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What Accounts for the Growth of Carbon Dioxide Emissions in Advanced and Emerging Economies? The Role of Consumption, Technology and Global Supply Chain Participation

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ABSTRACT

This paper examines the driving forces behind the growth in carbon dioxide emissions in forty advanced and emerging economies between 1995 and 2008. We use the global supply chain concept introduced in Timmer et al. (2014) to measure CO₂ emissions in internationally fragmented production networks and embed the concept in structural decomposition analysis. Our findings suggest that rising levels of domestic consumption are related to increased carbon dioxide emissions in both advanced and emerging economies. A substantial share of CO₂ emissions growth in emerging economies is accounted for by increased participation in global supply chains. However, even for countries that rapidly integrated in global production networks, such as China, rising domestic consumption accounts for the majority of territorial emissions.

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1. Introduction

Carbon dioxide (CO₂) atmospheric emissions from the burning of fossil fuels are considered the main anthropogenic cause of global warming (IPCC, 2014). Notwithstanding a temporary slowdown due to the 2007–08 financial crisis, carbon dioxide emissions expanded three times faster in the 2000s compared to the 1990s. As a result, world average annual per capita CO₂ emission levels increased to nearly 5 metric tons in 2010, up from about 4 metric tons in the 1990s (World Bank, 2015). International negotiations to reduce global emissions, such as those under the aegis of the United Nations Framework Convention on Climate Change, focus mainly on territorial emissions of greenhouse gasses. It has long been argued that such a territorial account of emissions should adjust for the consumption of imported goods and transfer the corresponding emissions responsibility to the consumer (Wiedmann, 2009; Kander et al., 2015).

As a result of the growth in trade, the amount of trade-embodied CO₂ and other greenhouse gasses has increased substantially (Davis and Caldeira, 2010; Davis et al., 2011; Peters et al., 2011; Xu and Dietzenbacher, 2014). Yet, attributing responsibility for emissions that arise from the consumption of goods that are produced abroad is sensitive to the aggregation level of the data used in empirical analysis

(Lenzen et al., 2004; Steen-Olsen et al., 2014; de Koning et al., 2015). In addition, rapidly falling communication and coordination costs have given rise to an intricate network of global supply chains and concomitant intermediates trade (Johnson and Noguera, 2012; Ferrarini and Hummels, 2014; Timmer et al., 2014). As a result, consumption of a product in country *i* that is purchased from country *j* may lead to emissions in other countries that are involved further upstream in the production network.

This paper uses the Global Supply Chain (GSC) concept developed in Timmer et al. (2014) to measure the CO₂ emissions in internationally fragmented production networks. We identify global supply chains by the country and industry where the last stage of a good's production takes place prior to delivery to the final user. The global supply chain comprises all the value added and related CO₂ emissions that directly or indirectly contribute to the final product.

Next, we apply structural decomposition analysis, which is a commonly used method to assess for the drivers of changes in emissions and material use (see e.g. de Haan, 2001; Guan et al., 2008; Xu and Dietzenbacher, 2014; Arto and Dietzenbacher, 2014). What sets our method apart from previous approaches is its incorporation of the GSC concept. This gives rise to three dimensions along which changes in a country's CO₂ emission levels are accounted for: (i) variations in a country's degree of participation in GSCs; (ii) changes to the CO₂ efficiency within the supply chains it is part of; and (iii) shifts in the level of consumption or its composition (e.g. toward different types of goods).

The basis of our analysis is the World Input-Output Database (WIOD), which tracks goods and services from conception through

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the different phases of production, all the way to the final consumers (Timmer et al., 2015). Compared to other multi-regional input-output data that have recently become available, such as the EXIOBASE (Tukker et al., 2013), the WIOD offers a more limited breakdown of industries and products. For some product groups, this may result in an inaccurate estimation of the CO₂ emissions they embody (Steen-Olsen et al., 2014). However, WIOD offers the advantage of availability of previous years' price tables, which we need for the application of structural decomposition analysis.¹

This paper proceeds as follows: Section 2 presents the production and consumption accounts of carbon dioxide emissions by regions and economies and along the global supply chains. Section 3 describes the structural decomposition method and presents results on the drivers of changes in countries' CO₂ emissions. Section 4 provides concluding remarks.

2. Production, consumption and trade related CO₂ flows in global supply chains

This section first describes the data and introduces the main formulae. Second, we analyze CO₂ emissions from production, consumption and net trade flows. Third, we introduce and illustrate the concept of global supply chains. This serves as an introduction and building block for the decomposition in the next section to examine the drivers of change in CO₂ emissions.

The World Input-Output Database provides World Input-Output Tables (WIOTs) from 1995 onwards. It covers 40 economies, including all 27 members of the EU (per January 2007) and 13 other major economies: Australia, Brazil, Canada, (People's Republic of) China, India, Indonesia, Japan, Mexico, Russia, (Republic of) Korea, Taipei-China, Turkey and the USA. These economies were chosen by considering both the requirement of data availability of sufficient quality and the desire to cover a major part of the world economy. Together, the economies cover more than 85% of world GDP in 2008, at current exchange rates. In addition, a model for the remaining non-covered part of the world economy is estimated, called the 'Rest of the World' region.² The WIOTs have an industry by industry format. They provide details for 35 industries mostly at the two-digit ISIC rev. 3 level or groups thereof, covering the overall economy (the industries distinguished are shown in Appendix Table A1). The WIOTs are built up from published and publicly available statistics from national statistical institutes around the world, plus various international statistical sources such as OECD and UN National Accounts, UN Comtrade and IMF trade statistics (see Timmer et al., 2015 for an overview of the content, concepts, and sources). The environmental accounts of the World Input-Output Database provide annual country-sector specific data on CO₂ emissions. The IO coefficients for the RoW in the WIOTs are estimated by assuming an 'average developing country', calculated as the weighted average share of Brazil, Russia, India, China, Indonesia and Mexico. The data and methods for estimating CO₂ emissions per sector in the RoW were similar to that for non-UNFCCC reporting countries, such as China and India, using corresponding default values provided by the IPCC guidelines (see Genty et al., 2012 for further information). All data used in this paper is publicly available at www.wiod.org.

¹ Eora (Lenzen et al., 2013) also provides multi-regional input-output tables in previous years' prices. However, Eora relies on imputation methods to fill up blanks or unreliable data for countries with less well-developed statistics. WIOD has been constructed using a conceptual framework based on the system of national accounts (Timmer et al., 2015).

² Subsuming all but 40 countries singled out in WIOD, the Rest of the World (RoW) aggregate is highly heterogeneous. It includes natural resource-rich countries, such as Nigeria, Saudi Arabia and Venezuela, which are important providers of agriculture and/or mining products. It also includes countries with an entirely different profile and prominent in the Asian production networks, such as Malaysia, the Philippines and Thailand. Disaggregating many of the countries currently lumped into the RoW aggregate remains a key challenge for multi-region input-output tables in future work (Stadler et al., 2014).

