Qatari trade *surplus*. Bringing down Qatar's 90 billion US-Dollar surplus to zero would lower global emissions by 62 mln tons or 0.21 percent. This is roughly equivalent to Bangladesh's total annual emissions. The Qatari example is linked to Stylized Fact 7 on fossil fuel exports running surpluses and the corresponding concern that this type of imbalance fosters global fossil fuel supply and therefore global emissions. Taking a further look at which countries' trade re-balancing lowers global emissions, the role of fossil fuel exports becomes even more evident: out of the top five countries, only the US have an initial deficit, while in all other cases the emission reductions result from bringing down surpluses of fossil fuel exporters, namely Qatar, Saudi-Arabia (32.6 mln tons world emission reduction), Australia (26.2 mln tons), and Kazakhstan (22.9 mln tons).

Another interesting case is the removal of the Indian trade deficit. Even though India's exports are more carbon-intensive than its imports, re-balancing Indian trade lowers global emissions by 14.2 mln tons of CO₂. The reason appears to lie in the very high absolute level of carbon intensity for both Indian ex- and imports. Out of all countries covered in the WIOD data set, only Indonesia imports products that are on average more carbon intensive than India's imports. Cutting the Indian trade balance lowers Indian overall consumption and as this consumption is particularly carbon intensive, this decrease has positive environmental side effects.

Generally and in line with our expectations based on the stylized facts established in Section 2, Figure 8 shows that eliminating country-level trade imbalances is environmentally beneficial in most cases. For 79 percent of countries, trade re-balancing leads to lower global emissions. For those countries, where re-balancing leads to an increase of global emissions, this increase is far smaller than the strongest decrease we see for countries like Qatar or the US. The only two countries, for which a re-balancing leads to a double-digit mln ton increase of world emissions, are Russia (12.2 mln tons) and Canada (12.0 mln

Figure 9: Change in Global Carbon Emissions per Absolute Value of Removing Trade Imbalance per Country, Each Country Balanced Separately



tons). For Canada, this is perfectly in line with expectations. It is one of two top ten fossil fuel exporters with a trade deficit — and a considerable one at almost 50 bln USD. If Canada eliminates its trade deficit, it needs to align its own production less with its own consumption and more with what it can sell internationally — leading Canada to produce and sell more fossil fuels for and on the export market. This increase in fossil fuel supply drives down global fossil fuel prices and in turn drives up global fossil fuel demand and carbon emissions.

The Russian case, on the other hand, shows the importance of accounting for the full general equilibrium adjustments in assessing the carbon footprints of trade imbalances. Given Russia's large trade surplus, its role as one the world's major fossil fuel exporters, and its extremely fossil fuel intensive exports, one would expect a Russian re-balancing to lower global emissions. But at the same time, the Russian *consumption* mix is at the higher end of the carbon intensity, too, so an increase of Russian import demand may drive global emissions up. The net effect, taking into account the reshuffling of global value chains, is unclear without a quantitative assessment as is possible in our model framework.

The patterns in Figure 8 are of course driven to a considerable amount by the sheer size of national trade imbalances. Even if the carbon footprint per dollar of the US deficit

is small, the total becomes large because the US deficit is so huge. To get an impression of the different countries' imbalances emission effects *controlling* for the overall size of the imbalance, Figure 9 shows how global carbon emissions change per million USD of removed trade imbalance in the 141 country-level counterfactual scenarios.¹³ It becomes clear that, if it wasn't for its size, the effect of the US deficit on global emissions would be minor. Further, per dollar, the Australian (heavy on coal) surplus is for example more of a global emission driver than the Saudi-Arabian (heavy on oil) surplus.

Comparing the relative magnitudes of Russia and Canada, the very similar amounts by which their re-balancing would increase total emissions comes about in two very different ways: the removal of the Canadian deficit is among the world's "dirtiest" per dollar, but its level is moderate to begin with, while the elimination of one dollar of the Russian surplus is only mildly driving up emissions, but the Russian surplus is among the largest in the world in absolute terms.

