The Carbon Footprint of Global Trade Imbalances

Hendrik Mahlkow* & Joschka Wanner†

March 2023

Abstract

International trade is highly imbalanced both in terms of values and in terms of embodied carbon emissions. We show that the persistent current value trade imbalance patterns contribute to a higher level of global emissions compared to a world of balanced international trade. Specifically, we build a Ricardian quantitative trade model including sectoral input-output linkages, trade imbalances, fossil fuel extraction, and carbon emissions from fossil fuel combustion and use this framework to simulate counterfactual changes to countries' trade balances. For individual countries, the emission effects of removing their trade imbalances depend on the carbon intensities of their production and consumption patterns, as well as on their fossil resource abundance. Eliminating the Qatari trade surplus and the US trade deficit would lead to the largest environmental benefits in terms of lower global emissions. Globally, the simultaneous removal of all trade imbalances would lower world carbon emissions by 0.62 percent or 184 million tons of carbon dioxide.

JEL-Codes: F14; F18; Q56
Keywords: Carbon emissions; international trade; gravity

*Austrian Institute of Economic Research, Kiel Institute of the World Economy, Contact: hendrik.mahlkow@ifw-kiel.de

†University of Potsdam, Kiel Institute of the World Economy, Berlin School of Economics, Contact: joschka.wanner@uni-potsdam.de.

1 Introduction

A quarter to a third of global CO2 emissions is embodied in goods that are traded internationally. 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 (decoupling its *consumption footprint* of emissions associated with products ending up in the US from its *production footprint* of emissions being emitted by US producers) and put a constraint on China to act as the world's supplier of carbon-intensive products (with a corresponding over-proportional production footprint). 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. This implies that the Russian *extraction footprint* can surpass the emissions associated with Russian production or consumption. The possibility to run a trade surplus enables fossil fuel exporters 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.

For our quantitative analysis, we develop 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' production, consumption, and extraction footprints. As an environmentally extended version of Caliendo and Parro (2015), the model is closely related to the contributions by Shapiro (2021), Caron and Fally (2022), and Klotz and Sharma (2023), 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).[1]

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

[1]Shapiro (2021) is observationally equivalent to the original Caliendo and Parro (2015) framework, but additionally captures global emissions and its welfare implications; Caron and Fally (2022) include a more detailed modeling of fossil fuel production and trade and incorporate non-homothetic preferences; Klotz and Sharma (2023) incorporate fossil fuel use and emissions in transportation.

demand. We calculate how the country's different emission footprints 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.

We find that a global re-balancing of international trade would lower global emissions by 0.62 percent. While this is not a huge number on first sight, it is considerable given that (i) the scenario does not explicitly implement any environmental policy and (ii) prior literature finds that a move to total autarky for all countries would lower emissions by a rather mild (considering the extreme scenario) 5 percent. In terms of individual countries' imbalances, the US deficit indeed fosters emissions by sustaining the carbon-intensive US consumption. Most of the individual countries' imbalances that are particularly environmentally detrimental, however, are found to be the *surpluses* of major fossil fuel exporters with their disproportionately large extraction footprints.

Our exercises come with one important disclaimer. Unlike a growing literature on the *sources* of trade imbalances (cf. e.g. Cuñat and Zymek, 2019; Felbermayr and Yotov, 2021; Reyes-Heroles, 2016), 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 calculate the magnitudes of the adjustments that such a balancing would entail in terms of carbon emissions.

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, Chen, Li, Li, and Chen (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.

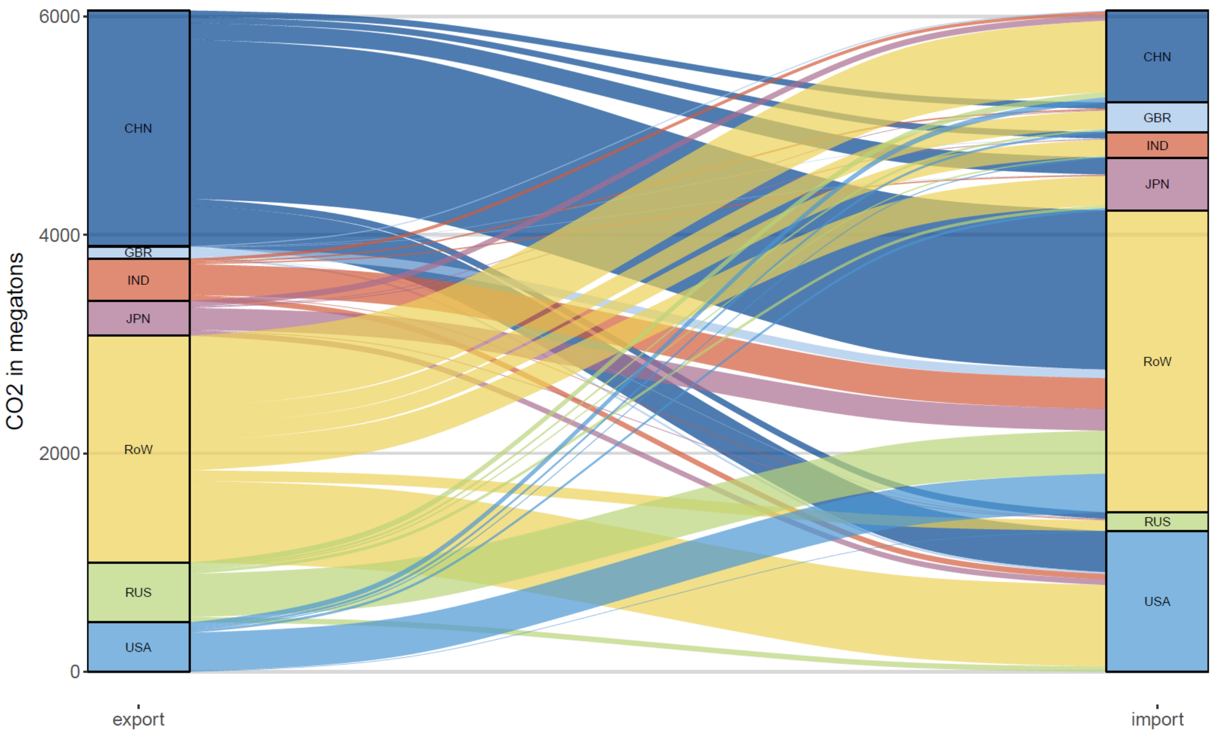
2 Trade Imbalances and Embodied Emissions: A Look at the Data

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. In this section, unless stated otherwise, we use data from the World Input-Output Database (WIOD, see Timmer, Dietzenbacher, Los, Stehrer, and de Vries, 2015), which captures the period from 2000 to 2014.

