CENTRO STUDI LUCA D'AGLIANO

WWW.DAGLIANO.UNIMI.IT

CENTRO STUDI LUCA D'AGLIANO
DEVELOPMENT STUDIES WORKING PAPERS

N. 413

January 2017

CO2 embedded in trade: trends and fossil fuel drivers

*Sylvain Weber**
*Reyer Gerlagh***
*Nicole A. Mathys****
*Daniel Moran*****

* University of Neuchâtel

** Tilburg University

*** Federal Office for Spatial Development and University of Neuchâtel

**** Norwegian University of Science and Technology

ISSN 2282-5452

CO₂ embedded in trade: trends and fossil fuel drivers¹

version 23 May 2016

Sylvain Weber, University of Neuchâtel, Switzerland

Reyer Gerlagh, Tilburg University, Netherlands

Nicole A. Mathys, Federal Office for Spatial Development and University of Neuchâtel,
Switzerland

Daniel Moran, Norwegian University of Science and Technology, Norway

Abstract

The amount of CO₂ embedded in trade has substantially increased since 1990. We study the trends and some drivers over the period 1995-2009. We find that traded goods tend to have higher emission-intensities compared to average final demand. The second finding is that independently of sector structure, dirty countries tend to specialize in emission-intensive sectors. This finding suggests a comparative advantage mechanism for CO₂ and lends support to the hypothesis that trade liberalization tends to increase global emissions. The third finding is that, on average, emission-intensive countries have shifted from trade deficits to surpluses, so a larger share of goods is now produced in emission-intensive countries, consequently increasing global emissions. Finally, our analysis points to coal abundance as an important driver for high levels of both domestic emissions per value added *and* sector specialization into emission-intensive sectors. Hence coal abundance is an important driver of net CO₂ exports.

JEL Classification Numbers:

Key Words: CO₂ embedded in trade, fossil fuel.

¹ This paper is prepared within the "Value Added in Motion (VAM)" project funded by the Enel Foundation. We are also grateful for financial support from CREE (Oslo Centre for Research on Environmentally friendly Energy) and the Research Council of Norway..

1. Introduction

The major message of the most recent IPCC report (“Climate Change 2014”) reads “Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history.” For the first time, the IPCC report also presents statistics showing the effect of trade and globalization on emission patterns. Carbon embodied in trade has increased dramatically over the last decades. But the effect of trade on emissions is politically contentious, and governments could not agree on the presentation of these data; they were cut from the Summary for Policy Makers (Victor et al. 2014). Yet it is important to understand the role of trade since international policy approaches that ignore trade distort incentives for firms and countries (Kander et al 2015). This paper studies the consequences of trade trends on global emissions and some drivers of embodied carbon. Understanding of both topics is necessary to develop effective global and national climate policies.

Linkages between international trade and climate change are extensive (see de Melo and Mathys 2010 for an overview). After the introduction of the Kyoto Protocol, it was suspected that carbon emissions could “leak” when climate policies in Annex I countries would lead emission-intensive firms to relocate the production of carbon-intensive goods to outside-Annex I countries, which then would be imported back into Annex I countries. As a response to the concerns over carbon leakage, the consumption-based accounting (CBA) (also called carbon footprint) principle was introduced. According to the CBA principle it should be the final consumer of a good, not the producer, who is held accountable for emissions. The topic of CBA accounting has been well explored theoretically and empirically (e.g. Davis and Caldeira 2010, Peters et al. 2011, Kanemoto 2013, Aichele and Felbermayr 2012). Holding final consumers accountable for emissions embodied in the goods they consume is challenging, since it requires that the representatives of final consumers understand the mechanisms involved and have instruments to influence emissions up in the production chain, even if these emissions occur abroad. More generally, policy makers may want to understand how carbon taxes affect embodied emissions in trade flows and emissions themselves, both domestic and foreign, *and* how other factors affect emissions and embodied emissions. The carbon intensity of trade, differentiated between imports and exports, is an important indicator for the effects of carbon taxes on trade (Atkinson et al 2011). Such measurements will become increasingly important if policy makers decide to introduce significant domestic carbon taxes.

Carbon emissions embodied in trade are a significant part of global emissions. They have risen over the last 15 years, from about one quarter of total emissions before 2000 to approximately one third post-2000 (Figure 1). This mirrors the growth in the traded portion of global GDP over the same period. The sharp decline in 2008 is likely due to the

global economic downturn but the upward trend is expected to continue. Understanding the evolution and determinants of trade embodied emissions is not only of interest from the trade perspective, as outlined above, but also in general for climate change.

Figure 1: Evolution of the share of CO₂ emissions embodied in international trade; Source: WIOD, own calculations²

In this paper we decompose net CO₂ exports and investigate the relative contribution of its elements, and their determinants. The decomposition enables us to see whether net CO₂ exports are mainly driven by trade deficits, sectoral structure of the exporting country or average emission efficiency of the country. Furthermore, if the latter two effects are positively (negatively) correlated, increased trade would, everything else held equal, lead to increased (decreased) emissions at the worldwide level. We extend the literature and go one step further and search for the determinants of sectoral structure and emission intensities when controlling for sectoral structure. We focus on fossil fuel reserves and climate policies such as the Kyoto protocol, as suggested by the literature

² The denominator counts global CO₂ emissions. The nominator sums all CO₂ emissions embedded in trade. If a commodity is imported, repackaged and exported, emissions are counted twice. In this sense, there is double counting and the chart overestimates the share of traded emissions. To avoid this problem the concept of the value added of trade can be applied (Johnson and Noguera 2012).

(Michielsen 2013, Gerlagh et al 2015, Grether et al 2014, Aichele and Felbermayr 2012, 2015), as potential drivers. By isolating these drivers our study provides insight into the impacts of fossil fuel market developments and future carbon policies on the evolution of emissions at the global level.

We use a comprehensive global production and trade dataset, the World Input-Output Database (WIOD). The database covers 40 individual countries and aggregates together the remaining countries into a “rest of the world” region. Each country is comprised of 35 sectors and the database provides annual data for 1995-2009. This dataset traces input-output linkages at the global level, it reflects global value chains, and it allows measuring of the carbon content of trade including all direct and upstream carbon emissions embodied in intermediates.

The paper is structured as follows. Section 2 gives an overview of the literature. Section 3 describes the data used and the methodology applied to compute embodied carbon emissions. Section 4 presents and discusses the results, and section 5 concludes.

2. Literature review

Our analysis builds on and combines several strands of the literature: it uses the most recent databases to construct embodied emissions at the world wide level, per country, sector and year, taking global value chains into account. It decomposes net CO₂ exports to uncover the underlying mechanisms, taking serious the warning by Jakob and Marschinski (2013) that a look into emission intensities and trade deficits is needed to isolate different mechanisms. After presenting some descriptive statistics and decompositions, we investigate energy abundance and environmental policy stringency (measured by participation at the Kyoto agreement or other policy stringency indexes) as significant determinants of embodied emissions. To the best of our knowledge, this is the first time that both determinants are tested together in a comprehensive framework and on a large sample. Below we present the main literature connected to the various parts of our analysis.

Grossman and Krueger (1993) decompose the effect of trade on domestic emissions into three factors. The *scale* effect captures the mechanism that trade leads to increased economic activity and hence to increased emissions. The *composition* effect captures a country’s sectoral specialization, and the mechanism implies that trade liberalization increases (decreases) domestic emissions when a country specializes in ‘dirty’ (‘clean’) sectors. The *technique* effect captures the mechanism that trade leads to more efficient production technologies, and thus to lower emissions. Using the above decomposition, in their seminal paper Antweiler et al. (2001) conclude that increased trade tends to reduce SO₂ concentrations. A series of papers followed, assessing the link between trade and the environment, with more recent contributions focusing on climate change. Cole (2006),

Frankel and Rose (2005) and Managi et al. (2009), looked at energy and trade, and also addressed endogeneity issues of trade and income. Some recent papers zoom in on the firm level, but are then limited to one or a few countries (e.g. Cole et al. 2014). Our analysis is connected to this literature as we use a similar decomposition technique.

A different strand of literature focuses on the emission content of trade. It follows the older empirical trade literature, based on the Heckscher-Ohlin-Vanek model, which analyzes the factor content of trade, and extends the classic factors such as labour with environmental factors such as carbon. Antweiler (1996) proposes to compute the pollution terms of trade, i.e. the ratio between the average pollution content per dollar of exports and the average pollution content per dollar of imports. The pollution terms of trade measure is independent of trade imbalances and is therefore appropriate as a long run structural indicator. It contrasts with the balance of embodied emissions in trade (emissions embodied in imports minus emissions embodied in exports) as proposed by Muradian et al. (2002), which is sensitive to more volatile trade imbalances. We connect to this literature as we consider fossil fuel endowments as explanatory for carbon embedded in trade.

The pollution content of trade analysis is challenging as it requires good statistics on global value chains and measures for environmental inputs into production, to compute the emission or carbon content of trade. Recently, theory has been extended (Trefler and Zhu, 2010 and Johnson and Noguera, 2012) and better data on world input-output linkages became available resulting in a large number of contributions. Grether and Mathys (2013) extend the work by Antweiler (1996) with new more detailed data on input-output tables and SO₂ emissions. They find that large, poor and emerging countries such as Indonesia, China and Chile, exhibit high emission intensities for exports relative to imports, while large, rich countries such as the US, Germany and Japan are characterized by lower export emission intensities compared to their import emission intensities. Kanemoto et al. (2013) use the Eora input-output database (similar to WIOD) and compare embodied air pollution in trade (i.e. air pollution emitted in service production for export) against embodied carbon in trade, for the period 1970-2012. They find that since 1970 the US and EU air pollution footprints have remained relatively flat – with reduced domestic emissions more than offset by increased imports of pollution embodied in imported goods. They conclude that global air pollution emissions have remained flat despite successful regulation in major emitters; a lesson with obvious consequences for carbon regulation. In our analysis, we also consider the effect of income levels on the composition of trade, related to the typical CO₂ footprint of various sectors, and the CO₂ content of trade controlling for the composition. We consider both exports and imports, separately.