5.2 Balancing all Countries' Trade Simultaneously

In our other counterfactual scenario, we set the trade imbalances of all 141 countries and regions simultaneously to zero. Given the trade imbalance patterns established in Section 2, as well as the insights from the re-balancing of individual countries' international trade, we clearly expect that a global re-balancing will lower world emissions. However, it is clear that the exact implications of this large shock on the world trade network cannot be inferred from aggregating the 141 separate, smaller shocks considered in the previous subsection, but a distinct quantitative analysis is required that takes into account that effects will partly offset one another and that adjustment mechanisms will differ, when many countries simultaneously massively alter their import demand and export supply.

Overall, we find that the simultaneous removal of all trade imbalances reduces global carbon emission by 0.62 percent or 184.1 million tons of CO₂ per year. Is this a large effect? It is approximately equivalent to the total annual emissions of Argentina — the number 27 emitter of CO₂ in the world. One has to keep in mind that re-balancing global trade is not primarily an environmentally motivated policy. Compare the effect for example to the simultaneous introduction of carbon tariffs for all country pairs at

¹³Exact values can be found in the last column of Table B1 in the Appendix.

a level that equalizes bilateral carbon price differentials studied by Larch and Wanner (2017): they find a smaller global emission reduction of 0.5 percent for this explicit climate policy measure. Or to the emission reduction pledges made by individual countries in the Paris Agreement studied by Larch and Wanner (2019): re-balancing global trade lowers global carbon emissions by about 50 percent as much as China (i.e. the world’s largest emitter of CO₂) honouring its Paris reduction target rather than following a business-as-usual emission path. Or to the total contribution of international trade to global carbon emissions studied by Shapiro (2016): he finds that international trade in total increases emissions by 5 percent compared to a situation of total autarky. Comparing this to the effect of a global re-balancing implies that more than 10 percent of international trade’s total contribution to global emissions are due to the imbalances currently characterizing world trade.

Figure 10: Percentage Changes in Carbon Emissions, All Countries Balanced Simultaneously

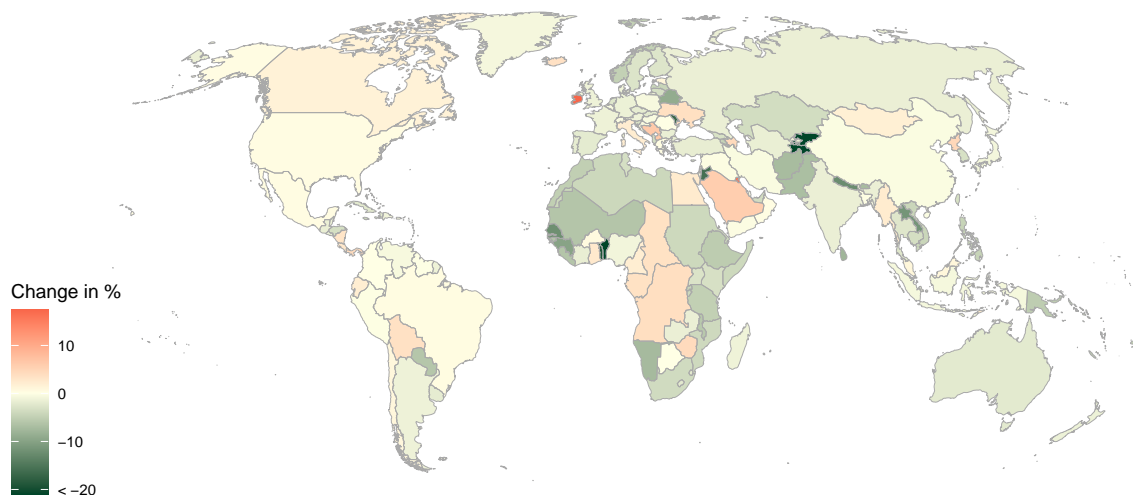


Figure 10 breaks down the global emission reduction into the percentage changes in national carbon emissions.¹⁴ Note the difference in how to read this figure in comparison to Figure 8: there, each country’s colouring reported the (absolute) change in *global* emissions in response to a country-level re-balancing, while now, each country’s coloring reports the *national* (percentage) emission change in response to a global re-balancing.