We briefly introduce notation and the derivation of production and consumption accounts (see Peters (2008) for a detailed exposition). Let $g = 1, \dots, G$ index the 35 industries, and let i and $j = 1, \dots, N$ index the 40 countries plus the RoW region distinguished in the WIOTs. Let $\mathbf{f}$ be the $GN \times 1$ vector of CO₂ emissions from each country-industry with typical element, $f_i(g)$, the CO₂ emissions per unit of gross output of industry g in country i .³ Although we will apply annual data in our empirical analysis, time subscripts are left out of the equations for ease of exposition.

Output from an industry is either consumed as a final product and/or used as an intermediate input. Denote $\mathbf{c}_{ij}$ a $G \times 1$ vector with country j 's consumption of goods produced in country i . Consumption is broadly defined to include private and public consumption, as well as investment (i.e. final demand in input-output parlance). Also, let $\mathbf{z}_{ij}$ be a $G \times 1$ vector denoting country j 's usage of intermediate inputs from country i . The $G \times 1$ vector of output $\mathbf{y}_i$ from country i is split between consumption and intermediate inputs:

$$\mathbf{y}_i = \sum_j (\mathbf{c}_{ij} + \mathbf{z}_{ij}) \quad (1)$$

Next, let $a_{ij}(g,h) = z_{ij}(g,h)/y_j(h)$ be the amount of intermediate input g used to produce one unit of good h , where g is produced in country i and h is made in country j . Products can be used domestically (in case $i = j$) or abroad ($i \neq j$). Hence, $\mathbf{A}_{ij}$ is the $G \times G$ matrix with typical element $a_{ij}(g,h)$. At the heart of the global input-output model is the matrix $\mathbf{A}$ with dimensions $GN \times GN$ that tracks the movement of intermediate inputs across countries and industries:

$$\mathbf{A} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1N} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{N1} & \mathbf{A}_{N2} & \cdots & \mathbf{A}_{NN} \end{bmatrix}$$

The diagonal sub-matrices track the requirements for domestic intermediate inputs, while the off-diagonal elements track the requirements for foreign intermediate inputs. The matrix $\mathbf{A}$ summarizes the flows of all intermediate goods and using this we can rewrite the stacked market clearing conditions from Eq. (1) as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_N \end{bmatrix} = \begin{bmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1N} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{N1} & \mathbf{A}_{N2} & \cdots & \mathbf{A}_{NN} \end{bmatrix} \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_N \end{bmatrix} + \begin{bmatrix} \mathbf{c}_{11} & \mathbf{c}_{12} & \cdots & \mathbf{c}_{1N} \\ \mathbf{c}_{21} & \mathbf{c}_{22} & \cdots & \mathbf{c}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{c}_{N1} & \mathbf{c}_{N2} & \cdots & \mathbf{c}_{NN} \end{bmatrix} \quad (2)$$

Below the following will be useful:

$$\mathbf{C} \equiv \begin{bmatrix} \mathbf{c}_{11} & \mathbf{c}_{12} & \cdots & \mathbf{c}_{1N} \\ \mathbf{c}_{21} & \mathbf{c}_{22} & \cdots & \mathbf{c}_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{c}_{N1} & \mathbf{c}_{N2} & \cdots & \mathbf{c}_{NN} \end{bmatrix}, \text{ and } \mathbf{y} \equiv \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_N \end{bmatrix}$$

Rearranging Eq. (2) we arrive at the fundamental input-output identity introduced by Leontief (1949):

$$\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{C} \mathbf{u}, \quad (3)$$

where $\mathbf{I}$ is a $GN \times GN$ identity matrix with ones on the diagonal and zeros elsewhere, and $\mathbf{u}$ is a $N \times 1$ vector of ones that sums the rows of matrix $\mathbf{C}$. $(\mathbf{I} - \mathbf{A})^{-1}$ is famously known as the Leontief inverse. It

³ Matrices are indicated by boldfaced capital letters (e.g. $\mathbf{A}$), vectors are columns by definition and are indicated by boldfaced lowercase letters (e.g. $\mathbf{f}$), and scalars (including elements of matrices or vectors) are indicated by italicized letters (e.g. $CO_2^{consumption}$). A prime indicates transposition (e.g. $\mathbf{f}'$). The notation $\text{diag}(\mathbf{f})$, indicates a matrix with the elements of the vector $\mathbf{f}$ on the main diagonal.

represents the total production values in all stages of production that are generated in the production process of one unit of consumption

Pre-multiplying Eq. (3) with the CO₂ vector of emission coefficients $\mathbf{f}$ gives the CO₂ emissions from *production* in country i :

$$CO_{2i}^{production} = \mathbf{u}_p' \text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1} \mathbf{C} \mathbf{u}_i, \quad (4)$$

where $\mathbf{u}_p$ is a $\text{GN} \times 1$ vector with ones and zeros that sums CO₂ emissions from production in a country. For example, for country i , $\mathbf{u}_p$ has ones in the cells associated with the industries of country i and zeros elsewhere. The CO₂ emissions from *consumption* in country i are:

$$CO_{2i}^{consumption} = \mathbf{f}'(\mathbf{I} - \mathbf{A})^{-1} \mathbf{c}_i, \quad (5)$$

where $\mathbf{c}_i \equiv \begin{bmatrix} c_{1i} \\ c_{2i} \\ \vdots \\ c_{Ni} \end{bmatrix}$, the $\text{GN} \times 1$ vector of consumption of goods in country i (i.e. a specific column of matrix $\mathbf{C}$).

Table 1 summarizes consumption, production and the derived net transfers of CO₂ emissions for a selection of countries and regional aggregates in 1995 and 2008. For the world as a whole, carbon emissions from production expanded to 25,598 Mega tons (Mt) in 2008, an increase of more than 30% from 18,946 Mt in 1995.⁴ Production-based accounting of emissions—in the first three columns of Table 1—shows that Asia's global carbon emissions in 2008 increased to nearly twice their size in 1995, while CO₂ emissions in most other countries also increased but at a slower pace. In 2008, the six Asian economies singled out in WIOD accounted for more than a third of global carbon emissions from production. The North American Free Trade Agreement (NAFTA) group of countries (the United States, Canada, and Mexico) and the Rest of the World each were responsible for about a fifth of global emissions from production, while the 27 member states of the European Union (EU) together accounted for a little more than one seventh.