Stylized fact 1: 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 1. 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

Figure 1: Bilateral Flows of Embodied CO2 Emissions in International Trade, 2014

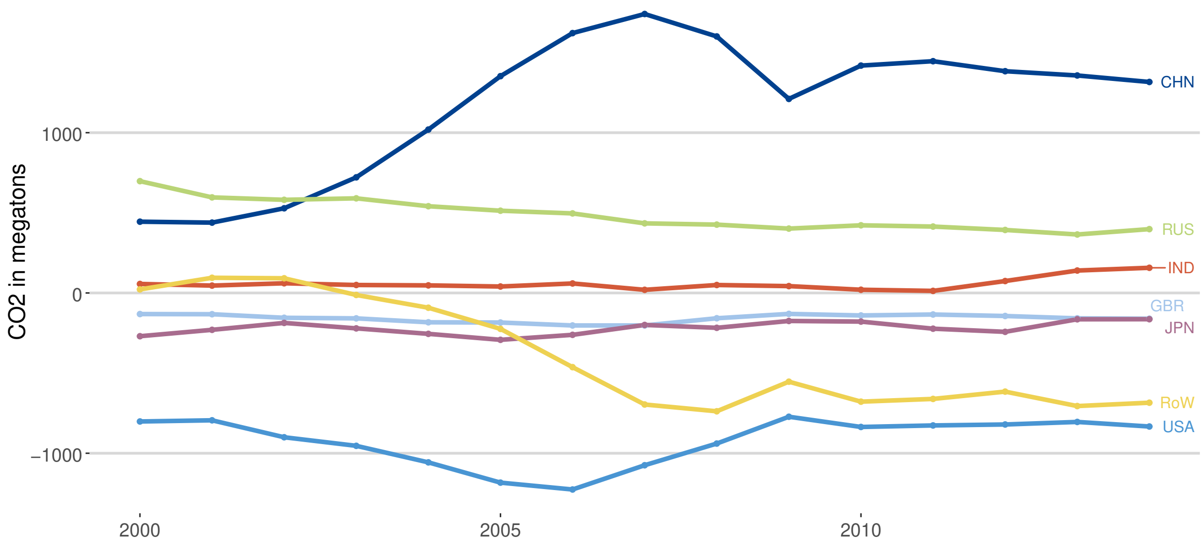


exports embody 453 megatons, while the embodied emissions in their imports amount to 1286 megatons of CO2. As the US, Great Britain and Japan are both net importers of embodied CO2, while India and Russia are net exporters. Russia is also the country with the largest share of net exports to total exports in embodied emissions, which amount to 68 percent, followed by China with 60 percent. Figure 1 implies large gaps between production and consumption footprints.

Stylized fact 2: The asymmetry in traded emissions is highly persistent.

Figure 2 depicts the imbalance of traded CO2 emissions embodied in exports and imports for the same countries as in Figure 1, 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

Figure 2: Embodied CO2 Emissions Imbalance in International Trade, by Year



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 3: Trade is highly asymmetric in value terms, too.

Figure 3 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 axis relates to their total exports (left) and imports (right) in billions of USD in 2014. It hence reproduces Figure 1, 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 4: Value trade imbalances are persistent, too.

Figure 3: Bilateral Trade Flows, 2014

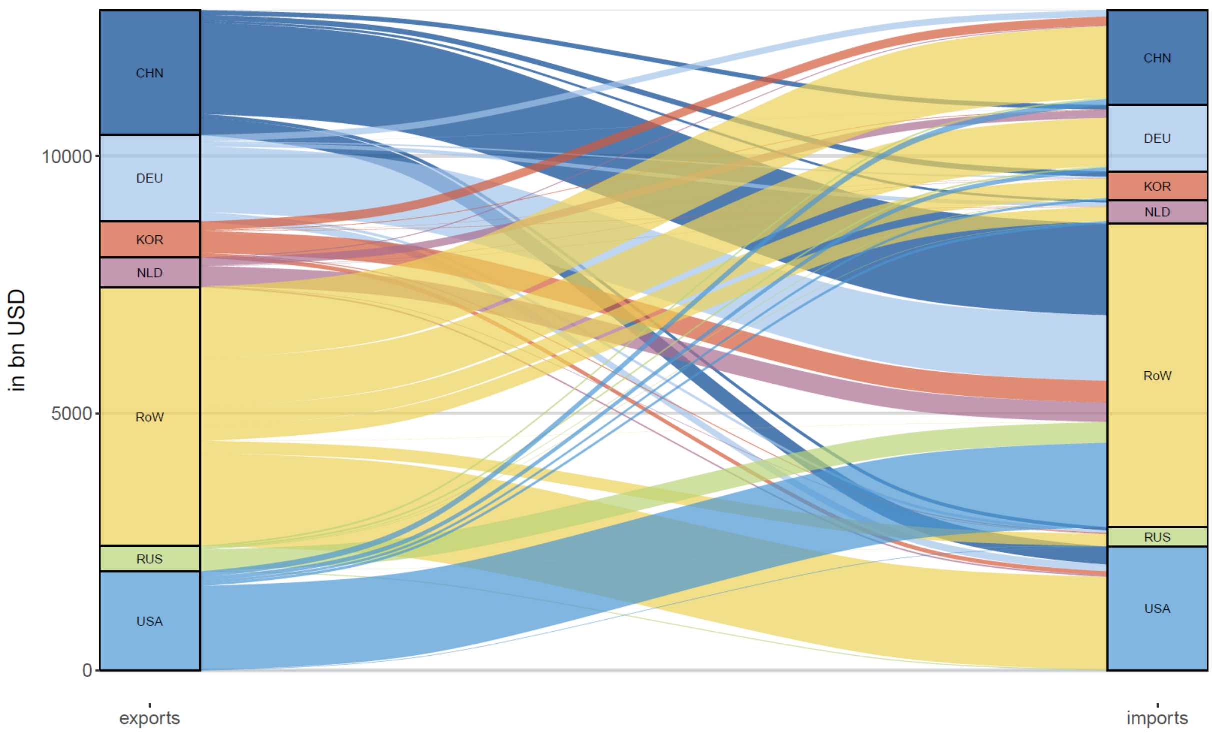


Figure 4: Trade Imbalance, by Year

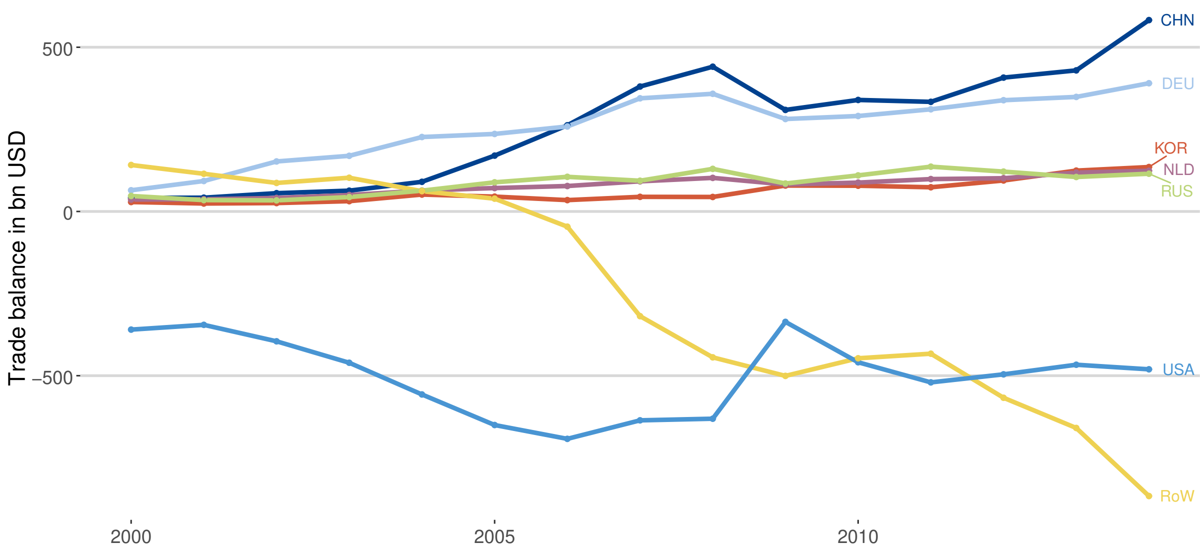


Figure 5: Correlation of Trade Imbalances and Carbon Intensities of Exports vs. Imports, 2014