¹⁴For the exact values of change in carbon emissions and welfare see Table B1 in the Appendix

The national emission effects are very heterogeneous and range from an increase of 17 percent in Ireland (which starts off from a trade surplus of about one third the value of its GDP) to an immense reduction of 46 percent in Benin (starting off in turn from a vast trade deficit). Emission changes by the two largest emitters (China and the US), whose huge imbalances contributed strongly to the motivation of this paper, turn out to be rather mild — at least in percentage terms. The US increases their emissions by 0.30 percent, while Chinese emissions go down by 0.36 percent.

6 Conclusions

International trade allows countries to decouple the amount of carbon emissions associated with their production from the emissions embodied in their consumption. Trade balance puts a bound to the decoupling: while a country does not have to export one ton of carbon for every ton imported, under trade balance, it has to export one dollar worth of products for every dollar imported. Trade imbalances soften this restriction. The implications of this softening depend on which types of countries ending up consuming more than producing or vice versa. We show that the current pattern of global trade imbalances raises environmental concerns, because countries with a particularly carbon-intensive import mix tend to run a deficit (i.e. import more than they could afford under trade balance), fostering the global production of emission intensive goods, and fossil fuel exporters tend to run a surplus, increasing the globally available supply of these fuels.

We use a multi-sector Ricardian quantitative trade model with carbon emissions from fossil fuel combustion to simulate the re-balancing of individual countries' current accounts and of global trade. In terms of individual countries' imbalances, world emissions could be brought down most by eliminating the US trade deficit or the trade surplus of major fossil fuel exporters, such as Qatar, Saudi-Arabia, or Australia. The overall global imbalances are found to contribute considerably to global carbon emissions: re-balancing global trade entirely would bring down global emissions by 0.62 percent, reducing the overall carbon footprint of international trade by more than ten percent.

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APPENDIX

A Data

Table A1: GTAP 10 Regions and Data Overview, Year 2014

| GTAP code | Country | Trade imbalance in mln USD | Value added | Emissions in mln tons |
|-----------|----------------------|-------------------------------|-------------|--------------------------|
| ALB | Albania | -2343.17 | 11955.50 | 4.35 |
| ARE | United Arab Emirates | -13680.01 | 396477.27 | 161.17 |
| ARG | Argentina | 6767.33 | 524917.01 | 187.40 |
| ARM | Armenia | -2253.64 | 10944.23 | 5.27 |
| AUS | Australia | 41754.88 | 1383609.54 | 372.34 |
| AUT | Austria | 2235.27 | 391237.43 | 55.29 |
| AZE | Azerbaijan | 7088.01 | 74423.94 | 33.13 |
| BEL | Belgium | -75638.19 | 452280.68 | 99.50 |
| BEN | Benin | -7743.74 | 7123.36 | 5.59 |
| BFA | Burkina Faso | 769.18 | 11402.38 | 2.52 |
| BGD | Bangladesh | -9735.54 | 169376.85 | 60.52 |
| BGR | Bulgaria | -3655.52 | 51136.79 | 41.03 |
| BHR | Bahrain | -967.56 | 33915.49 | 28.59 |
| BLR | Belarus | -20848.68 | 65749.51 | 56.60 |
| BOL | Bolivia | 3407.70 | 31822.74 | 18.27 |
| BRA | Brazil | -41415.40 | 2223440.86 | 450.83 |
| BRN | Brunei | 2809.08 | 17369.52 | 7.86 |
| BWA | Botswana | 573.03 | 16020.92 | 6.78 |
| CAN | Canada | -42865.02 | 1687535.52 | 574.32 |
| CHE | Switzerland | 39130.01 | 689491.09 | 40.18 |
| CHL | Chile | 2001.82 | 240799.03 | 80.55 |
| CHN | China | 486436.24 | 9602143.61 | 7974.83 |
| CIV | Cote d'Ivoire | -27.16 | 32265.88 | 9.24 |
| CMR | Cameroon | -2550.08 | 28760.74 | 6.78 |
| COL | Colombia | -2955.56 | 357556.80 | 73.95 |
| CRI | Costa Rica | 933.08 | 47342.48 | 7.28 |
| CYP | Cyprus | -2319.61 | 22611.49 | 11.90 |
| CZE | Czechia | 17142.39 | 190182.19 | 85.92 |
| DEU | Germany | 180357.17 | 3507375.98 | 678.33 |
| DNK | Denmark | 1973.72 | 295647.05 | 51.79 |
| DOM | Dominican Republic | -4123.47 | 59480.13 | 18.91 |
| ECU | Ecuador | 3069.28 | 99092.79 | 35.77 |
| EGY | Egypt | -34352.70 | 296185.65 | 170.26 |
| ESP | Spain | 1567.14 | 1296336.14 | 237.55 |