With increasing interests in climate change, a large number of studies have investigated the global carbon content of trade (Hertwich and Peters 2008, 2009, Peters et al. 2011, Davis and Caldeira 2010, Davis et al. 2011, Atkinson et al. 2011, Wiebe et al. 2012,

Chen and Chen 2011). These papers focus on cross-sectional considerations and typically use one-year input-output data, and provide mainly descriptive discussions (cf. Peters et al. 2011) without analyzing structural causes for the observed pattern of the carbon content of trade. Peters et al. (2012) and Sato (2013) provide overviews of data and techniques used in these papers and note that findings are overall robust across studies. A series of paper focuses on specific countries (mainly China, Japan, US, UK), or country pairs, to accommodate the increasing political interest (Shui and Harriss 2006, Ackermann et al. 2007, Dietzenbacher and Mukhopadhyay 2007, Li and Hewitt 2008, Liu et al. 2010, Xu et al. 2011, Minx et al. 2011, Dietzenbacher et al. 2012, Zhang 2012, Lopez et al. 2013, Barrett et al. 2013). Yet, Jakob et al. (2013) and Jakob and Marschinski (2013) emphasize that one should be careful when interpreting net emission transfers and their effects on overall emissions. In particular, emission intensities and trade deficits need to be analyzed separately (as also mentioned by Antweiler 1996). As a case in point, the US net imports of emissions from China are for almost 50% attributable to the large trade deficit between the US and China. We build on this literature, looking into global CO₂ flows over a longer period 1995-2009.

Xu and Dietzenbacher (2014) exploit the WIOD dataset and provide a dynamic structural decomposition analysis, where they distinguish between emission intensities, trade structure of intermediate goods, production technology, trade structure of final products and total final demand. They find that for many developed countries, the growth of emissions embodied in imports is much higher than the growth of emissions embodied in exports, being driven mainly by a change in the structure of trade, both in intermediate and final products. They also observe that emerging economies like the BRIC countries have increased their share in global production and trade at the expense of developed countries, which tends to increase the global average emission intensity. We use the same database, and extend the analysis with an econometric approach to uncover systematic relations between economic growth and CO₂ flows.

Aichele and Felbermayr (2012, 2014) move from computations of carbon contents, descriptive statistics and decompositions, to evaluate the effect of the Kyoto agreement on carbon embodied in trade.³ They control for the endogenous selection of countries in the Kyoto Protocol, and find that binding commitments under Kyoto have increased committed

³ More generally, pollution haven effects are observed whenever environmental policy acts as a determinant of comparative advantages. At the same time, one has to consider the factor endowment effect; if, as empirically observed, dirty industries not only are intensive in environmental inputs but also in capital inputs, trade theory suggests that capital abundant high income countries have a comparative advantage in dirty industries. Grether et al. (2012) have determined the relative strength of these two effects in a bilateral gravity framework.

countries' embodied carbon imports from non-committed countries by around 8% and the emission intensity of their imports by about 3%. In the same vein but applied to the energy content of trade and looking at energy endowments as determinants of comparative advantages, Gerlagh et al. (2015) find for a high-income country sample that a one standard deviation increase in energy abundance increases energy embodied in trade by about 20%. The authors also find that energy-abundant countries have 7-10% higher employment and 13-17% higher net exports in energy-intensive sectors vis-à-vis otherwise comparable countries.⁴ Sato and Dechezleprêtre (2015) study the effect of energy prices on trade for a panel of 42 developed and developing countries. Using a traditional gravity-equation approach they find statistically significant but very small effects of energy prices on trade flows. Douglas and Nishioka (2012) test trade-theoretical predictions from the Heckscher-Ohlin-Vanek and Trefler and Zhu (2010) framework. They find no evidence that developing countries specialize in emissions-intensive sectors; instead, evidence suggests that emission intensities differ systematically across countries because of differences in production techniques. Results confirm that international differences in emission intensity are substantial, but suggest that they do not play a significant role in determining patterns of trade. We build on this literature, using a comprehensive worldwide dataset (WIOD) and including fossil fuel abundance into the analysis.

When trying to establish causal links between environmental policy and environmental outcomes various proxies for environmental policy stringency are available (e.g. Kyoto participation, policy effects on energy prices). Recent studies present new environmental policy indexes: Brunel and Levinson (2013) calculate each country's predicted emissions based on its industrial composition and compare that with actual emissions to calculate a measure for the normalized average emissions intensity of its industries. Where actual emissions exceed predicted emissions, they conclude that environmental regulation is less stringent than average, and vice versa. Sauter (2014) proposes two policy indexes: one based on a collection of laws (policy input index) and a second one based on sectoral emission data (pollutant performance index). We calculate an emission intensity measure comparable to Brunel and Levinson (2013), used as dependent variable, and will use Sauter's collection of laws as independent variable.

3. Data and Methodology

3.1. Data

All data on production, trade, consumption, sectoral CO₂ emissions, and carbon footprints were taken from the WIOD multi-regional input-output (MRIO) database (Timmer 2012,

⁴ Michielsen (2013) and Grether et al. (2014) investigate the importance of energy endowments for industry location in the US and China respectively.

Dietzenbacher et al. 2013). WIOD is one dataset of a new generation of global trade databases being used, among other applications (e.g. see Lenzen et al. 2013, Kanemoto et al. 2014, Moran et al. 2014, Simas et al. 2014), for tracing flows of carbon embodied in trade along the whole value chain. For this study WIOD was chosen over the EXIOBASE (Tukker et al. 2013), Eora (Lenzen et al. 2012, Lenzen et al. 2013), and GTAP (GTAP 2012, Andrew and Peters 2013) databases because of its homogenous sector classification and its sectoral, spatial, and temporal detail and coverage. For a discussion of the relative strengths and weaknesses of these databases see Dietzenbacher et al. (2013) and Tukker and Dietzenbacher (2013). The EXIOBASE and GTAP databases do not provide a time series. The Eora database covers more countries and years than does WIOD, but in its homogenous classification (which is necessary in order to do inter-country comparisons) it offers less sectoral detail than WIOD (26 sectors vs. 35). Hence, following the suggestion by Steen-Olsen et al. (2014), we opt for the WIOD dataset with more sectoral details at the expense of the number of separately reported countries. For a detailed comparison of WIOD, Eora and GTAP, see Owen et al. (2014).

Carbon footprinting as an instance of environmentally extended input-output analyses suffers from some several sources of uncertainty and error. These have been discussed extensively since I-O was developed (for overviews see Wiedmann et al. 2011 and Geschke et al. 2014). A recent comparison of carbon footprints calculated using various databases showed a general convergence amongst results (Moran and Wood 2014). Two sources of uncertainty are particularly relevant in this study, to wit aggregation error and the sectoral composition of territorial emissions. Aggregation error (discussed very early, cf. Holzman 1953) refers to the fact that MRIO accounts are by necessity aggregated into a few dozen or hundred sectors while these sectors are in fact usually comprised of a multitude of different products. In environmentally-extended I-O analysis in particular it can be the case that a particular product within a sector can have a much higher or lower environmental load or carbon intensity than its parent sector as a whole (e.g. aluminium specifically vs. nonferrous metals in general). This heterogeneity can lead to distortions in the results. MRIO builders are keenly aware of this issue and are always seeking ways to improve sectoral resolution (Lenzen et al. 2014). Recent studies indicate that uncertainty arising from aggregation error is well understood and manageable (Andrew et al. 2009, Su et al. 2010, Lenzen 2011, Zhou et al. 2012, Steen-Olsen et al. 2013).

The other relevant source of uncertainty lies in the sectoral composition of the territorial CO₂ emissions accounts. Total national CO₂ emissions are well-reported and the IPCC and EU provide both data and guidance on how these emissions should be attributed amongst various sectors. However, some details of the sectoral allocation are left to the individual MRIO model builders. To our knowledge, this issue has not been studied much in

the academic literature. In future work, it should be possible to use cross-database comparison and sensitivity analyses to further investigate the robustness of our findings.

Additionally, several variables from the World Development Indicators (WDI, World Bank) are used: income, population and natural resource rents. The variable Kyoto is a dummy that indicates whether a country has ratified Kyoto in a given year or not. This variable is taken from Aichele and Felbermayr (2015). The CO₂ stringency variable is taken from Sauter (2014). The index (called narrow CO₂ input index) is constructed from the legal database ECOLEX and counts supra-national, national and sub-national laws, which explicitly refer to the goal of reducing CO₂ emissions.

3.2. Multi-region input-output analysis

We proceed under the assumption that the underlying MRIO database is reliable. Our empirical methodology derives from a standard input-output analysis as originally conceived by Leontief (1941, 1986). We start by decomposing total output into its components:⁵

$$(1) \quad x_i = A_i x_i + y_i + XP_i - MP_i \quad i = 1, \dots, N$$

where x_i is an $S \times 1$ vector of total output in each sector ($s = 1, \dots, S$) in country i , y_i is the vector of final demands, A_i is the matrix of intermediate input requirements, i.e. a matrix where each column indicates the inputs from all sectors needed to produce one unit of output for a given sector, $A_i x_i$ is the vector of intermediate demands, XP_i are total exports from country i and MP_i are total imports to country i . The total number of economic sectors in all countries is given by $N \cdot S$. The WIOD database covers $N = 41$ countries (listed in appendix Table 4) each containing $S=35$ sectors (listed in appendix Table 5), thus $N \cdot S = 1,435$, over the period 1995-2009.