The central columns of Table 1 show that the attribution of CO₂ emissions differs when they relate to the location of consumption instead of production. For example, China consumed goods and services associated with 4557 Mt of CO₂ emissions in 2008, which is nearly a quarter less than the emissions from production on Chinese territory during that year. The difference, equal to 1366 Mt of CO₂, constitutes net emission transfers embodied in China's goods and services exports. The final columns in Table 1 show that China's net emissions exports in 2008 have grown threefold, from 498 Mt of CO₂ in 1995. Despite the marked increase in net exports, the domestic share dominated total Chinese CO₂ emissions: the amount of carbon dioxide associated with goods and services produced and consumed in the country is more than three times the size of net emissions embodied in exports that year. This reflects the pace at which China's economy has expanded during the past three decades. Double-digit growth figures, the rapid absorption of labor and rising real incomes over time caused domestic consumption to soar in parallel with industrial production (ADB, 2015).

The EU and the United States dominate the opposite side of the CO₂ emissions spectrum shown in Table 1, with CO₂ emissions from consumption substantially outweighing production. Net CO₂ emission transfers through international goods and services imports were sizeable as a result and expanded between 1995 and 2008. More broadly, Table 1 suggests a pattern of CO₂ emission transfers from production processes that take place in emerging economies and cater to consumer markets in the more advanced countries. These findings are consistent

with results presented by Davis and Caldeira (2010) and Peters et al. (2011) using GTAP data.⁵

The divide in net carbon transfers among advanced and emerging economies also emerges from Fig. 1, ranking the five largest net carbon importers and exporters in 2008. Following the United States as the main net importer of embodied CO₂ emissions are France, Japan, Germany and the United Kingdom. Following the ranks of China as the main net carbon exporter are other emerging countries such as Russia, and India, but also Taipei-China and the Republic of Korea. The United States and China dwarf all other countries in terms of the absolute size of emissions consumed, produced and embodied in trade. Jointly, these two countries produce and consume about 40% of global carbon emissions. As a share of domestic production, net transfers of CO₂ exceed 23% for China and 17% for the US. In some countries, this share is even higher. For example, the exceptionally large role of nuclear power generation lowers domestically produced CO₂ emission levels in France, such that CO₂ net imports account for nearly 70% of emissions produced domestically (Ahmad and Wyckoff, 2003).

Additional insights about the bilateral patterns of trade-embodied emission transfers are gained from a network perspective of the data. Fig. 2 traces the network of the top 5% of bilateral CO₂ emission flows in 1995 and 2008. The size of the nodes relates to the magnitude of countries' total emissions trade balances; net exporters of embodied CO₂ are shown in red and net importers in blue. The arrows indicate the direction of bilateral emission transfers and connecting vectors' width relates to their intensity. The color distribution of the nodes in Fig. 2 suggests net CO₂ transfer from emerging to advanced countries. There are exceptions, such as Denmark and Turkey, which in 2008 were a net trade embodied CO₂ exporter and importer respectively. There are also some reversals over time, such as for Australia, Canada and Mexico, which by 2008 had become net carbon importers, from being net exporters back in 1995.⁶ The width of vectors in 2008 in comparison to 1995 suggest that bilateral carbon transfers have strengthened over time, particularly between China, the US and ROW. Bilateral transfers from China to the US increased from 159 Mt in 1995 to 407 Mt in 2008. China's transfers to ROW grew fourfold, to 440 Mt in 2008, while ROW transfers to the US more than doubled in size, to 383 Mt of embodied CO₂.

CO₂ transfers often involve bilateral relationships that run in both directions. Such is the case within NAFTA, where strong supply chain relationships between the US, Canada and Mexico imply that CO₂ emissions embodied in intermediate and final products are carried across national borders. Although less intensively, a similar pattern emerges in relation to Germany at the center of the European network. Russian exports account for a substantial share of trade-embodied CO₂ emissions to Western Europe. Asian developing countries' CO₂ net exports mainly involve Japan and the US as counterparts.

Which industries account for most CO₂ emissions? Fig. 3 breaks down emissions from production by sector. Electricity generation alone produced more than 44% of global CO₂ emissions in 2008.⁷ Large shares are also associated with the metals, minerals, chemical and mining sectors, as well as with transport, government and social services.

The previous results indicated broad trends in production, consumption and intercountry trade-related CO₂ emissions. As argued

⁴ Direct CO₂ emissions associated with the consumption of products by households are not included in the analysis. In WIOD, these household emissions are not allocated to the final consumption of particular products. Hence, the emissions of products presented in this paper refer to CO₂ emissions that occur during its production process.

⁵ CO₂ emission data differ across data sources. Also the attribution of CO₂ emission to production and consumption differs depending upon the multi-region input-output table that is used (Peters, 2012). Davis and Caldeira (2010), who use GTAP data and other environmental accounts, find that in 2004 about 6.2 Gt of CO₂ were emitted to produce goods that were ultimately consumed abroad. Based on the data we use, we find that in 2004 about 6.05 Gt of CO₂ was emitted for foreign consumption. Peters (2012) compares data and outcomes from various MRIOs and argues that aggregate levels and main trends are comparable, but at more detailed levels of analysis differences may emerge.

⁶ Indonesia recorded positive net embodied CO₂ imports in 2008 and appears in blue on the right-hand side panel of Figure 2. Between 2007 and 2008, emissions from production fell substantially, while emissions from consumption continued to increase. Indonesia was a net carbon exporter in the years before 2008.

⁷ This sector also includes water and gas, which WIOD aggregates with electricity. Appendix Table A1 lists the 35 sectors distinguished in WIOD.

Table 1
CO₂ emissions, 1995 and 2008.

		CO ₂ Production			CO ₂ Consumption			CO ₂ Net Transfers	
		1995	2008		1995	2008		1995	2008
		Emissions	Emissions	growth	Emissions	Emissions	growth	Emissions	Emissions
Asia		5191	9426	81.6	4883	8074	65.4	308	1352
	People's Republic of China	2723	5923	117.5	2225	4557	104.8	498	1366
	Republic of Korea	372	522	40.1	365	485	33.1	7	36
	Taipei, China	178	289	62.7	168	201	19.5	9	88
	India	721	1367	89.6	655	1316	100.8	66	51
	Indonesia	173	304	75.8	173	306	77.5	0	-3
	Japan	1024	1021	-0.3	1297	1208	-6.8	-273	-187
Europe (EU 27)		3381	3431	1.5	3818	4378	14.7	-437	-947
	Europe Advanced 15	2638	2757	4.5	3199	3682	15.1	-561	-926
	of which: Germany	725	690	-4.8	939	862	-8.2	-214	-171
	Europe Emerging 12	742	675	-9.1	619	696	12.5	124	-21
NAFTA		5000	5359	7.2	5217	6232	19.4	-217	-873
	United States	4342	4550	4.8	4619	5343	15.7	-277	-793
	Canada	398	456	14.5	347	474	36.6	51	-18
	Mexico	260	353	35.9	251	415	65.1	9	-61
Others		1997	2400	20	1666	2140	28	331	259
	Brazil	175	274	56.4	205	334	62.6	-30	-60
	Turkey	139	242	73.5	162	291	80.1	-23	-50
	Russian Federation	1412	1515	7.3	1033	1116	8.0	379	399
	Australia	271	369	36.2	266	399	49.9	5	-30
Rest of the world		3377	4982	47.5	3362	4774	42.0	15	208
World		18,946	25,598	35.1	18,946	25,598	35.1	0	0