Cont. on next page

Table A1: GTAP 10 Regions and Data Overview, Year 2014

| GTAP code | Country | Trade imbalance in mln USD | Value added | Emissions in mln tons |
|-----------|---------------------|-------------------------------|-------------|--------------------------|
| EST | Estonia | -2864.61 | 22522.75 | 8.19 |
| ETH | Ethiopia | -5733.23 | 52814.50 | 10.84 |
| FIN | Finland | 4267.87 | 245216.25 | 48.57 |
| FRA | France | -115212.47 | 2610786.47 | 318.43 |
| GBR | United Kingdom | -159068.00 | 2773050.42 | 427.35 |
| GEO | Georgia | -5866.56 | 14859.54 | 9.05 |
| GHA | Ghana | -4250.62 | 35221.30 | 10.97 |
| GIN | Guinea | -1078.71 | 5447.10 | 1.31 |
| GRC | Greece | -26502.13 | 212833.95 | 153.40 |
| GTM | Guatemala | -5006.40 | 57511.50 | 15.30 |
| HKG | Hong Kong SAR China | -13311.66 | 276082.48 | 91.95 |
| HND | Honduras | -2306.79 | 18989.88 | 8.45 |
| HRV | Croatia | -2247.68 | 50418.22 | 17.14 |
| HUN | Hungary | 11142.13 | 124501.45 | 39.43 |
| IDN | Indonesia | 14934.51 | 869277.45 | 441.79 |
| IND | India | -89042.61 | 1927078.40 | 1911.86 |
| IRL | Ireland | 80504.42 | 235671.17 | 44.22 |
| IRN | Iran | 11337.32 | 406410.50 | 537.07 |
| ISR | Israel | -14890.39 | 265342.99 | 64.54 |
| ITA | Italy | 27763.05 | 1981906.70 | 318.51 |
| JAM | Jamaica | -3075.55 | 12345.18 | 7.61 |
| JOR | Jordan | -14870.84 | 33216.81 | 26.23 |
| JPN | Japan | -40463.91 | 4496999.61 | 1015.52 |
| KAZ | Kazakhstan | 22842.54 | 212836.39 | 230.96 |
| KEN | Kenya | -12445.88 | 58615.36 | 14.77 |
| KGZ | Kyrgyzstan | -8645.19 | 6591.34 | 8.35 |
| KHM | Cambodia | -717.44 | 16156.26 | 7.71 |
| KOR | South Korea | 33287.68 | 1264253.41 | 498.85 |
| KWT | Kuwait | 54383.94 | 166433.37 | 81.08 |
| LAO | Laos | -3260.90 | 11371.35 | 3.63 |
| LKA | Sri Lanka | -9684.13 | 73173.07 | 25.63 |
| LTU | Lithuania | -5655.22 | 41695.97 | 10.84 |
| LUX | Luxembourg | -22250.18 | 59276.12 | 14.91 |
| LVA | Latvia | -5928.41 | 26242.71 | 8.93 |
| MAR | Morocco | -15237.54 | 108965.53 | 53.36 |
| MDG | Madagascar | 84.99 | 10808.26 | 2.42 |
| MEX | Mexico | -25813.56 | 1240187.92 | 419.72 |
| MLT | Malta | -5141.55 | 9068.52 | 3.67 |
| MNG | Mongolia | 737.81 | 11647.75 | 18.55 |
| MOZ | Mozambique | -3419.97 | 16075.36 | 4.16 |