Removing imports from equation (1) allows to express output in terms of purely domestic activities:

$$(2) \quad x_i = A_i^d x_i + y_{ii} + XP_i$$

where y_{ii} is the vector of final demands for domestic-produced goods, and A_i^d is the matrix that describes domestic intermediate input requirements.⁶

⁵ For a fuller explanation of the following standard steps, the reader may refer to Miller and Blair (2009) or Leontief's highly readable original work. For simplicity, we omit the time subscript.

⁶ That is, all imported intermediates are removed from the matrix A .

In the MRIO framework, emissions embodied in intermediate demands are ultimately allocated to the countries where final goods are consumed. Therefore, the exports XP_{ij} from country i to country j are further split in final demands and intermediate demands:

$$(3) \quad XP_{ij} = A_{ij}x_j + y_{ij}$$

where y_{ij} is the vector of country i 's exports to country j 's final demands, A_{ij} is the matrix of intermediate input requirements imported from country i to country j , and $A_{ij}x_j$ is the vector of imported intermediate inputs.

Substituting equation (3) into (2) yields the standard MRIO model:

$$(4) \quad x_i = A_i^d x_i + y_{ii} + \sum_{j \neq i} A_{ij} x_j + \sum_{j \neq i} y_{ij}$$

Stacking observations for all countries, we can write equation (4) in matrix form:

$$(5) \quad \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} = \begin{pmatrix} A_1^d & A_{12} & \cdots & A_{1N} \\ A_{21} & A_2^d & \cdots & A_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ A_{N1} & A_{N2} & \cdots & A_N^d \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{pmatrix} + \begin{pmatrix} \sum_j y_{1j} \\ \sum_j y_{2j} \\ \vdots \\ \sum_j y_{Nj} \end{pmatrix}$$

$$(6) \quad x = Ax + y$$

where x is an $N \cdot S \times 1$ vector of total output in all sectors in all countries, $\sum_j y_{ij}$ is an $S \times 1$ vector of the sum of final demands for goods from country i , y is the vector collecting final demands for all goods in all countries, and A is a block matrix in which each element (A_i^d or A_{ij}) is a matrix of dimension $S \times S$.

Re-arranging equation (6) yields the basic equation for I-O analysis:

$$(7) \quad x = (I - A)^{-1}y = Ly$$

where I is an $N \cdot S \times N \cdot S$ identity matrix, and $L = (I - A)^{-1}$ is the output-demand inverter, also known as the Leontief inverse matrix. Flows can thus be traced recursively through this technical coefficients matrix in order to calculate not just the direct requirements but the total requirements needed to produce one unit of a good.

Alternatively, we also consider the decomposition of total output in intermediate consumptions and value added. In this setting, the equivalent of (6) writes:

$$(8) \quad x = E'x + z$$

where E is a block matrix equivalent to A in (6), in which the elements are matrices E_i^d or E_{ij} of dimensions $S \times S$ where each row indicates the fraction of a unit of output produced by a given sector in country i that is consumed as intermediate consumption by all other sectors in country i or j , and z is the vector of values added.

Re-arranging equation (8) yields another basic equation for I-O analysis:

$$(9) \quad x = (I - E')^{-1}z$$

Global CO₂ emissions can now be expressed as territorial emissions T (also known as production-based) or consumption-based emissions C :

$$(10) \quad T = ex = \varepsilon z$$

$$(11) \quad C = \varphi y$$

where e is the row vector of emission intensities of output, i.e. the quantity of CO₂ emitted per unit of output, $\varepsilon = e(I - E')^{-1}$ is the row vector of emission intensities of value added, and $\varphi = e(I - A)^{-1}$ is the row vector of emission intensities of demand. At the worldwide level, we have $T = C$, but the two measures differ when applied to individual countries.

3.3. Empirical methodology, descriptive analysis

Before turning to our main research questions, we check whether some sectors are systematically and meaningfully more emission intensive than others. We do so by estimating the following two-way fixed-effect equations for emission intensities (of value added and of demand):

$$(12) \quad EIVA: \ln(\varepsilon_{ist}) = \pi_t + \gamma_{it} + \delta_{st} + \mu_{ist}$$

$$(13) \quad EID: \ln(\varphi_{ist}) = \pi_t + \gamma_{it} + \delta_{st} + \mu_{ist}$$

where ε_{ist} is the emission intensity of value added (EIVA) in sector s in country i at time t , φ_{ist} is the emission intensity of demand (EID), π_t is a time fixed effect, γ_{it} is a country-time fixed effect normalized to average to zero in each year, δ_{st} is a sector-time fixed effect normalized to average to zero in each year, and μ_{ist} is the remaining noise. Obviously, (12) and (13) cannot be estimated directly because of multicollinearity between the sets of time, country-time and sector-time fixed effects. Concretely, we proceed by estimating these equations without time fixed effects, and thereafter re-scale the country-time and sector-time fixed effects so that their average weighted by territorial emissions (i.e. T in (10)) for EIVA or consumption-based emissions (i.e. C in (11)) for EID are zero, while the remainder constitutes the time fixed effect. The interpretation of our coefficients is thus as follows: π_t is a time effect common to all countries and all sectors, while γ_{it} (δ_{st}) indicates the

divergence of country i (sector s) with respect to the country (sector) average in a particular year t .

In order to assess whether there are systematic differences in emission intensities, we consider the standard deviation of the noise (μ_{ist}) and compare it to the standard deviation of the country (γ_{it}) and sector terms (δ_{st}). If the latter are larger than the former, meaning that most of the differences across sectors are indeed explained instead of being random, we indeed observe systematic differences.

For each country, net CO₂ exports are given by:

$$(14) \quad \begin{aligned} NXP_i &= T_i - C_i = e_i x_i - \varphi_i y_i = \varphi_i (I - A_i) x_i - \varphi_i y_i \\ &= \varphi_i [(I - A_i) x_i - y_i] = \varphi_i (XP_i - MP_i) \end{aligned}$$

which we decompose into economic trade balances, sector specialization, and country-specific emission intensities as follows:

$$(15) \quad NXP_i = \bar{\varphi} u (XP_i - MP_i) + (\bar{\varphi}_s - \bar{\varphi} u) (XP_i - MP_i) + (\varphi_i - \bar{\varphi}_s) (XP_i - MP_i)$$

where φ_i is (like before) the row vector of sectoral emission intensities of demand in country i , $\bar{\varphi}_s$ is the row vector of world average emission intensities per sector, $\bar{\varphi}$ is the average emission intensity over all sectors and all countries (that is, a scalar), and u is a unity vector of dimensions $1 \times S$.

The first term on the right-hand-side of (15) represents the net CO₂ trade related to the economic trade balance. This term uses a world-wide average emission intensity of goods. Countries exporting much more than they import, such as China, tend to have a positive first term.

The second term represents the net CO₂ trade position related to the sector-structure of exports and imports. The term is positive if a country exports in sectors that tend to be emission intensive and/or it imports in sectors that tend to have low associated emissions. The second term is closely related to the pollution haven debate.

The third term represents the net CO₂ trade related to differences in the emission intensities between the (exporting) country i and the countries it imports from. The term is positive if domestic emission intensities exceed the sector world average and/or if the foreign emission intensities from which the country imports are below the sector world average. This term is thus expected to be positive for countries that have a domestically 'inefficient' production, and for countries whose trade partners are emission efficient. That is, this term measures the overall production efficiency of a country *relative* to its trading partners. A country such as the US may be emission-intensive compared to the EU, but if it

trades more intensely with China, then its relative performance to China matters more for its net trade in CO₂ position.

We will consider the decomposition proposed in (15) over time, to identify how the contributions of the three factors have evolved. Moreover, looking at the correlations between the different factors and their evolution over time will indicate whether trade tends to increase or decrease worldwide emissions. For example, a positive correlation between emission intensities and sector specialization (the second and third terms) would imply that dirty countries tend to specialize in dirty sectors, and more trade is then accompanied by more emissions, as CO₂ intensive countries specialize in CO₂ intensive sectors. Also, if emission intensive countries tend to exhibit a trade surplus, worldwide emissions would increase with trade everything else equal.

3.4. Identification

Finally, we will try to unravel if and how fuel markets, climate policies and trade opportunities drive changes in emission intensities and in trade patterns. To this end, we use an alternative specification of equations (12) and (13), by removing collinear sets of fixed effects and including explanatory variables:

$$(16) \quad \text{EIVA: } \ln(\varepsilon_{ist}) = \beta^{VA} Z_{it} + \gamma_i + \delta_{st} + \mu_{ist}$$

$$(17) \quad \text{EID: } \ln(\varphi_{ist}) = \beta^D Z_{it} + \gamma_i + \delta_{st} + \mu_{ist}$$

where Z_{it} includes country variables, such as income, fossil fuel income shares, and policies. The effect of these variables is identified through different trends between countries, as time fixed effects are absorbed by the sector-time fixed effects, and country characteristics that do not change over time are absorbed through the country fixed effects. Depending on the variables included in Z_{it} , the estimated coefficients β can answer questions such as whether domestic fossil fuel abundance, Kyoto policies, and trade opportunities tend to increase or decrease emission intensities.

