WHAT ACCOUNTS FOR THE GROWTH OF CARBON DIOXIDE EMISSIONS IN ADVANCED AND EMERGING ECONOMIES? THE ROLE OF CONSUMPTION, TECHNOLOGY, AND GLOBAL SUPPLY CHAIN TRADE

Benno Ferrarini and Gaaitzen J. de Vries

NO. 458

October 2015

ADB ECONOMICS WORKING PAPER SERIES

ASIAN DEVELOPMENT BANK

ADB

ADB Economics Working Paper Series

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

Benno Ferrarini and Gaaitzen J. de Vries

No. 458 | October 2015

Benno Ferrarini (bferrarini@adb.org) is Senior Economist, Economic Research and Regional Cooperation Department, Asian Development Bank.
Gaaitzen J. de Vries (g.j.de.vries@rug.nl) is Assistant Professor of Economics, Faculty of Economics and Business, Groningen Growth and Development Centre, University of Groningen, the Netherlands.

ASIAN DEVELOPMENT BANK

Asian Development Bank
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org

October 2015
ISSN 2313-6537 (Print), 2313-6545 (e-ISSN)
Publication Stock No. WPS157682-2

Note: In this publication, "$" refers to US dollars.

The ADB Economics Working Paper Series is a forum for stimulating discussion and eliciting feedback on ongoing and recently completed research and policy studies undertaken by the Asian Development Bank (ADB) staff, consultants, or resource persons. The series deals with key economic and development problems, particularly those facing the Asia and Pacific region; as well as conceptual, analytical, or methodological issues relating to project/program economic analysis, and statistical data and measurement. The series aims to enhance the knowledge on Asia's development and policy challenges; strengthen analytical rigor and quality of ADB's country partnership strategies, and its subregional and country operations; and improve the quality and availability of statistical data and development indicators for monitoring development effectiveness.

The ADB Economics Working Paper Series is a quick-disseminating, informal publication whose titles could subsequently be revised for publication as articles in professional journals or chapters in books. The series is maintained by the Economic Research and Regional Cooperation Department.

CONTENTS

TABLES AND FIGURES

TABLES

FIGURES

ABSTRACT

Climate policy pledges and negotiations involve commitments about the reduction of emissions within national borders. However, the rise of global value chains has changed the nature of production and international trade, blurring the attribution of ultimate responsibility for emissions. This paper applies a novel method that examines the change in territorial emissions due to changes in energy intensity, supply chain participation, and domestic and foreign consumption. 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 emissions growth in emerging economies is accounted for by higher participation in global production networks that serve expanding foreign consumption. However, even for economies that most rapidly integrated in global production networks, such as the People's Republic of China, rising domestic consumption accounts for the bulk of territorial emissions. Improved energy efficiency partially stemmed the spike in emissions from higher consumer demand.

Keywords: global multiregional input–output model, global value chains, structural decomposition analysis, World Input–Output Database

JEL Classification: D57, E01, F18, F64, Q56

I. INTRODUCTION

Carbon dioxide (CO_2) 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 recent global economic crisis, carbon emissions expanded three times faster in the 2000s compared to the 1990s. As a result, world average annual per capita emission levels surged to nearly 5 metric tons in 2010, up from about 4 metric tons in the 1990s (World Bank 2015). International negotiations, such as under the aegis of the United Nations Framework Convention on Climate Change, focus mainly on territorial emissions of greenhouse gas emissions as a byproduct of production and combustion processes taking place within national borders. However, a literature has emerged to argue that such a territorial accounting of emissions should be expanded to also reflect emission transfers from one country to another through international trade in goods and services (Wiedmann 2009, Kander et al. 2015).

Emission transfers have grown substantially during the past 2 decades. Global trade flows grew more than 5% annually, spurred by the rise of an intricate network of global supply chains and concomitant intermediates trade (Johnson and Noguera 2012; Baldwin 2014; Ferrarini and Hummels 2014). The amount of CO_2 embodied in cross-border trade increased as a result (Davis and Caldeira 2010; Davis, Peters, and Caldeira 2011; Peters et al. 2011; Xu and Dietzenbacher 2014). Because a substantial share of production is relocated to emerging economies, CO_2 emissions are said to be "leaking" to these economies.[1] To reflect such emissions leakage via international trade and to better gauge the carbon footprint of consumers according to their location in either the advanced or the emerging economies, recent research efforts have been aiming to adjust countries' territorial emissions for net emission transfers (Davis and Caldeira 2010; Peters at al. 2011). The "consumption-based" accounting ensuing from these efforts has generated valuable insights for policy and research (see Wiedmann 2009). However, they hardly fit the context of international negotiations, about commitments that are mainly for enactment within countries' own territories rather than in those of trade partners abroad.[2] Also, consumption-based measures do not distinguish the underlying drivers of emissions changes, which could inform the global attribution of responsibilities and help design effective mitigation policies for greenhouse gas emissions.