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Table A1: GTAP 10 Regions and Data Overview, Year 2014

| GTAP code | Country | Trade imbalance in mln USD | Value added | Emissions in mln tons |
|-----------|-------------------|-------------------------------|-------------|--------------------------|
| MUS | Mauritius | -1635.71 | 11840.63 | 5.13 |
| MWI | Malawi | -400.42 | 5798.70 | 1.23 |
| MYS | Malaysia | 43928.97 | 329384.90 | 236.36 |
| NAM | Namibia | -3470.27 | 12194.49 | 3.47 |
| NGA | Nigeria | 24450.11 | 563445.83 | 64.72 |
| NIC | Nicaragua | 339.11 | 11248.33 | 4.46 |
| NLD | Netherlands | 57425.84 | 793149.80 | 168.82 |
| NOR | Norway | 38212.65 | 462284.34 | 65.58 |
| NPL | Nepal | -7243.16 | 17515.64 | 5.84 |
| NZL | New Zealand | 1172.31 | 184257.30 | 33.44 |
| OMN | Oman | 11749.45 | 82402.18 | 60.08 |
| PAK | Pakistan | -26289.47 | 237314.81 | 136.53 |
| PAN | Panama | -14494.16 | 46132.15 | 34.21 |
| PER | Peru | -1288.76 | 202884.75 | 48.80 |
| PHL | Philippines | -30528.28 | 270383.40 | 97.49 |
| POL | Poland | -16574.43 | 485927.38 | 264.38 |
| PRI | Puerto Rico | -2433.09 | 103199.22 | 12.82 |
| PRT | Portugal | -5649.24 | 207528.84 | 50.10 |
| PRY | Paraguay | -2982.68 | 29076.10 | 5.02 |
| QAT | Qatar | 89336.88 | 212153.87 | 78.49 |
| ROU | Romania | -3217.68 | 188881.74 | 65.06 |
| RUS | Russia | 158412.95 | 1764105.40 | 1409.07 |
| RWA | Rwanda | -503.33 | 7323.00 | 1.55 |
| SAU | Saudi Arabia | 159977.67 | 761199.96 | 396.69 |
| SEN | Senegal | -5103.72 | 14027.11 | 6.12 |
| SGP | Singapore | -21924.48 | 255084.00 | 81.45 |
| SLV | El Salvador | -3413.68 | 24084.58 | 6.62 |
| SVK | Slovakia | 4012.25 | 94282.90 | 23.27 |
| SVN | Slovenia | -54.56 | 44199.00 | 13.13 |
| SWE | Sweden | 15726.35 | 513837.91 | 39.99 |
| TGO | Togo | -2616.31 | 3216.94 | 2.24 |
| THA | Thailand | 20989.16 | 382998.51 | 277.38 |
| TJK | Tajikistan | -4817.78 | 8565.34 | 4.56 |
| TTO | Trinidad & Tobago | 7785.93 | 28594.72 | 23.31 |
| TUN | Tunisia | -6031.78 | 43283.79 | 25.05 |
| TUR | Turkey | -55433.58 | 739319.88 | 304.85 |
| TWN | Taiwan | 78490.48 | 528385.13 | 233.53 |
| TZA | Tanzania | -6812.45 | 42772.13 | 10.02 |
| UGA | Uganda | 791.62 | 26364.69 | 5.35 |
| UKR | Ukraine | -768.69 | 119162.30 | 207.93 |