In addition, we test alternative measures of emission intensity that are relevant in the context of trade:

$$(18) \quad \ln(\varphi_{it} X P_{it} / \bar{\varphi}_{st} X P_{it}) = \beta^{Xi} Z_{it} + \gamma_i + \delta_t + \mu_{it}$$

$$(19) \quad \ln(\varphi_{it} X P_{ijt} / \bar{\varphi}_{st} X P_{ijt}) = \beta^{Xij} Z_{it} + \gamma_i + \delta_{jt} + \mu_{ijt}$$

The left-hand side variable in (18) measures the emission intensity of country i exports, relative to typical emissions for an average country with the same sector structure of exports. The dependent variable in (19) is identical, but specified for each bilateral country-pair. In this case, we control for partner-country-year fixed effects. These two

dependent variables are closely related to the third term of (15) and these two equations will give insights in the factors explaining country-specific emission intensities.

We then investigate the sector structure of trade by estimating the following four equations:

$$(20) \quad \ln(\bar{\varphi}_{st}XP_{it}/\bar{\varphi}_t uXP_{it}) = \beta_1 Z_{it} + \gamma_i + \delta_t + \mu_{it}$$

$$(21) \quad \ln(\bar{\varphi}_{st}MP_{it}/\bar{\varphi}_t uMP_{it}) = \beta_2 Z_{it} + \gamma_i + \delta_t + \mu_{it}$$

$$(22) \quad \ln(\bar{\varphi}_{st}XP_{ijt}/\bar{\varphi}_t uXP_{ijt}) = \beta_3 Z_{it} + \beta_4 Z_{jt} + \gamma_i - \gamma_j + \delta_t + \mu_{ijt}$$

$$(23) \quad \ln(\bar{\varphi}_{st}XP_{ijt}/\bar{\varphi}_t uXP_{ijt}) - \ln\left(\frac{\bar{\varphi}_{st}XP_{jit}}{\bar{\varphi}_t uXP_{jit}}\right) = \beta_5 (Z_{it} - Z_{jt}) + (\gamma_i - \gamma_j) + \mu_{ijt}$$

All the dependent variables in these equations are measures of sector structure and are linked to the second term in (15). The dependent variable in (20) measures the sector bias of exports towards emission-intensive sectors, i.e. how the exports structure of country i causes its emission intensity to differ from the average. In (21), we consider an equivalent variable for imports. In (22), the dependent variable measures the sector bias for all country-pairs of bilateral trade, considering each country-pair in both ways (i is both an exporter to j and an importer from j). We expect β_1 , β_2 , and β_3 , to be comparable, and β_4 to have opposite signs. In (23), we construct a symmetric equivalent that combines the exports and imports into a single variable containing the net exports. We expect β_5 to be about equal to $\beta_3 - \beta_4$. Note that the country-partner fixed effects in (22) and (23) are structured so that their number is equal to the number of countries, and not to the number of country-partner pairs.

3.5. Instrumenting and weighting observations

In our analysis, we investigate whether an increase in fossil fuel rents (e.g. coal) tends to increase or decrease the emission intensity of production (16), consumption (17), net exports (18)-(19), or that it changes the sector structure of trade (20)-(23). However, a correlation can also point to reverse causality: an increased demand for emission-intensive sectors leads to higher fossil fuel prices, and thus to higher fossil fuel rents. Therefore, we instrument the fuel rents. For each country, we calculate the share of that country, over the entire period, in worldwide fuel rents: s_i^c . In addition, for each year, we calculate the global fuel rents as a share of world GDP: R_t^g . The interaction between the country share and the world fuel rents is used as an instrument for each country's fossil fuel rent:

$$(24) \quad R_{it}^{inst} = s_i^c R_t^g$$

We test for endogeneity of resource rents through the Wu-Hausman F and Durbin χ^2 test and for the strength and information value of the instruments through an F-test in the first

stage equation.⁷ The instrument is informative and by construction there is no reverse causality. An increase in fossil fuel demand in one country in one year will have no effect on the interaction term for that country in that year.

We also use trade openness as an independent variable in our estimations. Similarly, to avoid endogeneity, we instrument openness through the interaction between a country's average openness over the entire period and the world trade share in world GDP, for each year.

We display weighted regressions in the main text and present unweighted results in the appendix. We discuss where the two approaches differ. Weighted estimations are warranted if we expect that larger observations have better quality, in relative terms, compared to observations related to small trade flows. Another way to interpret differences between weighted and unweighted estimations is that the former represents the marginal effect for the weighted average observation, while the latter represents the marginal effect for the unweighted average observation. The two outcomes will differ when big countries behave systematically different compared to small countries.

4. Results

4.1. Emission intensities

Figure 2 provides a first outlook of the differences in emission intensities between sectors. Emission intensities of value added are shown on the horizontal axis, while emission intensities of demand are presented on the vertical axis. These values are obtained from the estimation of equations (12) and (13). We weight observations for φ_{ist} by final demand, and for ε_{ist} by value added. Sectors with dark red labels have above average trade exposure (measured as exports plus imports divided by domestic production), while sectors with light blue labels have below average trade exposure.

We observe that a few sectors are much more emission intensive than all others. In particular, "Electricity, Gas and Water Supply" (ELCT), "Air Transport" (AIR), "Other non-metallic minerals" (MRLS) and "Water Transport" (WTR) are classified as the most emission intensive sectors, both in terms of value added and consumption. There is no clear-cut picture emerging concerning the degree of trade exposure and emission intensity.

⁷ By contrast to a standard instrumental variable estimation, in which all instruments would enter all first stage equations, we instrument every endogenous variable by its single instrument.

Note: this figure plots the coefficients $\pi_{2009} \cdot \delta_{s2009}$ obtained from (12) (horizontal axis) and (13) (vertical axis). These coefficients indicate the emission intensity of a typical sector in a typical country in 2009. Note the logarithmic scale. Red labels indicate trade intensive sectors (i.e. sectors with exports above average), while blue labels indicate sheltered sectors (i.e. sectors with exports below average). See Table 5 in the appendix for full sector names.

Table 1. Decomposition of emission intensity in country and sector specific factors.

Dependent variable	EIVA	EID
Equation number	(12)	(13)
sd sectors-year FE*	1.58	0.95
sd countries-year FE*	0.64	0.66
sd remaining noise	0.13	0.18
N	20,451	20,839
R ²	0.95	0.94

* Before calculating the country-year and sector-year standard deviation, we normalize these to have zero mean in each year, effectively constructing a year FE.

As there is a substantial gap between emission-intensive and emission-efficient sectors, we want to understand whether energy-intensity of traded goods and services tends to be higher or lower, compared to energy-intensity in non-traded goods and services. Figure 3 shows the development of emission-intensities over time, for worldwide consumption and worldwide exports, respectively.

Figure 3. Emission intensity of final consumption and exports, 1995-2009.

We observe that emission intensities remained stable between 1995 and 2003, and then rapidly declined. Figure 3 also shows that traded goods tend to have substantially higher emission intensities, relative to the average final consumption, implying that the sheltered sectors have substantially lower emission intensities. At first glance, this finding seems at odd with Figure 2, which showed that the most emission-intensive sectors are sheltered and overall no clear-cut picture can be identified. The seemingly contradicting finding is explained as follows: though the most emission-intensive sectors are sheltered, they are small compared to the next group of emission-intensive traded sectors. Specifically, the top

4 sectors in terms of emission intensities (ELCT, AIR, MRLS, WTR) made up only 3.5% of total worldwide final demand in 2009, and thereby contribute a limited amount to the average emission intensity of final demand. Among the trade-intensive sectors, we find “Coke, Refined Petroleum and Nuclear Fuel” (PTR), “Basic Metals and Fabricated Metal” (MTL) and “Chemicals and Chemical Products” (CHM) to be the most emission intensive sectors, making up 19.3% of total worldwide exports. Hence these sectors are relatively exposed to trade, large and relatively emission intensive.

Next, we portray in Figure 4 the relation between income and emission intensity. It shows that high-income countries tend to be more emission-efficient compared to low-income countries, but that for given income levels, there is also variation by a factor of about 2 in the emission intensity of production.

Figure 4. Emission intensity of value added versus income, 2009. Size of marker proportional to population.

Figure 5 displays the evolution of emission intensities for some of the largest countries. While Russia and Brazil saw their emission intensities increase and then decrease during the growth process, India and Japan show increased and China decreased emission intensities. The US do not show any significant change in emission intensities. The level of income is clearly negatively correlated with the level of emission intensities across countries (Fig 4), but the relation is less clear cut in the evolution over time (Fig 5).

Figure 5. Emission intensity of value added versus income for some selected (largest) countries, 1995-2009. Light labels are for 1995, dark labels are for 2009, arrows indicate the annual moves between 1995 and 2009.

4.2. Decomposing CO₂ embedded in trade

When considering the net embedded CO₂ exports or imports, it is important to separate the trade balance, sector structure, and emission efficiency effect as presented in equation (15). Figure 6 plots the efficiency effect against the sector structure effect for all countries in our sample. Two countries, the US and China, have the largest net CO₂ trade positions, as indicated by the size of their marker. But when compared to their total trade, China and Russia stand out as net CO₂ exporters because of their emission-intensive production, whereas the size of US CO₂ inflows is relatively moderate compared to the size of its domestic emissions.

Figure 6. Contribution of domestic efficiency compared to trade partners and sector structure of trade, to net CO₂ exports, 2009. Size of marker proportional to territorial CO₂ emissions. Note the different scales on the horizontal and vertical axis.