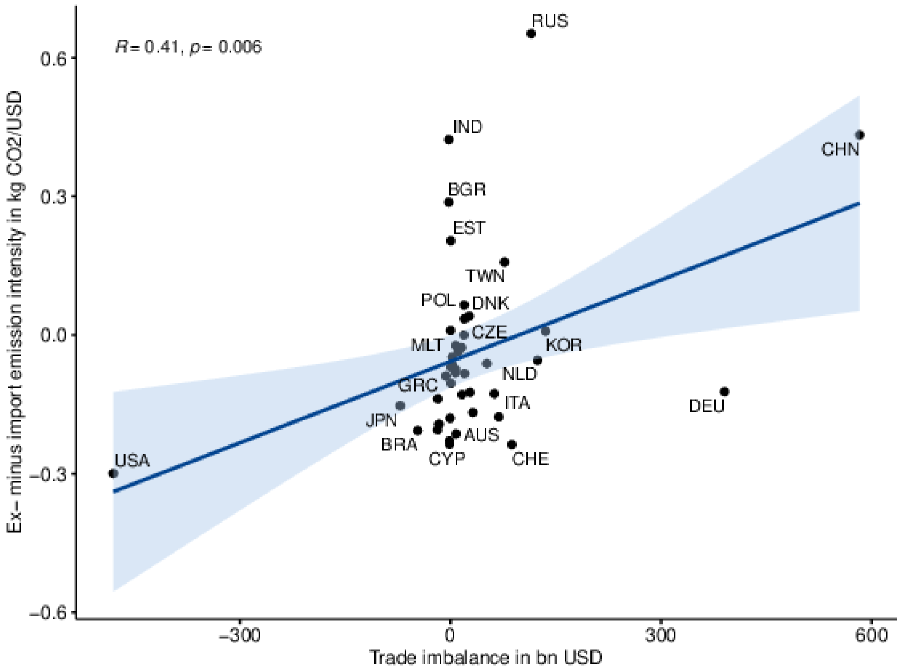
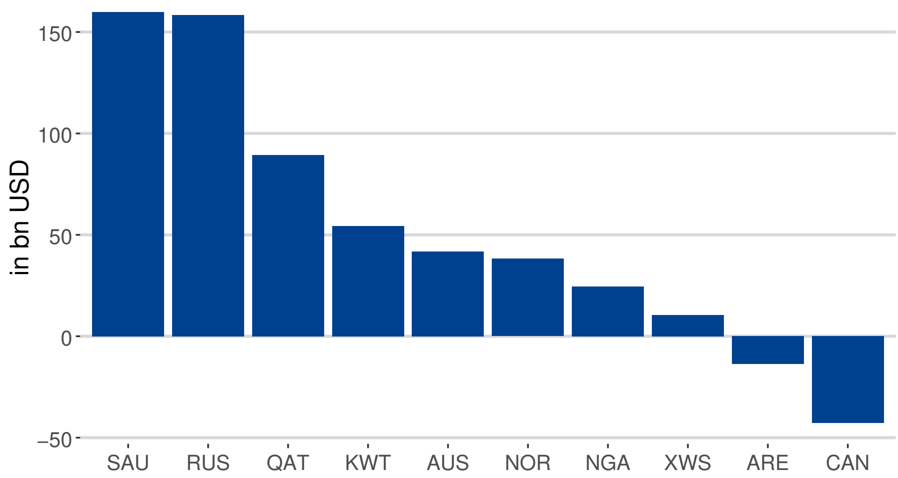


Figure 4 shows the annual trade imbalance in value terms of the same countries as in Figure 3 for the period 2000-2014. Similarly to the embodied emissions imbalances over time shown in Figure 2, a highly persistent pattern emerges. Though the fluctuations are somewhat larger, again none of the individual countries considered switches between net 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 5: 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

Figure 6: Trade Imbalance of the 10 Largest Fossil Exporters, 2014



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 5 makes clear, however, the opposite is true: the imbalances are positively correlated with the relative carbon-intensity of exports.[2] Countries supplying "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 6: Many large fossil fuel 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

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

intensities, but it's also about the products, the use of which *causes* carbon emissions, namely fossil fuels. If countries that are rich in fossil resources (and hence have large extraction footprints) 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 6 shows, this is exactly the case for many of the world's largest 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 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.

3 Model

We build 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 fossil fuel extraction and 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 (2021), Caron and Fally (2022), and Klotz

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

[4] Qatar'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).

and Sharma (2023).

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, and a set of sectors $\mathcal{J}$, indexed by j and k. Both primary and secondary fossil fuel sectors are part of $\mathcal{J}$ and the distinction between the different types of sectors will be discussed further below. In each sector, there is a continuum of goods $\omega^j \in [0, 1]$. Households in n obtain utility from consumption C according to a two-tier Cobb-Douglas utility function and experience disutility from global emissions:

$$u_n = \prod_{j \in \mathcal{J}} \left(\exp \int_0^1 \ln C_n(\omega^j) d\omega^j \right)^{\alpha_n^j} \left[\frac{1}{1 + (\mu_n^{-1} E)^2} \right],$$

where α is the constant sectoral expenditure share, $\sum_{j \in \mathcal{J}} \alpha_n^j = 1$, μ_n is a disutilty parameter that captures the regional distribution of climate damages, E are global carbon emissions, and the functional form for the climate damage component is taken from Shapiro (2016). 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 e.g. clean services expenditure.

3.2 Production

There are three types of sectors that are all part of the overall set $\mathcal{J}$: primary fossil fuels ($p \in \mathcal{P}$), secondary fossil fuels ($s \in \mathcal{S}$), and ordinary sectors ($o \in \mathcal{O} = \mathcal{J} \setminus \{\mathcal{P}, \mathcal{S}\}$). Primary fossil fuels are the fuels extracted from the earth, secondary fossil fuels are the ones burnt in production or consumption. The two may but do not have to coincide and the sets $\mathcal{P}$ and $\mathcal{S}$ therefore overlap, but are not identical. E.g. in the case of coal, what is extracted and what is used at later points is the same, while for oil, we distinguish the primary sector raw oil and the secondary sector petroleum.