Cont. on next page

Table A1: GTAP 10 Regions and Data Overview, Year 2014

| GTAP code | Country | Trade imbalance in mln USD | Value added | Emissions in mln tons |
|-----------|---------------|-------------------------------|-------------|--------------------------|
| URY | Uruguay | -2994.28 | 51908.09 | 6.14 |
| USA | United States | -606902.14 | 17031479.03 | 5155.36 |
| VEN | Venezuela | 4578.56 | 493900.27 | 159.62 |
| VNM | Vietnam | -22826.69 | 169502.70 | 138.78 |
| XAC | XAC | 11794.61 | 153467.99 | 23.78 |
| XCA | XCA | -383.37 | 1363.17 | 0.27 |
| XCB | XCB | -20814.46 | 110943.50 | 32.01 |
| XCF | XCF | 7257.54 | 59346.94 | 12.69 |
| XEA | XEA | 22412.17 | 71607.85 | 68.89 |
| XEC | XEC | -3952.84 | 75903.17 | 16.76 |
| XEE | XEE | -3192.33 | 6667.55 | 7.26 |
| XEF | XEF | -4517.72 | 20698.33 | 4.61 |
| XER | XER | -14837.16 | 99779.93 | 77.81 |
| XNA | XNA | -423.75 | 7444.20 | 1.70 |
| XNF | XNF | -10203.01 | 241004.49 | 164.84 |
| XOC | XOC | -16575.14 | 44920.10 | 17.16 |
| XSA | XSA | -5984.77 | 22988.63 | 8.08 |
| XSC | XSC | -68.47 | 6280.47 | 1.31 |
| XSE | XSE | 5034.34 | 67083.96 | 20.84 |
| XSM | XSM | 67.09 | 12729.08 | 2.98 |
| XSU | XSU | -2445.80 | 100485.37 | 163.13 |
| XTW | XTW | -0.18 | 154.35 | 0.06 |
| XWF | XWF | -7479.29 | 32291.07 | 8.61 |
| XWS | XWS | 10497.11 | 347602.94 | 182.46 |
| ZAF | South Africa | 7021.02 | 329231.36 | 425.38 |
| ZMB | Zambia | -245.07 | 25946.87 | 3.07 |
| ZWE | Zimbabwe | -1764.41 | 13942.35 | 11.26 |

B Detailed Results

Table B1: Results Emission Change

| Country | Balancing simultaneously | Balancing separately | |
|---------|--------------------------|---------------------------------------|----------------------|
| | Emission change in % | Global emission change in mln tons | in tons / mln USD |
| ALB | -3.66 | -0.34 | -142.99 |
| ARE | -3.66 | 0.69 | 50.68 |
| ARG | -1.35 | -1.07 | -157.49 |
| ARM | -4.73 | -0.69 | -304.71 |
| AUS | -2.21 | -26.17 | -626.66 |
| AUT | -1.35 | 0.01 | 5.99 |
| AZE | 4.32 | -1.66 | -234.55 |
| BEL | -0.54 | -9.23 | -122.09 |
| BEN | -46.28 | -4.24 | -547.26 |
| BFA | 0.65 | -0.03 | -45.28 |
| BGD | -0.19 | -2.81 | -288.34 |
| BGR | -1.66 | -1.02 | -279.63 |
| BHR | -1.49 | 0.15 | 160.14 |
| BLR | -8.95 | -8.08 | -387.34 |
| BOL | 3.51 | -0.29 | -84.17 |
| BRA | 0.38 | -1.84 | -44.35 |
| BRN | 5.57 | -1.59 | -567.40 |
| BWA | -0.02 | 0.05 | 86.31 |
| CAN | 1.51 | 12.05 | 281.09 |
| CHE | -0.37 | 1.35 | 34.49 |
| CHL | 0.96 | 0.07 | 35.65 |
| CHN | -0.36 | -4.35 | -8.93 |
| CIV | -1.79 | -0.20 | -7460.41 |
| CMR | 1.95 | 0.34 | 131.93 |
| COL | -0.02 | 0.81 | 272.56 |
| CRI | 2.69 | 0.01 | 13.22 |
| CYP | -4.19 | -0.31 | -131.64 |
| CZE | -1.98 | 0.54 | 31.70 |
| DEU | -1.50 | 4.08 | 22.60 |
| DNK | -1.10 | -0.22 | -111.78 |
| DOM | -1.22 | -1.12 | -272.09 |
| ECU | 1.99 | -0.53 | -172.34 |
| EGY | 2.37 | 5.67 | 165.12 |
| ESP | -2.14 | -0.09 | -58.14 |
| EST | 1.11 | -0.37 | -129.23 |
| ETH | -5.37 | -1.69 | -295.19 |