Aggregating all countries that were continuously net CO₂ exporters between 1995 and 2009, we find, as illustrated in Figure 7 that the trade balance surplus has become more important over the last years, while the country-specific effect remains the main driver. For the US, as shown in Figure 8, the economic trade imbalance has been a major source of its CO₂ net import position until 2008. The fact that we find all three factors, emission intensity, sector structure and trade balance, to contribute positively to the net CO₂ exports is somewhat worrying; countries with higher emissions per value added tend to specialize in dirty sectors and tend to export more than they import. In this sense, trade tends to increase global emissions. Also, on average, CO₂ exporting countries tend to export in emission-intensive industries, but most importantly, CO₂ exporting countries tend to have higher emissions per value added compared to their trade partners. Vice-versa, CO₂ importing countries tend to be more emission-efficient compared to their trade partners. The US, as a case in point, has large trade flows with China, and is more emission-efficient compared to China, explaining its large CO₂ imports, even though Figure 4 has shown that the US is rather emission-intensive compared to other countries of similar income level.

Figure 7. Decomposition of net CO₂ exports, aggregated over all countries (Bulgaria, China, Czech Republic, India, Poland, Russia, and Taiwan) that are net exporters every year between 1995 and 2009.

Figure 8. Decomposition of net CO₂ exports, USA, 1995-2009.

4.3. Patterns in emission intensity and trade specialization

We next ask how income, fossil fuel abundance, trade opportunities, and Kyoto affect emission-intensity of production and trade. While Almer and Winkel (2012) find no support for the hypothesis that Kyoto countries reduced domestic emissions, Aichele and Felbermayr (2013) obtain that higher fuel prices and a cleaner energy mix can be observed in countries that signed Kyoto. We include in addition to the environmental policy variable (instrumented) fossil fuel rents as a share of GDP and (instrumented) trade openness as independent variables.

Our results are provided in Table 2. The first row establishes a substantial negative effect of income on emission intensity. The efficiency improvement, however, does not catch up with income since the elasticity is significantly smaller than one in absolute value. Thus, overall emissions robustly increase with income. The second-order effect of income is small in size; there is no substantial Environmental Kuznets Curve.

We find that coal-abundance substantially increases emission intensity. A one percentage point increase in coal rents, as a share of income, increases the emission intensity of value added and exports by about 4%. For oil, evidence is weaker, but still significant for bilateral exports. For natural gas, we find a small negative effect: gas abundant countries tend to become less emission-intensive in years of high gas prices. That is, the results reflect the relative carbon-intensity of fuels, with gas being less carbon intensive than oil and oil being less carbon intensive than coal. Table 8 in the appendix confirms these findings for unweighted estimates. Some robustness tests, not presented in the main text but in the Appendix 3, however show a sign reversal for some fossil fuel coefficients dependent on the sample. We thus cannot rule out sample selection bias, and interpret the finding as weak evidence.

Table 6 in the appendix shows the first-stage for estimations (16) and (17) in Table 2. We see that the instruments are informative, and that supply of coal tends to increase almost proportionally with income, so that the rent share of coal tends to slightly decrease with income. The finding suggests that coal supply is mainly driven by domestic demand. Oil rents, on the other hand, are almost independent of income, suggesting that oil supply is not much related to domestic demand. Natural gas is somewhere between coal and oil. For trade and climate policies, we obtain mixed evidence. The results for value added and trade are sometimes reversed, and also for weighted versus unweighted estimates, we find a reversal of signs (compare Table 8 in the appendix with Table 2 in the main text). The results suggest that large countries increase the emission intensities with trade and that Kyoto ratification has not reduced the emission intensity, while for small countries (the unweighted estimate), both trade and ratification are correlated to decreasing emission

intensities. We also find a reversal of the coefficient if we substitute Sauter's CO2 stringency index for the Kyoto index, see Table 10 and Table 11 in the appendix.⁸

Table 2. Effects on emissions per value added and output, controlling for sector structure

Dependent variable	EIVA	EID	EI exports	EI exports
Equation number	(16)	(17)	(18)	(19)
ln(income)	-0.768***	-0.707***	-0.637***	-0.588***
ln(income)^2	0.001	-0.010*	-0.008	-
Rents coal	0.037*	0.027**	0.035***	0.039***
Rents oil	0.022**	0.006	0.022***	0.038***
Rents gas	-0.027*	-0.032***	-0.024***	-0.037***
Trade	0.431**	0.271***	0.077	-0.750***
Kyoto	0.050***	0.079***	0.020	-0.030***
Country FE	YES	YES	YES	YES
Partner-year FE	NO	NO	NO	YES
Sector-year FE	YES	YES	NO	NO
Year FE	NO	NO	YES	NO
Weights	YES	YES	YES	YES
N	19,430	19,861	585	11,108
R^2	0.879	0.899	0.986	0.976
R^2 within	0.087	0.125	0.718	0.613

Note: */**/***: significant at 10/5/1%. All regressions are weighted by VA, output, exports. Each rent is instrumented by its own instrument. The first stage estimations corresponding to the IV estimations are displayed in Appendix Table 6.

Subsequently, in Table 3, we consider the drivers for the composition of trade. High income countries tend to specialize in emission-intensive sectors, as exports in these sectors increase if we do not control for the trading partners (see column 20). However, imports in emission-intensive sectors also increase (21), and when controlling for the trading partner, high-income countries seem to specialize in emission-extensive sectors (22a, 23). The results are suggestive of the following pattern. High-income countries have comparative advantages in emission-extensive sectors (22a, 23), but they also trade more with other high-income partners who demand imports from emission-intensive sectors. The net effect of an income increase is then still an increase in the emission-intensity of trade, for both imports and exports. This pattern is also found for unweighted estimates (Table 9).

⁸ We have not controlled for endogeneity of the Kyoto or CO2 index.

The estimates also provide some (weak) evidence for coal abundance leading to specialization in dirty sectors, and oil and gas abundance leading to specialization in relatively clean sectors. Increased trade leads to an unambiguous increase in the share of emission-intensive sectors. Not only are the traded goods more emission intensive, compared to the average consumption good, but increased trade amplifies the difference. The result is confirmed for the unweighted estimates.

The Kyoto ratification is positively correlated with an increase in imports of emission-intensive sectors (21, both weighted and unweighted), but not when controlling for the trading partner (22b). The result suggests a shift in trading partners, following Kyoto ratification, as a potential consequence of reducing domestic emissions. But the effect on exports, controlled for trading partners, is not robust for weighted versus unweighted estimates. There might be structural differences between large and small countries.

Table 3. Effects on sector structure

Dependent variable	Exports (separate)	Imports (separate)	Bilateral exports (joint)	Bilateral imports (joint)	Bilateral exports-imports
Equation number	(20)	(21)	(22a)	(22b)	(23)
ln(income)	0.071***	0.019**	-0.034***	0.035***	-0.070***
ln(income)^2	0.006**	-0.001	-	-	-
Rents coal	-0.011*	0.004	0.022***	-0.012**	0.024***
Rents oil	0.002	-0.002	-0.005*	0.015***	-0.017***
Rents gas	0.010**	0.002	-0.014***	-0.013***	-0.002
Trade	0.105***	0.088***	0.240***	-0.288***	0.326***
Kyoto	0.000	0.011**	0.025***	-0.013**	-0.002
Country FE	YES	YES	YES	YES	JOINT
Partner FE	NO	NO	YES	YES	JOINT
Year FE	YES	YES	YES	YES	NO
Weights	YES	YES	YES	YES	YES
N	585	585	22,709	22,709	11,017
R^2	0.921	0.902	0.933	0.933	0.733
R^2 within	0.052	0.094	0.021	0.021	0.053

Note: */**/***: significant at 10/5/1%. All regressions are weighted by trade flows. Each rent is instrumented by its own instrument. The first stage estimations corresponding to the IV estimations are displayed in Appendix, Table 7.

5. Conclusion and discussion

Trade has to be taken into account when designing effective GHG mitigation policies. Global emissions are not reduced when countries export their emissions outside of a regulatory zone, nor is it desirable that domestic abatement policies are undermined by carbon-intensive imports. Thus it is crucial to have a good understanding of the trends and drivers of CO₂ embodied in trade.

We find that more carbon-intensive countries tend to specialize in carbon-intensive export sectors, suggesting that an increase in trade will tend to increase global emissions. Additionally, our findings show that more trade-exposed sectors are more emissions intensive than sheltered sectors, and that increasing trade tends to further increase the emission-intensity of traded goods. One possible mechanism underlying this positive correlation is based on fossil fuels as production factor. We find coal abundance to lead both to a specialization in 'dirty' sectors, and to increase emissions per output, when controlling for sector structure: a fossil-fuel-endowment effect.

These findings highlights the importance of considering trade, and paying due attention to fossil fuel markets, specifically coal, when designing CO₂ reduction strategies. Many of the most carbon-intensive countries are also developing economies. As their income grows, their emission intensity tends to decline, but insufficiently to reduce overall emissions. Though our analysis does not offer immediate solutions to disconnect income growth and increased trade from increased emissions, it offers some insights into the drivers, and as such, is helpful to focus the search for future effective measures.