Notes: CO₂ emissions in Mega tons (Mt). Growth is the percentage change between 1995 and 2008 (2008/1995-1*100%). Numbers may not sum due to rounding. Europe Advanced 15 = Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. Europe Emerging 12 = Bulgaria, Cyprus, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. Detailed results for European countries are shown in Annex Table 2. Sources: Authors' computations based on World Input-Output Database, release November 2013.

in the introduction, cross-country differences between emissions from production and consumption originated because of the rapid increase in international trade and the emergence of global supply chains. The origins of emissions from the consumption of final products can be traced using the global supply chain concept introduced by Timmer et al. (2014). Meng et al. (2015) refer to it as a backward-linkage approach because it traces the emissions throughout the production stages leading up to a final good or service. CO₂ emissions in global supply chains are estimated as follows:

$$\mathbf{K} = \text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1} \text{diag}(\mathbf{C}\mathbf{u}). \quad (6)$$

The only (but crucial) difference with Eq. (4) is that in Eq. (6) the elements of the row-wise aggregation of matrix $\mathbf{C}$ are put on the diagonal

of a matrix. An element of the resulting matrix $\mathbf{K}$ gives the CO₂ emissions from industry g in country i that is involved in the global supply chain of a product with the final stage of completion in industry h of country j . This is illustrated in Fig. 4. For example, using Eq. (6) we can estimate the CO₂ emissions by each country-industry (in the rows of Fig. 4) that is involved in the production process of electronics from China's electrical and optical equipment sector (in the column).⁸ The CO₂ emissions can be read from the respective column of China's electrical and optical equipment sector in Fig. 4.

In Table 2 we apply the supply chain approach to assess CO₂ emissions per unit value of final output. For illustration, we compare the amount of CO₂ emissions associated with each one million US dollars of goods of electronics and automotive products where the final production stage was either in China, the Republic of Korea, Japan, or the United States. The CO₂ emissions in global supply chains per million US dollar of final output shown in Table 2 are estimated using the first part of Eq. (6), namely $\text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1}$. For example, 3.38 k tons (kt) of CO₂ were emitted globally in 1995 and 1.41 kt in 2008 to produce 1 million US\$ (in constant 1995 prices) worth of electronics by China. For comparison, in 2008 about 0.33 kt of CO₂ was emitted in the global production network of electronic products that had their final assembly stage in the electrical and optical equipment sector of the United States.

Table 2 suggests that electronic products finalized on China's territory in 2008 generated twice the amount of CO₂ emissions compared to supply chains ending in the Republic of Korea, and more than three times those with the final stage of completion in Japan and the United States. A similar pattern emerges from CO₂ emissions in the automotive supply chains (see the bottom part of Table 2). Meng et al. (2015) argue that one key factor behind such differences is variation in the structure of energy use across countries. For example, the CO₂ emission intensity in production processes using coal is higher compared to natural gas. Since coal accounts for a relatively large part of China's energy use (Meng et al., 2015), it explains part of the higher CO₂ emissions in the GSCs ending in China.

⁸ We refer to final products from the electrical and optical equipment sector as electronics and to those from the transport equipment sector as automotive products.

Fig. 1. Production, consumption and net trade in CO₂ emissions, 2008. Notes: Shown are the top five net carbon dioxide emission importers from the top down and the top five net carbon exporters from the bottom up. Source: authors' elaboration based on World Input-Output Database, release November 2013.

Fig. 2. CO₂ emissions embodied in international trade flows. AUS = Australia, AUT = Austria, BEL = Belgium, BGR = Bulgaria, BRA = Brazil, CAN = Canada, PRC = People's Republic of China, CYP = Cyprus, CZE = Czechoslovakia, DEN = Denmark, EST = Estonia, FIN = Finland, FRA = France, GER = Germany, GRC = Greece, HUN = Hungary, IND = India, INO = Indonesia, IRE = Ireland, ITA = Italy, JPN = Japan, KOR = Republic of Korea, LTU = Lithuania, LUX = Luxembourg, LVA = Latvia, MEX = Mexico, MLT = Malta, NET = Netherlands, POL = Poland, POR = Portugal, ROM = Romania, ROW = Rest of the world, RUS = Russian Federation, SPA = Spain, SVK = Slovakia, SVN = Slovenia, SWE = Sweden, TAP = Taipei, China, TUR = Turkey, UKG = United Kingdom, USA = United States of America. Notes: shown are the top 5% of bilateral emissions flows in 1995 and 2008. The size of the nodes relates to the size of countries' total emissions trade balances. Net exporters (net producers) of embodied CO₂ emissions are shown in red and net importers (net consumers) in blue. The arrows indicate the direction of embodied bilateral emissions flows and their width indicates the relative intensity. Source: authors' elaboration based on World Input-Output Database, release November 2013.

Fig. 3. CO₂ emissions by sector in 2008. Notes: Industry codes in brackets (see Annex Table A1). (Source: authors' elaboration based on World Input-Output Database, release November 2013.)

To quantify the effects of GSCs participation on country and regional emission patterns, along with the effects of consumer demand and improvements in CO₂ efficiency within GSCs, a full GSC production-based analysis is needed. This we turn to next.

3. Embedding the global supply chain concept in structural decomposition analysis

The method we introduce here is an adaptation of the structural decomposition analysis introduced by Los et al. (2014). In Los et al. (2014), the global supply chain concept is embedded in structural

decomposition analysis and used to study drivers in the skill structure of labor demand.⁹ Our method is similar in nature and approach to theirs, but aims to explain drivers of CO₂ emissions from production. Carbon dioxide emissions from production in country *i* are given by Eq. (4) and repeated here for ease of illustration:

$$CO_{2i}^{production} = \mathbf{u}_p' \text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1} \mathbf{C} \mathbf{u}.$$

⁹ See chapter 13 of Miller and Blair (2009) for an introduction to structural decomposition analysis.

			Final products of a global supply chain, identified by country-industry of completion								CO ₂ emissions
			Country 1				...	Country N			
			Industry 1	...	Industry G	...	Industry 1	...	Industry G		
CO ₂ emissions from country-industries participating in global supply chains	Country 1	Industry 1									
		...									
		Industry G									
	...	...									
	Country N	Industry 1									
		...									
Industry G											
Total CO ₂ emissions for each global supply chain										World CO ₂ emissions from production	

Fig. 4. An accounting framework for global supply chains. Notes: Cell values represent the CO₂ emissions from production by the country-industry given in the row, within the global supply chain corresponding to the country-industry of completion given by the column. (Source: modification of Fig. 1 in Timmer et al. (2014).)