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Table B1: Results Emission Change

| Country | Balancing simultaneously | Balancing separately | |
|---------|--------------------------|---------------------------------------|----------------------|
| | Emission change in % | Global emission change in mln tons | in tons / mln USD |
| FIN | -2.76 | -0.18 | -42.02 |
| FRA | -1.40 | -19.69 | -170.93 |
| GBR | -1.34 | -18.43 | -115.87 |
| GEO | -3.19 | -1.40 | -238.12 |
| GHA | 2.55 | -0.23 | -54.59 |
| GIN | -9.91 | -0.29 | -270.82 |
| GRC | 0.25 | 0.00 | 0.03 |
| GTM | -1.73 | -1.08 | -215.40 |
| HKG | -1.65 | -2.02 | -151.42 |
| HND | -3.40 | -0.84 | -364.02 |
| HRV | -0.60 | -0.26 | -113.80 |
| HUN | -0.53 | 0.06 | 5.45 |
| IDN | -0.78 | -5.29 | -354.35 |
| IND | -1.62 | -14.20 | -159.52 |
| IRL | 17.35 | 4.62 | 57.37 |
| IRN | -0.46 | 0.13 | 11.67 |
| ISR | -0.71 | -1.88 | -126.51 |
| ITA | 2.14 | 0.56 | 20.27 |
| JAM | -4.27 | -0.73 | -238.64 |
| JOR | -15.79 | -7.16 | -481.56 |
| JPN | -0.94 | -6.50 | -160.68 |
| KAZ | -3.63 | -22.89 | -1001.91 |
| KEN | -3.22 | -3.25 | -261.09 |
| KGZ | -33.60 | -4.11 | -475.40 |
| KHM | -3.41 | -0.25 | -344.16 |
| KOR | -3.21 | -0.29 | -8.68 |
| KWT | 16.11 | -9.52 | -175.03 |
| LAO | -11.51 | -0.58 | -178.26 |
| LKA | -7.83 | -4.05 | -417.83 |
| LTU | -3.36 | -1.27 | -224.08 |
| LUX | -3.42 | -2.03 | -91.05 |
| LVA | -4.44 | -1.38 | -233.48 |
| MAR | -5.05 | -5.23 | -342.93 |
| MDG | -1.25 | -0.07 | -772.68 |
| MEX | 0.33 | -0.90 | -34.84 |
| MLT | -13.51 | -0.77 | -149.83 |
| MNG | 1.78 | 0.38 | 516.52 |
| MOZ | -3.99 | -9.55 | -2791.35 |