6. References

- Aichele R. and G. Felbermayr (2012), "Kyoto and the Carbon Footprint of Nations", *JEEM*, 63, 336-354.
- Aichele R. and G. Felbermayr (2013), "The Effect of the Kyoto Protocol on Carbon Emissions", *Journal of Policy Analysis and Management*, 32(4), 731-757.
- Aichele R. and G. Felbermayr (2015), "Kyoto and Carbon Leakage: an empirical analysis of the carbon content of bilateral trade", *Review of Economics and Statistics*, 97 (1): 104-115.
- Almer C. and R. Winkler (2012), "The Effect of Kyoto Emission Targets on Domestic CO₂ Emissions: A Synthetic Control Approach", unpublished report.
- Andrew, R., Peters, G., & Lennox, J. (2009). Approximation and regional aggregation in multi-regional input-output analysis. *Economic Systems Research*, 21(3), 311–335.
- Andrew, R. M., & Peters, G. P. (2013). A Multi-Region Input-Output Table based on the Global Trade Analysis Project Database (GTAP-MRIO). *Economic Systems Research*, 25(1), 99-121. doi: 10.1080/09535314.2012.761953

- Antweiler W. (1996), "The pollution terms of trade", *Economic Systems Research*, 8(4), 361-365.
- Antweiler W., Copeland B.R. and M. S. Taylor (2001); "Is free trade good for the Environment", *American Economic Review*, 91(4), 877-908, DOI:10.1257/aer.91.4.877
- Atkinson G., Hamilton K., Ruta G. and D. van der Mensbrugghe, "Trade in 'virtual carbon': Empirical results and implications for policy", *Global Environmental Change*, 21 (2), 563-574, DOI: 10.1016/j.gloenvcha.2010.11.009
- Barrett J., Peters G., Wiedmann T., Scott K., Lenzen M., Roelich K., C. Le Quéré (2013), "Consumption-based GHG emission accounting: a UK case study", *Climate Policy*, 13 (4), 451-470, DOI: 10.1080/14693062.2013.788858.
- Brunel C. and A. Levinson (2013), "Measuring Environmental Regulatory Stringency", *OECD Trade and Environment Working Papers* 2013/05.
- Chen Z.M. and G.Q. Chen (2011), "Embodied carbon dioxide emission at supra-national scale: a coalition analysis for G7, BRIC, and the rest of the world", *Energy Policy*, 39, 2889-2909, doi:10.1016/j.enpol.2011.02.068
- Cole M.A. (2006), "Does trade liberalization increase national energy use?", *Economic Letters*, 92, 108-112, doi:10.1016/j.econlet.2006.01.018
- Cole M., R.J.R. Elliott and T. Okubo (2014), "International environmental outsourcing", *Review of World Economics*, 150, 639-664, DOI 10.1007/s10290-014-0193-6
- Collier P and B. Goderies (2012), "Commodity prices and growth: An empirical investigation", *European Economic Review*, 56: 1241-1260.
- Davis, S. J. and Caldeira, K. (2010), "Consumption-based Accounting of CO₂ Emissions", *Proceedings of the National Academy of Sciences*, 107, 5687–5692.
- Davis, S. J., Peters, G. P., and Caldeira, K. (2011): The supply chain of CO₂ emissions, *Proceedings of the National Academy of Sciences*, 108, 18554–18559, doi:10.1073/pnas.1107409108
- De Melo J. and N. A. Mathys (2010), "Trade and Climate Change: The Challenges Ahead", *CEPR DP* 8032.
- Dietzenbacher, E., Lenzen, M., Los, B., Guan, D., Lahr, M. L., Sancho, F., Yang, C. (2013). Input-Output Analysis: The Next 25 Years. *Economic Systems Research*, 25(4), 369-389. doi: 10.1080/09535314.2013.846902
- Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., & de Vries, G. (2013). The Construction of World Input-Output Tables in the WIOD Project. *Economic Systems Research*, 25(1), 71-98. doi: 10.1080/09535314.2012.761180
- Dietzenbacher E., Pei J. and C. Yang (2012), "Trade, production fragmentation, and China's carbon dioxide emissions", *JEEM*, 64(1), 88-101, DOI: 10.1016/j.jeem.2011.12.003

- Dietzenbacher E. and K. Mukhopadhyay (2007), "An Empirical Examination of the Pollution Haven Hypothesis for India: Towards a green Leontief Paradox?", *Environmental and Resource Economics*, 36, 427-449, DOI 10.1007/s10640-006-9036-9
- Douglas S. and S. Nishioka (2012), "International differences in emission intensity and emission content of global trade", *Journal of Development Economics*, 99(2), 415-427, DOI: 10.1016/j.jdeveco.2012.05.003
- Frankel J.A. and A. K. Rose (2005), "Is Trade Good or Bad for the Environment? Sorting out the Causality", *Review of Economics and Statistics*, 87(1), 85-91, DOI:10.1162/0034653053327577
- Geschke, A., Wood, R., Kanemoto, K., Lenzen, M., & Moran, D. (2014). INVESTIGATING ALTERNATIVE APPROACHES TO HARMONISE MULTI-REGIONAL INPUT-OUTPUT DATA. *Economic Systems Research*, 26(3), 354-385. doi: 10.1080/09535314.2014.937069
- Gerlagh R., Mathys N.A. and Th. O. Michielsen (2015), "Energy abundance, trade and industry specialisation", *Energy Journal*, 36 (3), dx.doi.org/10.5547/01956574.36.3.rger.
- Grether J.-M. and N. A. Mathys (2013), "The pollution terms of trade and its five components", *Journal of Development Economics*, 100(1), 19-31, DOI: 10.1016/j.jdeveco.2012.06.007
- Grether J.-M., Hotz I. and N.A. Mathys (2014), "Industry location in Chinese provinces: does energy abundance matter?", *Energy Economics*, 44, 383-391, DOI: 10.1016/j.eneco.2014.05.005
- Grether, J.M., Mathys, N.A., de Melo, J. (2012), "Unraveling the worldwide pollution haven Effect", *Journal of International Trade and Economic Development* 21 (1), 131-162.
- Grossman, G.M. and A.B. Krueger (1993), *Environmental Impacts of a North American Free Trade Agreement*. In "The Mexico-U.S. free trade agreement", P. Garber, ed. Cambridge, Mass.: MIT Press.
- GTAP. (2012). GTAP 8 Data Base. West Lafayette, IN, USA: Department of Agricultural Economics, Purdue University.
- Hertwich E.G. and G.P. Peters (2009), "Carbon footprint of nations: a global, trade-linked analysis", *Environmental Science & Technology*, 43 (16), 6414-6420.
- Holzman, M. (1953). Problems of classification and aggregation. In W. Leontief, H. B. Chenery, P. G. Clark, J. S. Duesenberry, A. R. Ferguson, A. P. Grosse, R. N. Grosse, M. Holzman, W. Isard & H. Kistin (Eds.), *Studies in the Structure of the American Economy* (pp. 326-359). New York, NY, USA: Oxford University Press.
- Jakob M. and R. Marschinski (2013), "Interpreting trade-related CO2 emission transfers", *Nature Climate Change*, 3, 19-23.

- Jakob M., Marschinski R. and M. Hübler (2013) "Between a rock and a hard place: a trade-theory analysis of leakage under production- and consumption-based policies", *Environmental and Resource Economics*, 56, 47-72.
- Johnson, R.C., Noguera, G., 2012. « Accounting for intermediates: production sharing and trade in value added." *Journal of International Economics* 86 (2), 224–236.
- Kanemoto, K., Moran, D., Lenzen, M., & Geschke, A. (2014). International trade undermines national emission reduction targets: New evidence from air pollution. *Global Environmental Change*, 24(0), 52-59. doi: <http://dx.doi.org/10.1016/j.gloenvcha.2013.09.008>
- Li Y. and C.N. Hewitt (2008), "The effect of trade between China and the UK on the national global carbon dioxide emissions", *Energy Policy*, 36(6), 1907-1914, DOI: 10.1016/j.enpol.2008.02.005
- Liu X., Ishikawa M., Wang C., Dong Y., W. Liu (2010), "Analyses of CO2-emissions embodied in Japan-China trade", *Energy Policy*, 38(3), 1510-1518, DOI: 10.1016/j.enpol.2009.11.034
- Lopez L. A., Arce G. and J. E. Zafrilla (2013), "Parcelling virtual carbon in the pollution haven hypothesis", *Energy Economics*, 39, 177-186, DOI: 10.1016/j.eneco.2013.05.006
- Kander, Astrid, Magnus Jiborn, Daniel D. Moran, and Thomas O. Wiedmann (2015) "National Greenhouse-Gas Accounting for Effective Climate Policy on International Trade." *Nature Clim. Change*. Online before print. doi:10.1038/nclimate2555.
- Kanemoto, Keiichiro, Daniel D. Moran, Manfred Lenzen, and Arne Geschke. "International Trade Undermines National Emission Reduction Targets: New Evidence from Air Pollution." *Global Environmental Change*, 2013. doi:10.1016/j.gloenvcha.2013.09.008.
- Lenzen, M. (2011). Aggregation versus disaggregation in input-output analysis of the environment. *Economic Systems Research*, 23(1), 73-89. doi: 10.1080/09535314.2010.548793
- Lenzen, M., Geschke, A., Wiedmann, T., Lane, J., Anderson, N., Baynes, T., . . . West, J. (2014). Compiling and using input-output frameworks through collaborative virtual laboratories. *Science of the Total Environment*, 485–486(0), 241-251. doi: <http://dx.doi.org/10.1016/j.scitotenv.2014.03.062>
- Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012). Mapping the structure of the world economy. *Environmental Science & Technology*, 46(15), 8374–8381. doi: 10.1021/es300171x
- Lenzen, M., Moran, D. D., Bhaduri, A., Kanemoto, K., Bekchanov, M., Geschke, A., & Foran, B. (2013). International Trade of Scarce Water. *Ecological Economics*, 94, 78-85. doi: DOI: 10.1016/j.ecolecon.2013.06.018