All goods are produced using labor l and composite intermediate input bundles m from the own and other sectors. In all sectors, countries differ in their productivity for different goods from the continua, inversely captured by the input requirement a, and in the input cost shares γ. Primary fossil fuel sectors additionally use a sector-specific natural resource input r^p, which we think of as the different types of fossil fuel reserves. Secondary fossil fuel sectors that are not also primary sectors are linked to one specific primary fossil fuel sector (which we will index by p^s) in requiring a fixed quantity input from it, with the relative physical inputs shares for the primary fuel and other inputs determined by two additional technology parameters ν^{p^s} and ν^s. Intuitively, e.g. one liter of petroleum cannot be produced without a fixed quantity of raw oil. Other than the latter Leontief component, the production technologies are Cobb-Douglas and hence given by:

$$q_n(\omega^o) = [a_n(\omega^o)]^{-1} [l_n(\omega^o)]^{\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} \left[m_n^j(\omega^o)\right]^{\gamma_n^{j,o}} \quad \forall o \in \mathcal{O},$$

$$q_n(\omega^p) = [a_n(\omega^p)]^{-1} [r_n^p(\omega^p)]^{\gamma_n^{r,p}} [l_n(\omega^p)]^{\gamma_n^{l,p}} \prod_{j \in \mathcal{J}} \left[m_n^j(\omega^p)\right]^{\gamma_n^{j,p}} \quad \forall p \in \mathcal{P},$$

$$q_n^s(\omega^s) = [a_n(\omega^s)]^{-1} \times \min \left\{ \nu_n^{p^s} m_n^{p^s}, \nu_n^s [l_n(\omega^s)]^{\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} \left[m_n^j(\omega^s)\right]^{\tilde{\gamma}_n^{j,s}} \right\} \quad \forall s \in \mathcal{S} \setminus \mathcal{P},$$

with $\gamma_n^{l,o} + \sum_{j \in \mathcal{J}} \gamma_n^{j,o} = 1$, $\gamma_n^{r,p} + \gamma_n^{l,p} + \sum_{j \in \mathcal{J}} \gamma_n^{j,p} = 1$, and $\tilde{\gamma}_n^{l,s} + \sum_{j \in \mathcal{J} \setminus \{p^s\}} \tilde{\gamma}_n^{j,s} = 1$. Note that we distinguish $\tilde{\gamma}$ to indicate that these are not the overall cost shares in the exclusively secondary fossil fuel sectors. We still refer to the actual cost shares in this sector by γ, too, but note that they are endogenous in these sectors and will react to changes in the relative price of the primary fossil input compared to the remaining inputs. The intermediate input bundles are themselves Cobb-Douglas composites[5]:

$$m_n^j = \exp \int_0^1 \ln d_n(\omega^j) d\omega^j,$$

where $d_n(\omega^j)$ are the demands for the specific varieties ω^j as intermediate inputs. Unit costs (which equal the price due to perfect competition and constant returns to scale) in the ordinary, primary fossil fuel and secondary fossil fuel sectors are given by $c_n^o a_n(\omega^j)$, $c_n^p a_n(\omega^p)$, and $c_n^s a_n(\omega^s) \forall s \notin \mathcal{P}$, where the cost of the input bundles are given by

$$c_n^o = \Upsilon_n^o \left[w_n\right]^{\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} \left[P_n^j\right]^{\gamma_n^{j,o}} \quad \forall o \in \mathcal{O}, \tag{1}$$

$$c_n^p = \Upsilon_n^p \left[p_n^{r^p}\right]^{\gamma_n^{r,p}} \left[w_n\right]^{\gamma_n^{l,p}} \prod_{j \in \mathcal{J}} \left[P_n^j\right]^{\gamma_n^{j,p}} \quad \forall p \in \mathcal{P}, \tag{2}$$

$$c_n^s = \frac{P^{p^s}}{\nu_n^{p^s}} + (\nu_n^s)^{-1} \Upsilon_n^s \left[w_n\right]^{\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} \left[P_n^j\right]^{\tilde{\gamma}_n^{j,s}} \quad \forall s \in \mathcal{S} \setminus \mathcal{P}, \tag{3}$$

where $\Upsilon_n^o = (\gamma_n^{l,o})^{-\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} (\gamma_n^{j,o})^{-\gamma_n^{j,o}}$, $\Upsilon_n^p = (\gamma_n^{r,p})^{-\gamma_n^{r,p}} (\gamma_n^{l,p})^{-\gamma_n^{l,p}} \prod_{j \in \mathcal{J}} (\gamma_n^{j,p})^{-\gamma_n^{j,p}}$, $\Upsilon_n^s = (\tilde{\gamma}_n^{l,s})^{-\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} (\tilde{\gamma}_n^{j,s})^{-\tilde{\gamma}_n^{s,o}}$, w denotes the wage, P the price of a composite intermediate bundle, and p^{r^p} is the price of a specific fossil resource factor. Input requirement coefficients in all sectors are assumed to be drawn from type-III extreme value (Weibull) distributions, i.e. $Pr[a_n(\omega^j) \leq a] = 1 - \exp(-(A_n^j a)^{\theta^j})$, where A is a location parameter capturing a country's overall technology level in a sector capturing (the productivity component of) comparative advantage across sectors and θ is a dispersion parameter (inversely) capturing the extent of comparative advantage differences within sectors.[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:

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

[6]Note 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.

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. Crucially, in the primary fossil fuel sector, factor endowment differences enter as another source of comparative advantage, complementing the otherwise Ricardian trade structure in the model with a Heckscher-Ohlin component.

How can international trade allow emission-relevant specialization patterns in our model then? 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^j_{ni}, i.e. t units have to be shipped to deliver one unit from i to n. The cost distribution for country i delivering goods to country n depend on i's productivity and input costs, as well as on bilateral frictions between i and n and is given by

$$Pr[c_{ni}(\omega^j) \leq c] = 1 - e^{-(A^j_{ni}c)^{\theta j}},$$

with $A^j_{ni} = A^j_i/(t^j_{ni}c^j_i)$. 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 distribution inherits the Weibull form from the technology and cost distributions and is given by:

$$F_n^j(p) = 1 - e^{-(\bar{A}_n^j p)^{\theta^j}}, \quad \text{with} \quad \bar{A}_n^j = \left[\sum_{i \in \mathcal{N}} (A_{ni}^j)^{\theta^j} \right]^{1/\theta^j}.$$

$\bar{A}$ summarizes 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:

$$P_n^j = \exp\left(\int_0^\infty \ln(p) dF_n^j(p) \right) = \frac{\exp(-\varepsilon/\theta^j)}{\bar{A}_n^j}, \tag{4}$$

where $\varepsilon = 0.5772\ldots$ 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 is X_n^j. The share of this expenditures that is spent on goods from country i equals the share in which i is the lowest cost supplier and is given by a sectoral version of the EK gravity expression[7]:

$$\pi_{ni}^j = \frac{X_{ni}^j}{X_n^j} = \left(\frac{A_{ni}^j}{\bar{A}_n^j} \right)^{\theta^j}. \tag{5}$$

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 CO_2, 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 on the one hand incentivize other countries to produce more (less)

[7] As described in EK, this share can be calculated as the probability that i has the lowest costs of delivering a good ω to n: $Pr[c_{ni}(\omega^j) \leq \min\{c_{ns}(\omega^j); s \neq i\}] = \int_0^\infty \prod_{s \neq i} [\exp(-(A_{ns}^j c)^{\theta^j})] d(\exp(-(A_{ni}^j c)^{\theta^j}))$. 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 $(A_i^j/c_i^j)^\theta$, substitute the expression into (5) and simplify using (4).

fossil fuel intensively, but on the other hand incentivize fossil resource-abundant countries to extract less (more) fossil fuels from the ground.