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Table B1: Results Emission Change

| Country | Balancing simultaneously | Balancing separately | |
|---------|--------------------------|---------------------------------------|----------------------|
| | Emission change in % | Global emission change in mln tons | in tons / mln USD |
| MUS | -4.10 | -0.41 | -250.43 |
| MWI | -5.80 | -0.03 | -66.90 |
| MYS | 1.00 | -2.13 | -48.60 |
| NAM | -7.34 | -0.95 | -274.96 |
| NGA | -1.04 | -17.63 | -720.96 |
| NIC | 3.09 | 0.03 | 92.18 |
| NLD | -2.65 | -10.30 | -179.29 |
| NOR | -4.90 | -18.08 | -473.15 |
| NPL | -12.51 | -2.84 | -391.67 |
| NZL | -1.41 | -0.19 | -158.40 |
| OMN | 0.25 | -2.75 | -233.76 |
| PAK | -6.86 | -11.59 | -440.71 |
| PAN | 4.17 | -0.93 | -64.32 |
| PER | -0.15 | -0.27 | -208.23 |
| PHL | -4.53 | -6.96 | -227.95 |
| POL | -0.73 | -3.26 | -196.98 |
| PRI | -0.97 | -0.60 | -236.30 |
| PRT | -2.02 | -0.74 | -130.66 |
| PRY | -6.01 | -2.65 | -887.71 |
| QAT | -0.42 | -61.98 | -693.76 |
| ROU | -0.11 | -0.48 | -149.33 |
| RUS | -1.62 | 12.20 | 77.00 |
| RWA | -4.39 | 0.07 | 146.53 |
| SAU | 5.75 | -32.55 | -203.49 |
| SEN | -12.21 | -1.91 | -373.89 |
| SGP | 0.72 | -1.44 | -65.50 |
| SLV | -1.81 | -1.06 | -309.26 |
| SVK | -2.30 | 0.52 | 129.72 |
| SVN | -3.14 | -0.20 | -3704.70 |
| SWE | -2.84 | -0.37 | -23.29 |
| TGO | -19.31 | -0.98 | -374.63 |
| THA | -2.60 | 0.67 | 31.85 |
| TJK | -21.63 | -2.21 | -458.46 |
| TTO | -11.65 | -2.91 | -373.32 |
| TUN | -3.38 | -0.62 | -103.27 |
| TUR | -1.87 | -14.56 | -262.60 |
| TWN | -3.30 | -1.69 | -21.59 |
| TZA | -5.00 | -2.06 | -302.21 |

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Table B1: Results Emission Change

| Country | Balancing simultaneously | Balancing separately | |
|---------|--------------------------|---------------------------------------|----------------------|
| | Emission change in % | Global emission change in mln tons | in tons / mln USD |
| UGA | -2.93 | -0.21 | -269.90 |
| UKR | 3.71 | 0.02 | 28.88 |
| URY | -2.01 | -0.42 | -140.16 |
| USA | 0.30 | -41.41 | -68.25 |
| VEN | -0.65 | -2.47 | -539.23 |
| VNM | -4.32 | -5.34 | -233.80 |
| XAC | 3.76 | -5.20 | -441.08 |
| XCA | -1.42 | -0.07 | -176.13 |
| XCB | -2.35 | -2.92 | -140.07 |
| XCF | 3.47 | -2.46 | -338.70 |
| XEA | 4.56 | 4.97 | 221.95 |
| XEC | -4.02 | 0.47 | 117.71 |
| XEE | -16.89 | -1.66 | -519.95 |
| XEF | 3.54 | -0.31 | -68.44 |
| XER | 6.27 | 0.03 | 1.85 |
| XNA | -0.80 | -0.01 | -31.09 |
| XNF | -4.17 | 4.47 | 438.54 |
| XOC | -5.31 | 1.79 | 107.79 |
| XSA | -7.16 | -0.49 | -81.09 |
| XSC | -2.28 | -0.34 | -4893.86 |
| XSE | 2.27 | -1.45 | -288.21 |
| XSM | -0.13 | -0.19 | -2863.16 |
| XSU | -1.70 | -0.42 | -170.55 |
| XTW | 0.71 | -0.20 | -1105817.18 |
| XWF | -6.13 | -1.23 | -165.03 |
| XWS | -0.28 | -1.51 | -143.84 |
| ZAF | -3.79 | -5.30 | -755.02 |
| ZMB | -1.63 | -0.13 | -512.47 |
| ZWE | 4.20 | -0.04 | -22.52 |