Various factors drive a country's CO₂ emissions over time. These are changes in CO₂ emissions per unit of gross output, which determine $\mathbf{f}$. Also, there are changes to CO₂ emissions with a bearing on the reorganization of global supply chains, such as a relocation of intermediates production stages, which will affect CO₂ emissions through the term $\text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1}$. Changes in final demand, such as shifts in consumption patterns or the relocation of final assembly stages, are reflected in the matrix $\mathbf{C}$.

In turn, matrix $\mathbf{C}$ can be broken down into three components:

- (1) the total final consumption by each of the N countries, which is expressed by a $N \times 1$ vector $\mathbf{d}$ (these are the column sums of matrix $\mathbf{C}$, and the resulting vector is then transposed);
- (2) the final consumption shares of products in a country's total consumption, resulting in a $G \times N$ matrix of consumption shares, which is subsumed in a $GN \times N$ matrix $\mathbf{S}^*$ by stacking N times this $G \times N$ matrix; and
- (3) the final goods trade coefficients in a $GN \times N$ matrix $\mathbf{T}^*$, defined as the share of good g from country i in the total consumption of good g by country j . Hence¹⁰:

$$\mathbf{C} = [\mathbf{T}^* \circ (\mathbf{S}^* \cdot \text{diag}(\mathbf{d}))]. \quad (7)$$

Eq. (7) may be thought of as being influenced by three factors determining the global demand for goods and services and thus the CO₂ emissions associated with their production. First, total final demand is affected directly by a countries' income: when GDP grows, so does total final demand. Second, changing consumers' preferences affect the composition of consumption bundles through so-called Engel effects. For example, rising per capita incomes may affect the consumption bundle of, say, Chinese consumers, increasing their demand for meat and cars. Third, shifts in consumer preferences affect countries' market shares. Together, these three factors affect the relative size of global supply chains operating in the global economy and, with it, the amount of carbon dioxide that is being emitted. Apart from final consumption and the international trade in intermediate and final goods and services it generates, global emissions will reflect technological factors determining the CO₂ efficiency of production, as well as by changes in the type and composition of activities countries are specializing in.

¹⁰ The symbol $\circ$ stands for the "Hadamard product", obtained by cell-by-cell multiplication (i.e., $\mathbf{W} = \mathbf{X} \circ \mathbf{Y}$ implies that $w_{ij} = x_{ij}y_{ij}$, for all i and j).

To quantify these effects, note that the amount of global emissions ($\mathbf{f}^w$) associated with the production per unit value of each final product is given by $\mathbf{f}^w = \mathbf{f}(\mathbf{I} - \mathbf{A})^{-1}$. Since the WIOD database includes data on the GN industries and their CO₂ emissions as well as on the GN global supply chains these CO₂ emissions relate to, we are able to compute a $GN \times GN$ -matrix that contains the shares of each of the GN industries in total CO₂ emissions per unit of final demand produced by any of the GN global supply chains.¹¹ In such a matrix $\mathbf{R}$, rows represent the industries and columns the global supply chains in which emissions originate:

$$\mathbf{R} = \{\text{diag}(\mathbf{f})(\mathbf{I} - \mathbf{A})^{-1}\}(\text{diag}(\mathbf{f}^w))^{-1} \quad (8)$$

We can now substitute Eqs. (8) and (7) into (4) and express it in relation to a time period 0 and country i :

$$\text{CO}_{2,i,t=0}^{\text{production}} = \mathbf{u}'_p \mathbf{R}_0 \text{diag}(\mathbf{f}_0^w) [\mathbf{T}_0^* \circ (\mathbf{S}_0^* \cdot \text{diag}(\mathbf{d}_0))] \mathbf{u}. \quad (9)$$

Eq. (9) can be expressed in terms of the change in country i 's CO₂ emissions between two discrete time periods, 0 and 1, which allows us to disentangle five components that account for such a change¹²:

$$\text{CO}_{2,i,t=1}^{\text{production}} - \text{CO}_{2,i,t=0}^{\text{production}} = \mathbf{u}'_p \mathbf{R}_1 \text{diag}(\mathbf{f}_1^w) [\mathbf{T}_1^* \circ (\mathbf{S}_1^* \cdot \text{diag}(\mathbf{d}_1))] \mathbf{u} - \mathbf{u}'_p \mathbf{R}_0 \text{diag}(\mathbf{f}_0^w) [\mathbf{T}_0^* \circ (\mathbf{S}_0^* \cdot \text{diag}(\mathbf{d}_0))] \mathbf{u} =$$

$$\mathbf{u}'_p (\mathbf{R}_1 - \mathbf{R}_0) \text{diag}(\mathbf{f}_1^w) [\mathbf{T}_1^* \circ (\mathbf{S}_1^* \cdot \text{diag}(\mathbf{d}_1))] \mathbf{u} + \quad (10a)$$

$$\mathbf{u}'_p \mathbf{R}_0 (\text{diag}(\mathbf{f}_1^w) - \text{diag}(\mathbf{f}_0^w)) [\mathbf{T}_1^* \circ (\mathbf{S}_1^* \cdot \text{diag}(\mathbf{d}_1))] \mathbf{u} + \quad (10b)$$

$$\mathbf{u}'_p \mathbf{R}_0 \text{diag}(\mathbf{f}_0^w) [(\mathbf{T}_1^* - \mathbf{T}_0^*) \circ (\mathbf{S}_1^* \cdot \text{diag}(\mathbf{d}_1))] \mathbf{u} + \quad (10c)$$

$$\mathbf{u}'_p \mathbf{R}_0 \text{diag}(\mathbf{f}_0^w) [\mathbf{T}_0^* \circ (\langle \mathbf{S}_1^* - \mathbf{S}_0^* \rangle \cdot \text{diag}(\mathbf{d}_1))] \mathbf{u} + \quad (10d)$$

$$\mathbf{u}'_p \mathbf{R}_0 \text{diag}(\mathbf{f}_0^w) [\mathbf{T}_0^* \circ (\mathbf{S}_0^* \cdot (\text{diag}(\mathbf{d}_1) - \text{diag}(\mathbf{d}_0)))] \mathbf{u} \quad (10e)$$

¹¹ Not all supply chains are global. For example, some services sectors may demand little or no foreign inputs and thus have limited associated CO₂ emissions from abroad.

¹² The decomposition analysis represented by Eqs. (10a)–(10e) is not a unique solution. It alters with the choice of weights applied to the individual expressions and can in our case give rise to $120 (5 \times 4 \times 3 \times 2 \times 1)$ possible decompositions (see Dietzenbacher and Los, 1998). The results presented in the next section are an arithmetic average over Eqs. (10a)–(10e) and the so-called polar form, which consists in switching initial and final year weights in all the equations. Dietzenbacher and Los (1998) demonstrate that the average of all the potential decompositions is close to the average of the two polar decompositions.

Table 2
CO₂ emissions in GSCs of electronics and automotive products.