3.3.2 Trade balance

Total expenditures for sector j combines expenditure on intermediate bundles and for final consumption:

$$X_n^j = \sum_{k \in \mathcal{J}} \gamma_n^{j,k} \sum_{i \in \mathcal{N}} X_i^k \pi_{in}^k + \alpha_n^j I_n, \tag{6}$$

where the final absorption I_n consists of labour income (given by the total labour endowment L_n times the wage), resource income from the different types of fossil resources (given by the respective endowments R_n^p times the resource prices) and the trade deficit (D_n):

$$I_n = w_n L_n + \sum_{p \in \mathcal{P}} p_n^{r^p} R_n^p + D_n. \tag{7}$$

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

$$\sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} \left(X_n^j \pi_{ni}^j \right) - D_n = \sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} \left(X_i^j \pi_{in}^j \right). \tag{8}$$

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 extracts 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 consumption footprint. Globally, deficits in countries with "green" preferences, relatively "brown" production technologies, and large levels of production of fossil fuels 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, somewhat expanded by the presence of the fossil fuel sector and the non-constant input cost shares in a subset of these sectors.

Definition 1. *For given labor endowments L_n, resource endowments R_n^p, technology parameters A_n^j, θ^j $\gamma_n^{l,o}$, $\gamma_n^{j,o}$, $\gamma_n^{r,p}$, $\gamma_n^{l,p}$, $\gamma_n^{j,p}$, $\tilde{\gamma}_n^{l,s}$, $\tilde{\gamma}_n^{j,s}$, $\nu_n^{p^s}$ and ν_n^s, trade costs t_{ni}^j, and trade imbalances D_n, an equilibrium is a set of wages w_n, fossil resource prices $p_n^{r^p}$, composite intermediate goods prices P_n^j, and input cost shares in secondary fossil fuel production $\gamma_n^{l,s}$ and $\gamma_n^{j,s}$ that satisfy conditions* (1)–(8).

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 $\{w_n, p_n^{r^p}, P_n^j, \gamma_n^{l,s}, \gamma_n^{j,s}\}$ be a baseline equilibrium for global trade imbalances D_n and $\{w_n', p_n^{r^p\prime}, P_n^{j\prime}, \gamma_n^{l,s\prime}, \gamma_n^{j,s\prime}\}$ be a counterfactual equilibrium for global trade imbalances D_n'. Then, $\{\hat{w}_n, \hat{p}_n^{r^p}, \hat{P}_n^j, \hat{\gamma}_n^{l,s}, \hat{\gamma}_n^{j,s}\}$ satisfy the following equilibrium conditions* (9a)–(15b)*:*

Cost changes of the input bundles:

$$\hat{c}_n^o = [\hat{w}_n]^{\gamma_n^{l,o}} \prod_{j \in \mathcal{J}} \left[\hat{P}_n^j\right]^{\gamma_n^{j,o}} \qquad \forall o \tag{9a}$$

$$\hat{c}_n^p = \left[\hat{p}_n^{r^p}\right]^{\gamma_n^{r,p}} [\hat{w}_n]^{\gamma_n^f} \prod_{j \in \mathcal{J}} \left[\hat{P}_n^j\right]^{\gamma_n^{j,p}} \qquad \forall p \tag{9b}$$

$$\hat{c}_n^s = \gamma_n^{p^s,s} \hat{P}_n^{p^s} + (1 - \gamma_n^{p^s,s}) [\hat{w}_n]^{\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} \left[\hat{P}_n^j\right]^{\tilde{\gamma}_n^{j,s}} \ \forall s \notin \mathcal{P} \tag{9c}$$

Input cost share changes:

$$\hat{\gamma}_n^{p^s,s} = \frac{\hat{P}_n^{p^s}}{\hat{c}_n^s} \quad \forall s \notin \mathcal{P} \tag{10a}$$

$$\hat{\gamma}_n^{l,s} = \hat{\gamma}_n^{j,s} = (\hat{c}_n^s)^{-1} [\hat{w}_n]^{\tilde{\gamma}_n^{l,s}} \prod_{j \in \mathcal{J} \setminus \{p^s\}} \left[\hat{P}_n^j\right]^{\tilde{\gamma}_n^{j,s}} \qquad \forall s \notin \mathcal{P} \wedge j \neq p^s \tag{10b}$$

Price index change:

$$\hat{P}_n^j = \left[\sum_{i \in \mathcal{N}} \pi_{ni}^j \left(\hat{c}_i^j\right)^{-\theta^j}\right]^{\frac{-1}{\theta^j}} \tag{11}$$

Bilateral trade share change:

$$\hat{\pi}_{ni}^j = \left[\frac{\hat{c}_i^j}{\hat{P}_n^j}\right]^{-\theta^j} \tag{12}$$

Counterfactual total expenditure by country and sector:

$$X_n^{j'} = \sum_{k \in \mathcal{J} \setminus \{\mathcal{S} \setminus \mathcal{P}\}} \left(\gamma_n^{j,k} \sum_{i \in \mathcal{N}} \hat{\pi}_{in}^k \pi_{in}^k X_i^{k'}\right) + \sum_{s \in \mathcal{S} \setminus \mathcal{P}} \left(\hat{\gamma}_n^{j,s} \gamma_n^{j,s} \sum_{i \in \mathcal{N}} \hat{\pi}_{in}^s \pi_{in}^s X_i^{s'}\right) + \alpha_n^j I_n^{'} \tag{13}$$

Counterfactual final absorption:

$$I_n^{'} = \hat{w}_n w_n L_n + \sum_{p \in \mathcal{P}} \hat{p}_n^{r^p} p_n^{r^p} R_n^p + D_n^{'} \tag{14}$$

Factor price changes:

$$\hat{p}_n^{r^p} = \frac{\gamma_n^{r,p} \sum_{i \in \mathcal{N}} \hat{\pi}_{in}^p \pi_{in}^p X_i^{p'}}{p_n^{r^p} R_n^p} \tag{15a}$$

$$\hat{w}_n = \frac{1}{w_n L_n} \left(\sum_{j \in \mathcal{J} \setminus \{\mathcal{S} \setminus \mathcal{P}\}} \left(\gamma_n^{l,j} \sum_{i \in \mathcal{N}} X_i^{k'} \hat{\pi}_{in}^k \pi_{in}^k\right) + \sum_{s \in \mathcal{S} \setminus \mathcal{P}} \left(\hat{\gamma}_n^{l,s} \gamma_n^{l,s} \sum_{i \in \mathcal{N}} X_i^{s'} \hat{\pi}_{in}^s \pi_{in}^s\right)\right) \tag{15b}$$

Note that this second equilibrium definition has the advantage that there is no need to identify the level of the technology parameters A and ν and of the bilateral trade frictions t anymore. Also, for the primary production factors L and R^p, information on the baseline income earned from them is sufficient rather than separate information on their quantities and prices. Further note that rather than simply restating the counterfactual counterpart of (8) in our depiction of the equilibrium in changes, we directly translate trade balancing into the implied changes of the factor prices in order to have the equations exactly coincide with the ones used in our solution algorithm, which simply iterates over equations (9a)–(15a), with a dampening factor included in the factor price updates.[8] Finally note that in order to keep the expressions as simple as possible, we only consider exogenous changes in trade balances. Naturally, e.g. counterfactual trade cost changes could readily be incorporated.