- Lenzen, M., Moran, D. D., Kanemoto, K., & Geschke, A. (2013). Building Eora: a Global Multi-Region Input-Output Database at High Country and Sector Resolution. *Economic Systems Research*, 25(1), 20-49. doi: 10.1080/09535314.2013.769938
- Managi S., Hibiki A. and T. Tsurumi (2009), "Does trade openness improve environmental quality?", *JEEM*, 58(3), 346-363, DOI: 10.1016/j.jeem.2009.04.008
- Michielsen T.O. (2013) "The distribution of energy intensive sectors in the USA", *Journal of Economic Geography*, 13, 871-888, doi:10.1093/jeg/lbs045
- Minx J.C., Baiocchi P., Peters G.P., Weber C.L., Guan D. and K. Hubacek (2011), "A "Carbonizing Dragon": China's fast growing CO2 emissions revisited" *Environmental Science and Technology*, 45(11), 9144-9153.
- Moran, D., & Wood, R. (2014). Convergence between The Eora, WIOD, EXIOBASE, and OPENEU's Consumption-Based Carbon Accounts. *Economic Systems Research*, 26(3), 245-261. doi: 10.1080/09535314.2014.935298
- Moran, D. D., McBain, D., Kanemoto, K., Lenzen, M., & Geschke, A. (2014). Global Supply Chains of Coltan: A Hybrid Life Cycle Assessment Study Using a Social Indicator. *Journal of Industrial Ecology*, Online before print. doi: 10.1111/jiec.12206
- Muradian R. O'Connor and J. Martinez-Allier (2002), "Embodied pollution in trade: estimating the "environmental load displacement" of industrialised countries", *Ecological Economics*, 41, 51-67.
- Owen A., Steen-Olsen K., Barrett J., Wiedmann T. and M. Lenzen (2014), "A structural decomposition approach to comparing MRIO databases", *Economic Systems Research*, 26(3), 262-283, DOI: 10.1080/09535314.2014.935299
- Peters G. P. and E.G. Hertwich (2007), "CO2 embodied in international trade with implications for global climate policy", *Environmental Science and Technology*, 42(5), 1401-1407.
- Peters G. P., J. Minx, C. Weber, and O Edenhofer (2011), "Growth in emission transfers via international trade from 1990 to 2008 ", *Proceedings of the National Academy of Sciences*, 108(21), 8903-8908, DOI: 10.1073/pnas.1006388108
- Peters, G. P., Davis, S. J., and Andrew, R. (2012): A synthesis of carbon in international trade, *Biogeosciences*, 9, 3247-3276, doi:10.5194/bg-9-3247-2012
- Sato M., A. Dechezleprêtre (2015), Asymmetric industrial energy prices and international trade, Grantham working paper.
- Sato M. (2013), "Embodied carbon in trade: a survey of the empirical literature", *Journal of Economic Surveys*, 00(0), 1-31, DOI: 10.1111/joes.12027
- Sauter C. (2014), "How should we measure environmental policy stringency? A new approach", working paper, University of Neuchâtel.
- Shui B. and R. C. Harriss (2006), "The role of CO2 embodiment in US-China trade", *Energy Policy*, 34(18), 4063-4068, DOI: 10.1016/j.enpol.2005.09.010

- Simas, M., Wood, R., & Hertwich, E. (2014). Labor Embodied in Trade. *Journal of Industrial Ecology*, n/a-n/a. doi: 10.1111/jiec.12187
- Steen-Olsen K, Owen A, Hertwich E.G. and M. Lenzen (2014), "Effects of sector aggregation on CO2 multipliers in multiregional input-output analysis", *Economic System Research*, 26(3), 284-302, DOI: 10.1080/09535314.2014.934325
- Su, B., Huang, H. C., Ang, B. W., & Zhou, P. (2010). Input-output analysis of CO2 emissions embodied in trade: The effects of sector aggregation. *Energy Economics*, 32(1), 166-175. doi: doi:10.1016/j.eneco.2009.07.010
- Timmer, M. (2012). The World Input-Output Database (WIOD): Contents, Sources and Methods. Online at <http://www.wiod.org/publications/papers/wiod10.pdf>. WIOD Working Paper.
- Trefler, D., Zhu, S., 2010. The structure of factor content predictions. *Journal of International Economics* 82, 195–207.
- Tukker, A., de Koning, A., Wood, R., Hawkins, T., Lutter, S., Acosta, J., Kuenen, J. (2013). EXIOPOL – Development And Illustrative Analyses Of a Detailed Global MR EE SUT/IOT. *Economic Systems Research*, 25(1), 50-70. doi: 10.1080/09535314.2012.761952
- Tukker, A., & Dietzenbacher, E. (2013). Global Multiregional Input-Output Frameworks: An Introduction and Outlook. *Economic Systems Research*, 25(1), 1-19. doi: 10.1080/09535314.2012.761179
- Victor D.G., R. Gerlagh, and G. Baiocchi (2014), "Getting serious about categorizing countries", *Science* 345: 34-36.
- Wiebe K. S., Bruckner M., Guljim S. and Ch. Lutz (2012), "Calculating energy related co2-emissions embodied in international trade using global input-ouput model", *Economic System Research*, 24(2), 113-139, DOI:10.1080/09535314.2011.643293
- Wiedmann, Th., Wilting H.C., Lenzen M., Lutter St. and V. Palm (2011), "Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input-output analysis" *Ecological Economics*, 70(11), 1937-1945
- World Bank Development Indicators, World Bank, accessed on september 13rd 2015.
- Xu M. and E. Dietzenbacher (2014), "A structural decomposition analysis of the emissions embodied in trade", *Ecological Economics*, 101, 10-20, DOI: 10.1016/j.ecolecon.2014.02.015
- Xu M., Li R., Crittenden J. C. and Y. Chen (2011), "CO2 emissions embodied in Cina's exports from 2002 to 2008: a structural decomposition analysis", *Energy Policy*, 39(11), 7381-7388, DOI: 10.1016/j.enpol.2011.08.068
- Zhang Y. (2012), "Scale, Technique and Composition Effects in Trade-Related Carbon Emissions in China", *Environmental and Resource Economics*, 51, 371-389, DOI 10.1007/s10640-011-9503-9

Zhou, X., Shirakawa, H., & Lenzen, M. (2012). Aggregation effect in environmentally extended multi-region input-output analysis. In T. Yu, N. Chawla & S. Simoff (Eds.), *Computationally Intelligent Data Analysis for Sustainable Development*: Taylor & Francis.

7. Appendix 1. Data Description

Table 4: Country list (WIOD)

#	Country	Country code
1	AUS	Australia
2	AUT	Austria
3	BEL	Belgium
4	BRA	Brazil
5	BGR	Bulgaria
6	CAN	Canada
7	CHN	China
8	CYP	Cyprus
9	CZE	Czech Republic
10	DNK	Denmark
11	EST	Estonia
12	FIN	Finland
13	FRA	France
14	DEU	Germany
15	GRC	Greece
16	HUN	Hungary
17	IND	India
18	IDN	Indonesia
19	IRL	Ireland
20	ITA	Italy
21	JPN	Japan
22	LVA	Latvia
23	LTU	Lithuania
24	LUX	Luxembourg
25	MLT	Malta
26	MEX	Mexico
27	NLD	Netherlands
28	POL	Poland
29	PRT	Portugal
30	ROM	Romania
31	RUS	Russia
32	SVK	Slovakia
33	SVN	Slovenia
34	KOR	South Korea
35	ESP	Spain
36	ROW	Rest of World
37	SWE	Sweden
38	TWN	Taiwan
39	TUR	Turkey
40	GBR	UK
41	USA	USA

Table 5: WIOD sector list

#	Sector code	Sector
1	AGR	Agriculture, Hunting, Forestry and Fishing
2	AIR	Air Transport
3	MTL	Basic Metals and Fabricated Metal
4	CHM	Chemicals and Chemical Products
5	PTR	Coke, Refined Petroleum and Nuclear Fuel
6	CSTR	Construction
7	EDU	Education
8	ELEQ	Electrical and Optical Equipment
9	ELCT	Electricity, Gas and Water Supply
10	FINC	Financial Intermediation
11	FOOD	Food, Beverages and Tobacco
12	HLTH	Health and Social Work
13	HTLS	Hotels and Restaurants
14	LND	Inland Transport
15	LTHR	Leather, Leather and Footwear
16	MCHN	Machinery, Nec
17	MFG	Manufacturing, Nec; Recycling
18	MNS	Mining and Quarrying
19	OSRV	Other Community, Social and Personal Services
20	MRLS	Other Non-Metallic Mineral
21	OTRS	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies
22	PST	Post and Telecommunications
23	HHLD	Private Households with Employed Persons
24	GVT	Public Admin and Defence; Compulsory Social Security
25	PAP	Pulp, Paper, Paper , Printing and Publishing
26	ESTA	Real Estate Activities
27	LSNG	Renting of M&Eq and Other Business Activities
28	RTL	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods
29	PLST	Rubber and Plastics
30	VHCS	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel
31	CLTH	Textiles and Textile Products
32	VHCL	Transport Equipment
33	WTR	Water Transport
34	TRD	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles
35	WOOD	Wood and Products of Wood and Cork

8. Appendix 2. First stage results

The next two tables present the first stages associated with Table 2 and Table 3

Table 6. First stage estimations, related to equation (16) in Table 2

Dependent variable	Rents coal	Rents oil	Rents gas	Trade
--------------------	------------	-----------	-----------	-------

ln(income)	0.042***	-1.362***	-0.870***	-0.066***
ln(income)^2	-0.018***	0.174***	0.001	-0.039***
Coal $s_c \times R_t$	0.518***	-	-	-
Oil $s_c \times R_t$	-	0.838***	-	-
Gas $s_c \times R_t$	-	-	0.687***	-
Trade $s_c \times R_t$	-	-	-	0.877***
Kyoto	0.023***	0.110***	-0.090***	-0.005***
Country FE	YES	YES	YES	YES
Partner-year FE	NO	NO	NO	NO
Sector-year FE	YES	YES	YES	YES
Year FE	NO	NO	NO	NO
Weights	YES	YES	YES	YES
N	19,430	19,430	19,430	19,430
R^2	0.963	0.960	0.927	0.975
R^2 within	0.930	0.607	0.428	0.384

Note: */**/***: significant at 10/5/1%.