	China		South Korea		Japan		United States	
	1995	2008	1995	2008	1995	2008	1995	2008
GSCs of electronics products								
Own	3.19	1.22	0.42	0.29	0.16	0.21	0.39	0.19
Foreign	0.20	0.19	0.25	0.30	0.09	0.15	0.14	0.14
Total	3.38	1.41	0.68	0.59	0.25	0.35	0.53	0.33
GSCs of automotive products								
Own	3.39	1.30	0.46	0.30	0.18	0.21	0.46	0.28
Foreign	0.15	0.13	0.23	0.26	0.09	0.15	0.15	0.17
Total	3.54	1.44	0.69	0.57	0.27	0.36	0.61	0.45

Notes: The figures indicate the amount of CO₂ in kilotons (kt) for each 1 million US\$ final output produced in constant 1995 prices. Sources: authors' computations based on World Input-Output Database, release November 2013, and the World Input-Output Tables in previous years' prices (release December 2014).

The decomposition in Eqs. (10a)–(10e) isolates the partial effects of each of the five determinants, which jointly are exhaustive of the total change in a country's CO₂ emissions. The individual elements of this equation are interpreted in Table 3. Their bearing on a country's total CO₂ emissions from production is explained in terms of global supply chain trade, GSC CO₂ emission intensity, and consumption.

Note that the analysis examines changes in CO₂ emissions over time by means of comparative static changes. For example, we examine the change in CO₂ emissions due to changes in supply chain participation, holding everything else constant. Likewise, we examine changes in CO₂ emissions due to changes in consumption levels, holding everything else constant. And so forth.

To eliminate the impact of price effects, we follow Xu and Dietzenbacher (2014) and compute Eqs. (10a)–(10e) in terms of volumes, rather than current values. Specifically, we use the World Input-Output Tables in previous years' prices. Because output prices typically increase over time due to inflation, emissions per unit of gross output in the vector **f** and hence the relative importance of the various drivers would be biased if output values in current prices are used. To compute the volume growth of output between 1995 and 1996, we subtract the 1995 output in current prices from the 1996 output in previous years' prices. Similarly, we use output expressed in 1996 current prices and in 1997 previous years' prices, which provides the volume growth between 1996 and 1997, and so on. We thus compute the volume change between 1995 and 2008 by summing up the volume growth for each of the expressions in Eqs. (10a)–(10e). This chaining technique is also used and further explained in de Haan (2001) and Xu and Dietzenbacher (2014).

Table 4 summarizes the results of the decomposition analysis for a selected groups of countries and regions (results for individual European countries are shown in Annex Table 3). The first column of Table 4 gives the change in CO₂ emissions from production between 1995 and 2008.¹³ Subsequent columns show the five factors accounting for the change in CO₂ emissions. Changes in global consumption levels—in the third to last column—are further broken down into changes in domestic and foreign consumption levels.¹⁴

In 2008, China was the largest emitter of carbon dioxide emissions from production. Total CO₂ emissions more than doubled, from 2723 Mt in 1995 to 5923 Mt in 2008. The relocation of intermediate and final stages of production to China accounted for an increase of 550 Mt and 673 Mt of CO₂ emissions respectively, or roughly a third of the increase in Chinese emissions. However, Table 4 also shows that these supply chain effects are countered by a 1706 Mt reduction in

Table 3
The drivers of change in a country's CO₂ emissions from production.

Determinant	Eqs. (10a)–(10e) term	Descriptive examples
global supply chains	10a. Relocation of intermediates 10c. Relocation of final assembly	China starts sourcing certain electronic parts domestically, instead of relying on imports from other countries. Laptop assembly moves from Taipei-China to the People's Republic of China, due to lead firms' strategic search of locational advantages or changes in consumer preferences.
GSC CO ₂ emissions	10b. Changes in the amount of CO ₂ emissions generated along the GSC	Asian GSCs centered on China's assembly and other supplying countries manage to lower CO ₂ emission intensity of production over time.
Consumption	10d. Changes in consumption preferences 10e. Changes in global consumption levels	Consumer preference shifts toward products that emit more carbon dioxide along their GSCs. Relative demand for these products increases and so do the emissions by countries involved in these GSCs. Rising income increases consumption and thereby the CO ₂ emissions associated with their production.

emissions due to technological improvements, which reduced the CO₂ intensity of production in the period from 1995 to 2008. Per capita GDP in China nearly tripled between 1995 and 2008 (ADB, 2015). Consumption by Chinese citizens increased as a result. Increased domestic consumption accounts for the largest share of the change in CO₂ emissions in China since 1995, and equals 3216 Mt.

The increase in consumption by other countries accounts for an increase of 379 Mt CO₂ emissions in China. Jointly with the GSC effects of intermediate and final assembly relocation, this adds up to 1602 Mt of CO₂ emissions that may be ascribed largely to foreign drivers of Chinese CO₂ emissions from production. Our decomposition analysis thus suggests the expansion of domestic consumption bears twice as heavily on the increase in Chinese CO₂ emissions from production than does the increased involvement in production networks and foreign consumption.¹⁵ Table 4 also suggests that variations in the composition of consumption play a relatively minor role in China and elsewhere, consistent with previous findings in the literature (see e.g. Arto and Dietzenbacher, 2014). That is, the preference of Chinese consumers shifted towards the consumption of goods that embody more CO₂ emissions, but this effect added merely 89 Mt to China's CO₂ emissions from production.

Consumption accounts for the largest share of CO₂ emission growth also for the other Asian emerging economies. Except India, a large country itself, foreign consumption in smaller countries tends to play a relatively larger role compared to China. Technological advance partly offset CO₂ emission growth in all the Asian economies. The relocation over time of GSC intermediates production and assembly raised emissions in these countries too, but relative magnitudes suggest that they were less important than in China. Japan stands out among Asian and other countries in that it slightly reduced CO₂ emissions from production between 1995 and 2008. Technological efficiency, production relocation and other factors more than outweigh the upward pressure on carbon emissions from increased consumption.

The European Union only slightly increased its CO₂ emissions from production between 1995 and 2008, as technology and supply chain trade effects nearly offset an increase from higher (mainly domestic) consumption. Germany, the largest economy among the 15 most advanced EU member countries, shows a decline in carbon emissions, related to the offshoring of intermediate stages of production, substantial technological gains, and moderate changes in the location of final

¹³ Note that the change in CO₂ emissions from production is equal to the difference in CO₂ emissions from production between 1995 and 2008, shown in Table 1.

¹⁴ To distinguish CO₂ emissions from domestic and foreign consumption, we split the vector **d** into **d**^{domestic} and **d**^{foreign}. The vector **d**^{domestic} has domestic consumption as given and zeros elsewhere. In vector **d**^{foreign}, domestic consumption is set to zero.

¹⁵ This confirms the results from scenario analysis by Guan et al. (2008).

Table 4
Global supply chains CO₂ emissions accounting.