3.5 Carbon Emissions

3.5.1 Territorial emissions / Production footprints

Carbon emissions stem from fossil fuel combustion and are therefore modeled to be proportional to the usage of the secondary fossil fuel composite, either as an intermediate in production or in final consumption, weighted by the varying carbon intensities ι^s of the different fossil fuel types. Classic national emissions (i.e. production footprints) are hence given by

$$E_n = \sum_{s\in\mathcal{S}} \iota^s \left(\int_0^1 C_n(\omega^s) d\omega^s + \sum_{j\in\mathcal{J}} \int_0^1 m_n^s(\omega^j) d\omega^j \right) = \sum_{s\in\mathcal{S}} \frac{\iota^s X_n^s}{P_n^s}. \tag{16}$$

Note the difference to Shapiro (2021) 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 and distinguish between production, consumption, and extraction footprints. Further note that the territorial emissions that we denote as production footprints as part of our footprint trinity in fact also contain a consumption component which stems from the combustion of fossil fuels in final consumption (think of car fuel, for example).

[8] As the equilibrium is only defined up to a a normalization, we adjust factor prices in each iteration in such a way as to keep global nominal factor income constant.

3.5.2 Consumption footprints

With international trade, territorial emissions (i.e. production footprints) generally don't coincide with the amount of emissions embodied in the products *consumed* in a country. Our model including input-output linkages across sectors and countries allows us to track emissions along the whole global value chain and contrast territorial emissions to a country's consumption footprint, which is given by:

$$CF_n = \sum_{s\in\mathcal{S}} \underbrace{\iota^s[\boldsymbol{\gamma}^{s,\cdot} \oslash \mathbf{P}^s]'}_{\text{emission intensity}} \underbrace{[\mathbf{I}-\mathbf{A}]^{-1}}_{\text{Leontief Inverse}} \underbrace{[\boldsymbol{\pi}_n \odot \boldsymbol{\alpha}_n I_n]}_{\text{final demand}} \quad + \quad \underbrace{\frac{\alpha_n^s I_n}{P_n^s}}_{\text{consumption emissions}} \quad , \tag{17}$$

where $\boldsymbol{\gamma}^{s,\cdot} = [\gamma_1^{s,1}, \ldots, \gamma_1^{s,J}, \gamma_2^{s,1}, \ldots, \gamma_N^{s,J}]'$ collects secondary fuel input shares in all sectors and countries, $\mathbf{P}^s = [P_1^s, \ldots, P_N^s]' \otimes \mathbf{i}_J'$ collects secondary fossil fuel prices of all countries, $\otimes$ denotes the Kronecker product, $\mathbf{i}_J$ is a unit vector of length J, $\mathbf{A} = \begin{pmatrix} \mathbf{A}_{11} & \ldots & \mathbf{A}_{N1} \\ \cdot & \cdot & \cdot \\ \mathbf{A}_{1N} & \ldots & \mathbf{A}_{NN} \end{pmatrix}$ is the global input coefficient matrix, $\mathbf{A}_{in} = \begin{pmatrix} \gamma_i^{1,1}\pi_{in}^1 & \ldots & \gamma_i^{1,J}\pi_{in}^J \\ \cdot & \cdot & \cdot \\ \gamma_i^{J,1}\pi_{in}^1 & \ldots & \gamma_i^{J,J}\pi_{in}^J \end{pmatrix}$ is a bilateral input coefficient matrix, $\boldsymbol{\pi}_n = [\pi_{n1}^1, \ldots, \pi_{n1}^J, \pi_{n2}^1, \ldots, \pi_{nN}^J]'$ collects country n's trade shares with all partners and in all sectors, $\boldsymbol{\alpha}_n = [\alpha_n^1, \ldots, \alpha_n^J]' \otimes \mathbf{i}_N'$ collects country n's consumption shares across sectors, and $\oslash$ and $\odot$ denote element-wise division and multiplication, respectively. If a country e.g. uses a lot of steel, but does not produce it itself, this will drive up the consumption footprint, but not the production footprint. The calculation of the consumption footprint will also take into account whether this steal is sourced from countries with a dirty, e.g. coal-intensive, or a cleaner energy mix.

3.5.3 Extraction footprints

Territorial emissions and consumption footprints are the two common ways of carbon accounting. In line with Kortum and Weisbach (2021), we also consider a third dimension. Specifically, besides where the fossil fuels are burnt and where the products end up being consumed, we consider where the fossil fuels themselves originate from. We refer to this third way of carbon accounting as extraction footprints and they are given by:

$$EF_n = \sum_{p\in\mathcal{P}\cap\mathcal{S}} \iota^p \sum_{i\in\mathcal{N}} \frac{\pi_{in}^p X_i^p}{P_i^p} + \sum_{s\in\mathcal{S}\setminus\mathcal{P}} \sum_{i\in\mathcal{N}} \pi_{ni}^{p^s} \iota^s \sum_{m\in\mathcal{N}} \frac{\pi_{mi}^s X_m^s}{P_m^s}. \tag{18}$$

The first part corresponds to the primary fossil fuels that are at the same time secondary fossil fuels, i.e. that are directly burnt as part of the production process of other goods. Here, we simply need to know which quantity of the fuel a country sells overall and how carbon-intensive the fuel is. The second summand corresponds to the primary fossil fuels that are used as an input for a different, secondary fossil fuel which then goes on in a further step to be burnt and actually cause the carbon emissions. We don't attribute these secondary fossil fuels' emissions to the secondary producer (i.e. for example to the country where the oil refinery is located), but trace them back to where the primary fuel originated from (i.e. where for example the raw oil was extracted). For this second part, we obtain in the last sum (over m) the total sales of the exclusively secondary fossil fuels of country i. We can translate them into emissions using the emission intensity ι and they are connected to the corresponding primary fuel in a fixed way due to the Leontief component of the production structure. Knowing which share of the primary fuel was sourced from country n is therefore equivalent to knowing which part of the emissions from i's secondary fuels s can be traced back to country n's extraction.