Table 7. First stage estimations, related to equation (20) in Table 3

Dependent variable	Rents coal	Rents oil	Rents gas	Trade
ln(income)	0.045*	-1.368***	-0.911***	-0.092***
ln(income)^2	-0.030***	0.219***	-0.017	-0.047***
Coal $s_c \times R_t$	0.509***	-	-	-
Oil $s_c \times R_t$	-	0.845***	-	-
Gas $s_c \times R_t$	-	-	0.677***	-
Trade $s_c \times R_t$	-	-	-	1.051***
Kyoto	0.041**	-0.012	-0.109	-0.009
Country FE	YES	YES	YES	YES
Partner FE	NO	NO	NO	NO
Year FE	YES	YES	YES	YES
Weights	YES	YES	YES	YES
N	585	585	585	585
R^2	0.966	0.961	0.926	0.975
R^2 within	0.941	0.625	0.427	0.382

Note: */**/***: significant at 10/5/1%.

9. Appendix 3. Robustness

The next two tables present the equivalents for Table 2 and Table 3, but not using weighted estimates, but using unweighted estimations leaving out the smallest observations.

Table 8. Effects on emissions per value added and output, controlling for sector structure, excluding smallest observations (unweighted)

Dependent variable	EIVA	EID	EI exports	EI exports
Equation number	(16)	(17)	(18)	(19)
ln(income)	-0.862***	-0.839***	-0.742***	-0.732***
ln(income)^2	-0.008	0.009*	0.000	-
Rents coal	0.080**	0.071***	0.041**	0.061***
Rents oil	0.023	0.021***	0.036***	0.059***
Rents gas	-0.010	-0.027***	-0.028***	-0.028***
Trade	-0.220	-0.066	-0.137***	-0.386***
Kyoto	-0.060*	-0.042***	-0.035*	-0.030**
Country FE	YES	YES	YES	YES
Partner-year FE	NO	NO	NO	YES

Sector-year FE	YES	YES	NO	NO
Year FE	NO	NO	YES	NO
Weights	NO	NO	NO	NO
N	14,602	14,760	420	8,070
R ²	0.818	0.889	0.980	0.958
R ² within	0.032	0.129	0.688	0.357

Note: */**/***: significant at 10/5/1%. All regressions are unweighted but the smallest 25% observations are removed. Rents are instrumented.

Table 9. Effects on sector structure, excluding smallest observations (unweighted)

Dependent variable	Exports (separate)	Imports (separate)	Bilateral exports (joint)	Bilateral imports (joint)	Bilateral exports-imports
Equation number	(20)	(21)	(22a)	(22b)	(23)
ln(income)	0.071***	0.044***	-0.111***	-0.050***	-0.072***
ln(income) ²	0.002	-0.008***	-	-	-
Rents coal	0.015	-0.000	0.015**	-0.008	0.024***
Rents oil	0.004	-0.007**	-0.013***	0.001	-0.012***
Rents gas	0.004	0.006*	-0.003	-0.005	-0.001
Trade	0.190***	-0.057	0.287***	-0.136***	0.409***
Kyoto	0.014	0.021***	-0.021***	-0.004	-0.018***
Country FE	YES	YES	YES	YES	JOINT
Partner FE	NO	NO	YES	YES	JOINT
Year FE	YES	YES	YES	YES	NO
Weights	NO	NO	NO	NO	NO
N	420	420	16,815	16,815	8,070
R ²	0.932	0.909	0.625	0.625	0.669
R ² within	0.163	0.083	0.024	0.024	0.047

Note: */**/***: significant at 10/5/1%. All regressions are unweighted, but the smallest 25% observations are removed. Rents are instrumented.

The next two tables provide a robustness test for Table 2. In Table 10, we substitute Sauter's CO2 index for the Kyoto index used in the main text, but we note that Sauter's index is not available for major economies (US, China, Brazil and Indonesia). Therefore, we repeat the estimates from Table 2 for the restricted country sample in Table 11. We find that the change in country sample affects the Kyoto coefficients significantly. This is in line with the findings presented in Table 8, where major economies also received equal weight as small economies. As Sauter's index as the country sample is not representative. We repeat the estimates from Table 3 in Table 12, using Sauter's index, and in Table 13 for the same restricted sample but with the Kyoto index.

Table 10. Effects on emissions per value added and output, controlling for sector structure, using CO2 index instead of Kyoto

Dependent variable Equation number	EIVA (16)	EID (17)	EI exports (18)	EI exports (19)
ln(income)	-0.766***	-0.788***	-0.747***	-0.729***
ln(income)^2	-0.023*	-0.002	0.021***	-
Rents coal	0.004	0.004	0.054**	0.023*
Rents oil	0.007	0.003	0.016***	0.026***
Rents gas	-0.011	-0.017**	-0.012*	-0.025***
Trade	-0.260	-0.140	-0.093	-0.420***
CO2 index	0.238***	-0.008	-0.010	0.069***
Country FE	YES	YES	YES	YES
Partner-year FE	NO	NO	NO	YES
Sector-year FE	YES	YES	NO	NO
Year FE	NO	NO	YES	NO
Weights	YES	YES	YES	YES
N	17,420	17,851	525	8,922
R^2	0.852	0.889	0.985	0.972
R^2 within	0.145	0.214	0.766	0.668

Table 11. Effects on emissions per value added and output, controlling for sector structure, using Kyoto but same sample as if CO2 index was used

Dependent variable Equation number	EIVA (16)	EID (17)	EI exports (18)	EI exports (19)
ln(income)	-0.741***	-0.794***	-0.751***	-0.720***
ln(income)^2	-0.017	-0.001	0.023***	-
Rents coal	0.001	0.011	0.063**	0.017
Rents oil	0.008	0.004	0.018***	0.023***
Rents gas	-0.014	-0.017**	-0.013**	-0.025***
Trade	-0.265	-0.142	-0.087	-0.416***
Kyoto	-0.095***	-0.077***	-0.064***	-0.053***
Country FE	YES	YES	YES	YES
Partner-year FE	NO	NO	NO	YES
Sector-year FE	YES	YES	NO	NO
Year FE	NO	NO	YES	NO
Weights	YES	YES	YES	YES
N	17,420	17,851	525	8,922
R^2	0.852	0.889	0.986	0.972
R^2 within	0.145	0.216	0.773	0.668

Table 12. Effects on sector structure, using CO2 index instead of Kyoto

Dependent variable	Exports (separate)	Imports (separate)	Bilateral exports (joint)	Bilateral imports (joint)	Bilateral exports-imports
Equation number	(20)	(21)	(22a)	(22b)	(23)
ln(income)	0.113***	0.043***	-0.048***	0.013	-0.056***
ln(income)^2	0.002	-0.003	-	-	-
Rents coal	0.071***	0.022*	-0.026*	0.001	-0.044***
Rents oil	-0.004	-0.005*	-0.018***	0.014***	-0.028***
Rents gas	0.006	0.003	0.009**	-0.016***	0.018***
Trade	0.111***	0.060*	0.190***	-0.226***	0.270***
CO2 index	-0.088***	-0.043**	0.052**	-0.033	0.120***
Country FE	YES	YES	YES	YES	JOINT
Partner FE	NO	NO	YES	YES	JOINT
Year FE	YES	YES	YES	YES	NO
Weights	YES	YES	YES	YES	YES
N	525	525	18,309	18,309	8,864
R^2	0.906	0.905	0.911	0.911	0.727
R^2 within	0.175	0.063	0.078	0.078	0.110

Table 13. Effects on sector structure, using Kyoto but same sample as if CO2 index was used

Dependent variable	Exports (separate)	Imports (separate)	Bilateral exports (joint)	Bilateral imports (joint)	Bilateral exports-imports
Equation number	(20)	(21)	(22a)	(22b)	(23)
ln(income)	0.104***	0.039***	-0.043***	0.012	-0.048***
ln(income)^2	0.002	-0.003	-	-	-
Rents coal	0.076***	0.023*	-0.028*	0.004	-0.050***
Rents oil	-0.003	-0.005*	-0.018***	0.014***	-0.028***
Rents gas	0.006	0.004	0.008*	-0.016***	0.017***
Trade	0.110***	0.061**	0.186***	-0.218***	0.259***
Kyoto	0.007	0.018**	-0.013	-0.026***	0.004
Country FE	YES	YES	YES	YES	JOINT
Partner FE	NO	NO	YES	YES	JOINT
Year FE	YES	YES	YES	YES	NO
Weights	YES	YES	YES	YES	YES
N	525	525	18,309	18,309	8,864
R^2	0.904	0.905	0.912	0.912	0.725
R^2 within	0.161	0.064	0.084	0.084	0.103