	Change in CO ₂ emissions	Change in CO ₂ emissions accounted for by changes in:						
		GSC		Technology	Consumption			
	2008 minus 1995	Relocation of intermediates production stages	Relocation of final assembly	GSC CO ₂ emissions	Consumption preferences	Global Consumption levels	o/w domestic consumption levels	o/w foreign consumption levels
Asia	4235	631	739	–2231	142	4954	4221	733
People's Republic of China	3200	550	673	–1706	89	3594	3216	379
Republic of Korea	149	19	19	–91	3	199	120	79
Taipei, China	111	37	5	–57	23	104	42	62
India	646	14	36	–226	44	779	704	75
Indonesia	131	26	20	–15	0,01	100	65	35
Japan	–3	–14	–13	–136	–17	178	74	104
Europe	51	–287	–40	–899	–43	1319	828	492
Europe Advanced 15	119	–199	–79	–546	–4	946	549	397
of which: Germany	–34	–24	–1	–173	2	162	60	102
Europe Emerging 12	–68	–87	39	–353	–40	373	279	95
NAFTA	359	–426	–137	–1040	–347	2309	2018	290
United States	208	–381	–131	–909	–307	1935	1745	190
Canada	58	–18	2	–99	–28	200	125	75
Mexico	93	–27	–8	–33	–11	173	148	25
Others	402	–74	–66	–585	–197	1324	1012	312
Brazil	99	14	4	–7	–3	90	71	19
Turkey	102	36	7	–34	–6	99	83	16
Russian federation	103	–101	–63	–527	–166	961	720	241
Australia	98	–24	–14	–16	–21	174	138	36
Rest of the world	1605	156	122	–1018	468	1877	1382	495
World	6651	0	619	–5774	24	11,783		

Notes: CO₂ emissions in Mega tons (Mt). Europe Advanced 15 = Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom. Europe Emerging 12 = Bulgaria, Cyprus, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. Results for individual European countries are shown in Annex Table 3. Sources: authors' computations based on World Input-Output Database, release November 2013, and the World Input-Output Tables in previous years' prices (release December 2014).

assembly activities. Interestingly, the EU's 12 emerging economies as a group also experienced a fall in CO₂ emissions, due to strong technological gains and the relocation and declining importance of (partly heavy industry) intermediate stages of production.

The United States and NAFTA more broadly experienced a substantial increase in CO₂ emissions driven mainly by higher levels of domestic consumption, which was less than offset by other factors. Interestingly, Mexico's emissions decreased due to the offshoring of both intermediate and final assembly stages, despite the importance of its maquiladora trade with the US. This is likely in reflection of the rise of China as the world's leading manufacturing hub.

Other countries singled out in Table 4 increased carbon emissions. In relative terms, Brazil and Turkey experienced a substantial rise, due to strong economic growth and rising consumption levels, and also because of higher intermediates production and assembly. Relative to the magnitude of CO₂ levels in 1995, emissions in Russia grew by less than other countries in this aggregate, mainly because of high offsets from the relocation of production stages abroad. The Rest of the World aggregate is associated with a 1605 Mt increase in CO₂ emissions, mostly accounted for by domestic consumption and a net increase in intermediates production and assembly.

Finally, for the world as a whole, the final row of Table 4 shows that CO₂ emissions growth is related to a rapid rise in global consumption levels. The increase in global carbon dioxide emissions would have been almost twice as high if not for the rapid improvement in CO₂ efficiency within GSCs. In the setup of our decomposition method, CO₂ emissions arising from the relocation of intermediate production stages are identified by changes in the shares of each industry in total CO₂ emissions per unit of final demand. As such, they represent a redistribution of CO₂ emissions in global supply chains and are not suited to examine 'weak' carbon leakage (Peters, 2010) from offshoring of intermediates production. Hoekstra et al. (2016) use an extension of the structural decomposition method introduced by Arto and Dietzenbacher (2014) to examine carbon leakage from the offshoring of intermediate stages. With our method, we are able to examine carbon

leakage from the relocation of final assembly stages. Our findings suggest this relocation has contributed to an increase of 619 Mt of CO₂ emissions.

4. Concluding remarks

Climate change is a problem that requires global cooperation because the planet has a single climate system. It makes little difference where greenhouse gases are emitted. In order to design and implement policies to mitigate climate change, the root causes of global warming should be addressed, which in turn requires a better understanding of what drives changes in emissions. This paper supports this goal by devising an analytical framework that treats the world economy as an evolving production network. We used the global supply chain concept introduced by Timmer et al. (2014) to measure CO₂ emissions in fragmented production networks. In addition, we examined the drivers of the growth in CO₂ emissions by embedding the GSC concept in structural decomposition analysis.

Our findings suggest that CO₂ emissions per unit of output by broad product groups or sectors, such as electronics or automobiles, differ substantially depending where the final stage of assembly takes place. In addition, we find that a substantial share of rising CO₂ emission levels in emerging economies is accounted for by increased participation in global production networks and serving expanding foreign consumption. However, even for emerging economies that rapidly integrated in global production networks, most notably China, the increase of CO₂ emissions between 1995 and 2008 is mainly on account of rising levels of domestic consumption. For all the forty advanced and emerging economies that we analyzed, we find evidence that CO₂ emission intensity of goods produced in global supply chains fell rapidly, reducing but not eliminating the spike in CO₂ emissions from higher consumer demand. In light of these findings, the ratification of the 2015 Paris climate change agreement by the US and China is certainly a step in the right direction.

We used the World Input-Output Database to measure CO₂ emissions from all activities that are directly or indirectly needed to produce a final product. In contrast to detailed case studies that measure the CO₂ emissions embodied in a specific product, our approach provides a macro-perspective and describes major regional trends. This is informative, but not without limitations. Measured CO₂ emissions in global supply chains are affected by the aggregated nature of the data used in current empirical analysis (Lenzen et al., 2004; Steen-Olsen et al., 2014; de Koning et al., 2015). Temporal, sectoral and regional aggregation may all lead to deviations in appropriately attributing responsibility. For example, products with different CO₂ emission intensity are aggregated but may have different end users (e.g. domestic versus foreign consumption). Also, production processes of firms that produce for the domestic and foreign markets may differ (Timmer et al., 2015). Hence, distinguishing processing exports from regular exports and domestic use would improve estimates for countries heavily involved in global production networks. Furthermore, disaggregating and using reliable statistics for many of the countries currently lumped into the 'rest of the world' remains a key challenge for multi-region input-output tables in future work (Stadler et al., 2014). From a methodological point of

view, it is well known that there is co-dependency between the various drivers identified by structural decomposition analysis, thus casting doubt on the interpretation of the terms (Dietzenbacher and Los, 2000).