3.6 Welfare

The focus in our counterfactual scenarios lies on how the global level and distribution of carbon emissions is affected. Nevertheless, we can also evaluate welfare effects, which are given by a combination of changes in real consumption and in climate damages:

$$\hat{W}_n = \frac{\hat{I}_n}{\prod_{j \in \mathcal{J}} (\hat{P}_n^j)^{\alpha_n^j}} \frac{1 + \left(\mu_n^{-1} \sum_{i \in \mathcal{N}} E_i^{\prime}\right)^2}{1 + \left(\mu_n^{-1} \sum_{i \in \mathcal{N}} E_i\right)^2}. \tag{19}$$

As the trade imbalance features directly in the final absorption I, this expression is likely to be dominated for many countries by the first-order effect of the exogenous counterfactual change in D itself, rather than by general equilibrium adjustments. To dig deeper into the adjustment and the role that reduced climate damages play in welfare changes, we can compare the welfare change to changes in real consumption (only the first fraction in (19), i.e. welfare changes net of the emission effects) and to changes in real income, which additionally take out the imbalance component of final absorption.

3.7 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), labor income (wL), fossil resource income ($p^{r^p} R^p$), and initial trade imbalances (D) are obtained from input-output tables. Sectoral dispersion parameters (θ) are taken from the online database of Fontagné, Martin, and Orefice (2018).[9] For the service sectors we rely on estimates of Egger, Larch, and Staub (2012).

Data Source

The main input for our simulation comes from the GTAP 10 database (Aguiar, 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, $p^{r^p} R^p$, D) for the year 2014.[10] 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.

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

[10]This 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.

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.[11]

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 surplus the imbalances of trade deficit countries are reduced proportionally,[12] 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.

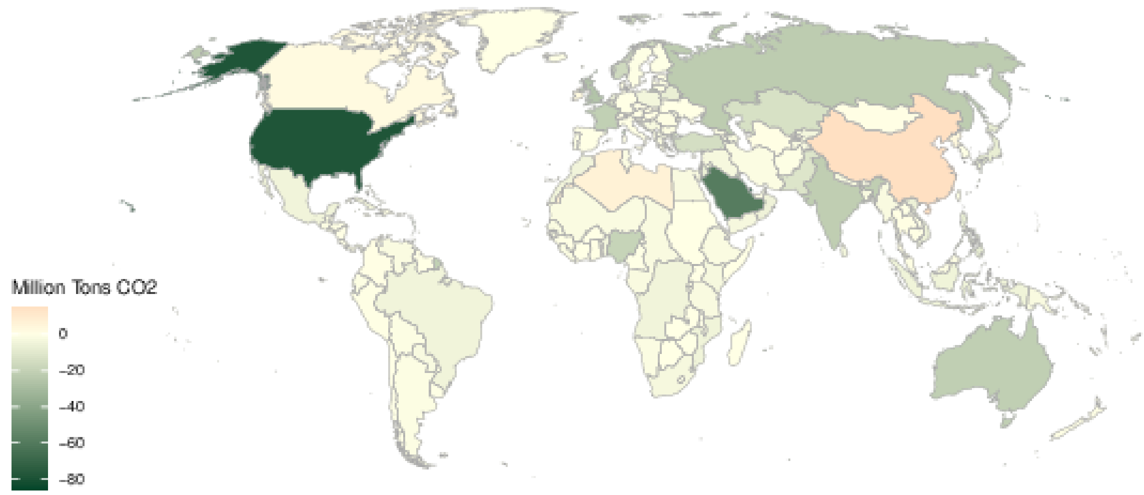
Figure 7 shows the change of global carbon emissions for all 141 counterfactuals. The value of each country represents the change in global carbon emission in the scenario where the respective country's imbalance is removed.[13] One thing that becomes apparent right away is the large effect on global 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 consumption footprint by consistently running a deficit indeed leads to a lower-emission new global production and consumption pattern. Specifically, global CO2 emissions would

[11] Please note that the presented results are still preliminary and based on a simplified version of the model presented in Section 3, featuring the full input-output structure, but a single factor and Cobb-Douglas production functions in all sectors.

[12] If 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.

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

Figure 7: Change in Global Carbon Emissions from the Removal of the Corresponding Country's Trade Imbalance, Each Country Balanced Separately



go down by 41.4 mln tons or 0.14 percent.[14] This is roughly equivalent to Bulgaria's total annual emissions. Note that the global emission reduction in response to a US re-balancing does *not* stem from lower US territorial emissions. The US in fact slightly increases their production footprint 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 6 on fossil fuel exporters running surpluses and the corresponding concern that this type of imbalance fosters global fossil fuel supply and therefore global emissions. Taking away the Qatari surplus reduces Qatar's possibility to maintain its relatively large extraction footprint. 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

[14] All emission quantities refer to CO2 emissions only and to the model base year 2014.

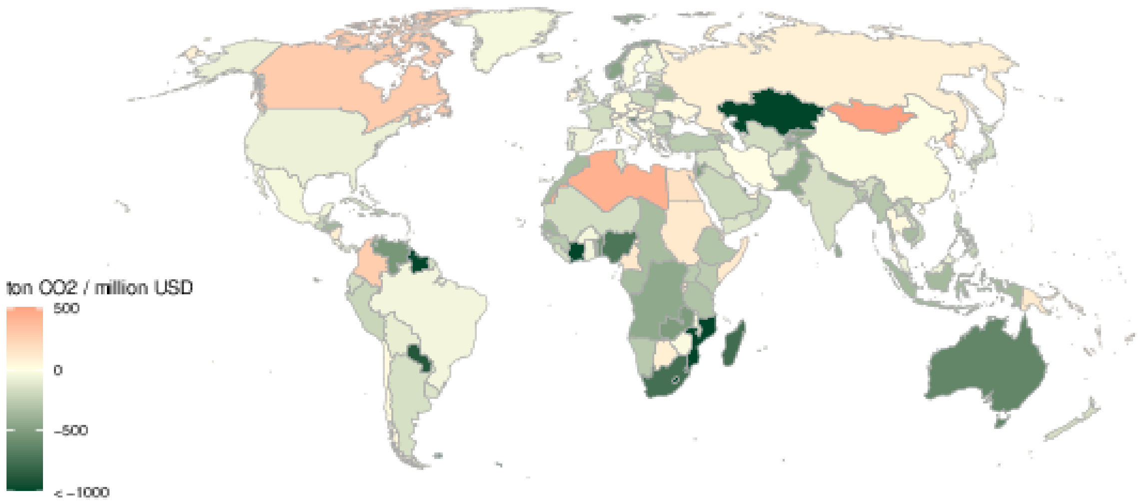
from bringing down surpluses of high-extraction footprint fossil fuel exporters, namely Qatar, Saudi-Arabia (32.6 mln tons world emission reduction), Australia (26.2 mln tons), and Kazakhstan (22.9 mln tons).

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's 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 7 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 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

Figure 8: Change in Global Carbon Emissions per Absolute Value of Removing Trade Imbalance per Country, Each Country Balanced Separately



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 7 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 8 shows how global carbon emissions change per million USD of removed trade imbalance in the 141 country-level counterfactual scenarios.[15] 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

[15]Exact values can be found in the last column of Table B1 in the Appendix.

in the world in absolute terms.