Various researchers at universities and international agencies are working on the compilation of new and better multi-regional input-output tables, to address the data issues described. Once available, these tables will allow to test the sensitivity of measured CO₂ emissions in GSCs. In addition, as the development of these tables matures, linkages are possible with satellite data (e.g. on agricultural yields and production, see Costinot et al., 2016) as well as developing intercountry social accounting matrices (e.g. accounting for households with different incomes and consumption profiles). This opens up a promising and important research agenda to study the impact of globalization, technology, and consumption on greenhouse gas emissions.

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Appendix A

Appendix Table A1

List of sectors distinguished in the World Input-Output Database.

#	ISIC rev 3.1	Label
1	AtB	AGRICULTURE, HUNTING, FORESTRY AND FISHING
2	C	MINING AND QUARRYING
3	15 t16	FOOD , BEVERAGES AND TOBACCO
4	17 t18	Textiles and textile
5	19	Leather, leather and footwear
6	20	WOOD AND OF WOOD AND CORK
7	21 t22	PULP, PAPER, PAPER , PRINTING AND PUBLISHING
8	23	Coke, refined petroleum and nuclear fuel
9	24	Chemicals and chemical
10	25	Rubber and plastics
11	26	OTHER NON-METALLIC MINERAL
12	27 t28	BASIC METALS AND FABRICATED METAL
13	29	MACHINERY, NEC
14	30 t33	ELECTRICAL AND OPTICAL EQUIPMENT
15	34 t35	TRANSPORT EQUIPMENT
16	36 t37	MANUFACTURING NEC; RECYCLING
17	E	ELECTRICITY, GAS AND WATER SUPPLY
18	F	CONSTRUCTION
19	50	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
20	51	Wholesale trade and commission trade, except of motor vehicles and motorcycles
21	52	Retail trade, except of motor vehicles and motorcycles; repair of household goods
22	H	HOTELS AND RESTAURANTS
23	60	Land transport; transport via pipelines
24	61	Water transport
25	62	Air transport
26	63	Supporting and auxiliary transport activities; activities of travel agencies
27	64	POST AND TELECOMMUNICATIONS
28	J	FINANCIAL INTERMEDIATION
29	70	Real estate activities
30	71 t74	Renting of machinery & equipment and other business activities
31	L	PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY
32	M	EDUCATION
33	N	HEALTH AND SOCIAL WORK
34	O	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES
35	P	PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS

Appendix Table 2

CO₂ emissions in European countries, 1995 and 2008.

	CO ₂ Production			CO ₂ Consumption			CO ₂ net transfers	
	1995	2008	growth	1995	2008	growth	1995	2008
	Emissions	Emissions		Emissions	Emissions		Emissions	Emissions
Austria	44	54	24	78	86	10	−35	−32
Belgium	101	96	−4	103	127	23	−2	−31

(continued on next page)

Appendix Table 2 (continued)

	CO ₂ Production			CO ₂ Consumption			CO ₂ net transfers	
	1995	2008	growth	1995	2008	growth	1995	2008
	Emissions	Emissions		Emissions	Emissions		Emissions	Emissions
Bulgaria	57	49	−14	35	37	8	22	11
Cyprus	4	7	60	8	12	64	−3	−5
Czech Republic	107	101	−5	90	97	8	17	4
Germany	725	690	−5	939	862	−8	−214	−171
Denmark	64	100	56	65	66	1	−1	34
Spain	203	261	28	238	365	53	−35	−105
Estonia	17	16	−6	13	14	12	4	1
Finland	53	57	6	56	68	21	−3	−12
France	284	273	−4	384	462	20	−100	−189
United Kingdom	451	449	0	499	596	20	−48	−147
Greece	75	93	24	92	143	56	−16	−49
Hungary	48	46	−5	50	57	13	−2	−11
Ireland	26	32	24	28	54	93	−3	−23
Italy	360	378	5	434	509	17	−74	−131
Lithuania	13	13	2	14	21	50	−1	−8
Luxembourg	6	3	−53	6	7	15	0	−4
Latvia	9	8	−7	10	13	37	−1	−5
Malta	2	2	22	3	3	12	−1	−1
Netherlands	154	169	10	157	186	19	−3	−17
Poland	314	290	−8	255	281	10	59	10
Portugal	46	53	15	54	67	25	−7	−14
Romania	120	90	−25	101	103	2	20	−13
Slovakia	40	37	−8	29	37	31	11	−1
Slovenia	11	15	36	13	19	51	−2	−5
Sweden	47	49	5	66	84	27	−19	−34

Notes: CO₂ emissions in Mega tons (Mt). Growth is the percentage change between 1995 and 2008 ($2008/1995-1*100\%$). Numbers may not sum due to rounding. Source: authors' computations based on World Input-Output Database, release November 2013.

Appendix Table 3

Global supply chains CO₂ emissions accounting for European countries.

	Change in CO ₂ emissions		Change in CO ₂ emissions accounted for by changes in:					
	2008 minus 1995	GSC		Technology	Consumption			
		Relocation of intermediates production stages	Relocation of final assembly	GSC CO ₂ emissions	Consumption preferences	Global Consumption levels	<i>o/w domestic consumption levels</i>	<i>o/w foreign consumption levels</i>
Austria	10	4	2	−9	−1	15	6	9
Belgium	−4	−20	−2	−16	−2	36	11	25
Bulgaria	−8	−8	−3	−29	6	26	15	11
Cyprus	3	0	0	−1	1	3	3	1
Czech Republic	−5	−10	8	−42	0	39	23	16
Germany	−34	−24	−1	−173	2	162	60	102
Denmark	36	24	0	−15	−2	29	9	20
Spain	58	−17	−3	−44	2	119	93	26
Estonia	−1	−1	9	−8	−14	13	10	3
Finland	3	−5	−1	−17	1	25	14	11
France	−11	−58	11	−52	−14	101	61	40
United Kingdom	−2	−69	−42	−93	2	201	141	60
Greece	18	−6	−21	−19	21	43	40	3
Hungary	−2	−2	1	−16	−6	20	13	7
Ireland	6	−5	1	−11	2	19	14	5
Italy	18	−3	−17	−50	−10	98	52	45
Lithuania	0	0	0	−8	−1	9	6	3
Luxembourg	−3	−4	0	−1	0	2	1	1
Latvia	−1	0	0	−6	−1	6	4	1
Malta	0	0	0	0	0	1	1	0
Netherlands	15	−7	−3	−26	−7	58	25	34
Poland	−24	−37	22	−163	−17	171	139	32
Portugal	7	−2	−2	−11	2	20	14	6
Romania	−30	−25	−3	−60	−5	62	50	12
Slovakia	−3	−7	5	−20	0	19	11	8
Slovenia	4	0	0	−2	−1	6	4	2
Sweden	3	−7	−2	−8	0	19	8	10

Notes: CO₂ emissions in Mega tons (Mt). Sources: authors' computations based on World Input-Output Database, release November 2013, and the World Input-Output Tables in previous years' prices (release December 2014).

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