5.2 Balancing all Countries' Trade Simultaneously

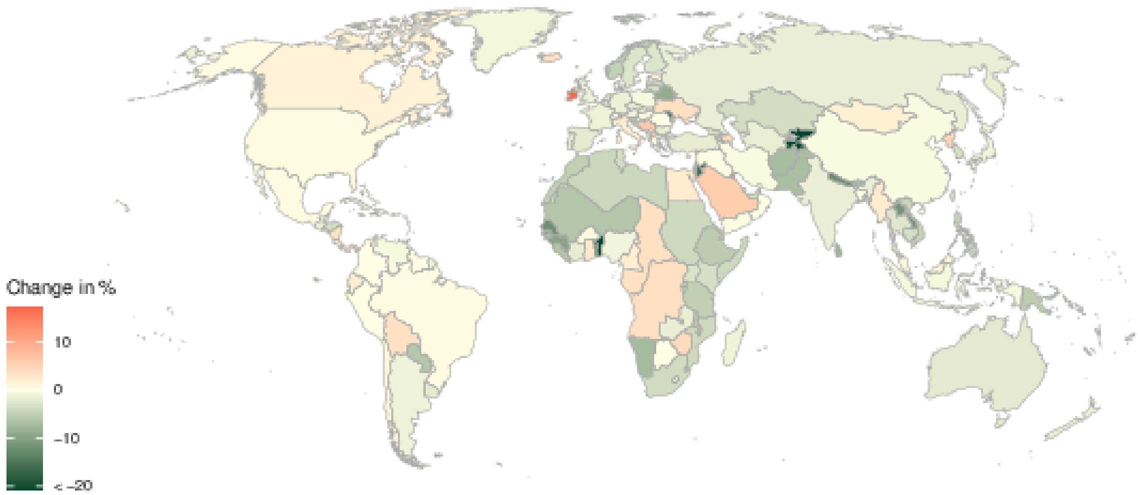
In our other counterfactual scenario, we set the trade imbalances of all 141 countries and regions simultaneously to zero. Given the trade imbalance patterns established in Section 2, as well as the insights from the re-balancing of individual countries' international trade, we clearly expect that a 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 scenario. Compare the effect for example to the simultaneous introduction of carbon tariffs for all country pairs at 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 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 9 breaks down the global emission reduction into the percentage changes in national carbon emissions.[16] Note the difference in how to read this figure in comparison to Figure 7: 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.

[16]For the exact values of change in carbon emissions and welfare see Table B1 in the Appendix

Figure 9: Percentage Changes in Carbon Emissions, All Countries Balanced Simultaneously



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 and in their supply of fossil fuels. 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 end 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 develop 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.

References

Aguiar, A., M. Chepeliev, E. Corong, R. McDougall, and D. Van der Mensbrugghe (2019, 6). The GTAP Data Base: Version 10. *Journal of Global Economic Analysis 4*(1), 1–27.

Caliendo, L. and F. Parro (2015). Estimates of the Trade and Welfare Effects of NAFTA. *Review of Economic Studies 82*(1), 1–44.

Caron, J. and T. Fally (2022). Per Capita Income, Consumption Patterns, and CO2 Emissions. *Journal of the Association of Environmental and Resource Economists 9*(2), 235–271.

Copeland, B. R., J. S. Shapiro, and M. S. Taylor (2021). Globalization and the Environment. *NBER Working Paper 28797.*

Cuñat, A. and R. Zymek (2019). Bilateral Trade Imbalances. *CESifo Working Paper 7823.*

Dekle, R., J. Eaton, and S. Kortum (2007). Unbalanced Trade. *American Economic Review: Papers and Proceedings 97*(2), 351–355.

Dekle, R., J. Eaton, and S. Kortum (2008). Global Rebalancing with Gravity: Measuring the Burden of Adjustment. *IMF Staff Papers 55*(3), 511–540.

Eaton, J. and S. Kortum (2002). Technology, Geography, and Trade. *Econometrica 70*(5), 1741–1779.

Eaton, J. and S. Kortum (2012). Putting Ricardo to Work. *Journal of Economic Perspectives 26*(2), 65–90.

Egger, P., M. Larch, and K. E. Staub (2012). Trade Preferences and Bilateral Trade in Goods and Services: A Structural Approach. *CEPR Working Paper 9051.*

Egger, P. and S. Nigai (2015). Energy Demand and Trade in General Equilibrium. *Environmental and Resource Economics 60*(2), 191–213.

Felbermayr, G. and Y. V. Yotov (2021, 10). From theory to policy with gravitas: A solution to the mystery of the excess trade balances. *European Economic Review 139*, 103875.

Fontagné, L., P. Martin, and G. Orefice (2018). The International Elasticity Puzzle Is Worse Than You Think. *Journal of International Economics 115*, 115–119.

Klotz, R. and R. Sharma (2023). Trade Barriers and CO2. *Journal of International Economics*, 103726.

Kortum, S. and D. Weisbach (2021). Optimal Unilateral Carbon Policy. *Cowles Foundation Discussion Paper 2659.*

Larch, M. and J. Wanner (2017). Carbon Tariffs: An Analysis of the Trade, Welfare, and Emission Effects. *Journal of International Economics 109*, 195–213.

Larch, M. and J. Wanner (2019). The Consequences of Unilateral Withdrawals from the Paris Agreement. *CESifo Working Paper 7804.*

Li, Y., B. Chen, C. Li, Z. Li, and G. Chen (2020, 10). Energy Perspective of Sino-US Trade Imbalance in Global Supply Chains. *Energy Economics 92*, 104959.

Reyes-Heroles, R. (2016). The Role of Trade Costs in the Surge of Trade Imbalances. *unpublished working paper*.

Shapiro, J. S. (2016). Trade Costs, CO2, and the Environment. *American Economic Journal: Economic Policy 8*(4), 220–254.

Shapiro, J. S. (2021). The Environmental Bias of Trade Policy. *Quarterly Journal of Economics 136*(2), 831–886.

Shapiro, J. S. and R. Walker (2018). Why is Pollution from U.S. Manufacturing Declining? The Roles of Environmental Regulation, Productivity, and Trade. *American Economic Review 108*(12), 3814–3854.

Timmer, M. P., E. Dietzenbacher, B. Los, R. Stehrer, and G. J. de Vries (2015). An Illustrated User Guide to the World Input-Output Database: the Case of Global Automotive Production. *Review of International Economics 23*(3), 575–605.

Appendix

A Data

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

GTAP code	Country	Trade imbalance in mln USD	Value added in mln USD	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	Value added	Emissions
		in mln USD		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

Cont. on next page

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

GTAP code	Country	Trade imbalance	Value added	Emissions
		in mln USD		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	Value added	Emissions
		in mln USD		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

	Balancing simultaneously	Balancing separately	
Country	Emission change	Global emission change	
	in %	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

Cont. on next page

Table B1: Results Emission Change

	Balancing simultaneously	Balancing separately	
Country	Emission change	Global emission change	
	in %	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

Cont. on next page

Table B1: Results Emission Change

	Balancing simultaneously	Balancing separately	
Country	Emission change	Global emission change	
	in %	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

Cont. on next page

Table B1: Results Emission Change

	Balancing simultaneously	Balancing separately	
Country	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