This paper incorporates global supply chain trade directly into the production-based accounting framework. By doing so, we provide a novel measure of the energy intensity of products produced in global value chains (GVCs). This measure is used in a structural analysis to account for the sources of changing emissions within economies. The changes in CO_2 emissions of an economy may stem from changes in an economy's participation in GVCs, improvements in energy efficiency within GVCs, and changes in consumption levels.[3]

---

[1] We use the term "carbon leakage" to denote CO_2 emissions embodied in internationally traded goods and services, as well as emission transfers associated with countries' offshoring of carbon-intensive production abroad (see Kander et al. 2015). In the UNFCCC-related literature, carbon leakage refers to the ratio of carbon emissions increase in a specific industry outside the country over the reduction of carbon emissions in the domestic sector, as the result of domestic environmental policy.

[2] Although commitments are predominantly for enactment within national territories, climate change agreements have long reflected extraterritorial aspects and incentives. For example, the Clean Development Mechanism of the Kyoto Protocol allows a country to implement an emission mitigation project in developing countries and make it count toward its own emission-reduction commitment. Also see IPCC (2014).

[3] Structural decomposition analysis is a common tool in accounting for the sources of emissions (see, for example, de Haan 2001, Guan et al. 2008, Xu and Dietzenbacher 2014, Arto and Dietzenbacher 2014). But the novelty here is that we incorporate GVCs into the analysis.

To overcome official statistics' limitations to the analysis of global supply chains, much of the literature on international emission transfers relies on the Multiregion Input–Output (MRIO) and environmental data tables from the Global Trade Analysis Project (GTAP). This database combines national input–output tables with international trade statistics and has been a workhorse for computable general equilibrium analyses applied to final goods trade. However, GTAP does not embody the necessary information for a full geographic breakdown of inputs sourced through GVCs (Timmer et al. 2015; Ferrarini and Hummels 2014).

Partly overcoming these limitations are two MRIO databases that recently became publicly available: the World Input–Output Database (WIOD) and the Trade in Value Added (TiVA) database. Instead of allocating imports proportionally across industries and final demand as in previous MRIOs, these databases rely on the United Nations' classification of Broad Economic Categories (BEC) and detailed trade data to determine import sources by agent as well as the sourcing shares of intermediate and final goods. As a result, these MRIOs are particularly suitable for the study of GVCs. The analysis in this paper relies on the WIOD, because it makes available MRIO tables in previous years' prices, which are necessary for the analysis here. The World Input–Output Tables in the WIOD are used in combination with detailed country-specific environmental national accounts constructed by Genty, Arto, and Neuwahl (2012) to account for country differences in emission intensities due to differences in production techniques (Douglas and Nishioka 2012).[4]

The paper presents in Section II the production and consumption accounts of CO_2 emissions by main regions and economies represented in the WIOD. Section III describes the accounting method used to assess the drivers of countries' emission levels. The following sections interpret the results and draw conclusions.

II. CARBON DIOXIDE PRODUCTION, CONSUMPTION, AND EMISSION TRANSFERS VIA TRADE AND GLOBAL SUPPLY CHAINS

Table 1 summarizes consumption, production, and net transfers of CO_2 emissions for a selection of economies and regional aggregates in 1995 and 2008.[5] For the world as a whole, carbon emissions expanded to 25,598 megatons (Mt) in 2008, an increase of more than 30% from 18,946 Mt in 1995. Production-based accounting of emissions—in the first five columns of Table 1—shows that Asia's share of global carbon emissions in 2008 ballooned to nearly twice their size in 1995, while the shares of most other countries and regions fell. In 2008, the six Asian economies singled out in the WIOD accounted for more than a third of global carbon emissions. The North American Free Trade Agreement (NAFTA) group of countries (the United States [US], Canada, and Mexico) and the rest of the world (ROW) aggregate each were responsible for about a fifth of global emissions, while the 27 member states of the European Union (EU) together accounted for more than one-seventh.[6]

[4] See Timmer et al. (2015) for an introduction and overview of WIOD.

[5] We also have data for 2009 but restrict the analysis to the precrisis years. Once data is available for more recent years, the changes during and after the economic and financial crisis can be examined.

[6] Subsuming all but 40 economies singled out in the WIOD, the ROW aggregate is highly heterogeneous. It most strongly reflects oil-producing nations, such as Saudi Arabia and other countries in the Northern African and Middle-Eastern region. However, 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 economies currently lumped into the ROW aggregate remains a key challenge for MRIOs in the years ahead.

Table 1: Total Carbon Dioxide Emissions, 1995 and 2008

	CO_2 Production					CO_2 Consumption					CO_2 Net Transfers			
	1995 Emissions	Share	2008 Emissions	Share	Growth	1995 Emissions	Share	2008 Emissions	Share	Growth	1995 Emissions	Share	2008 Emissions	Share
Asia	**5,191**	**27.4**	**9,426**	**36.8**	**81.6**	**4,883**	**25.8**	**8,074**	**31.5**	**65.4**	**–308**	**–5.9**	**–1,352**	**–14.3**
People's Republic of China	2,723	14.4	5,923	23.1	117.5	2,225	11.7	4,557	17.8	104.8	–498	–18.3	–1,366	–23.1
Republic of Korea	372	2.0	522	2.0	40.1	365	1.9	485	1.9	33.1	–7	–2.0	–36	–7.0
Taipei,China	178	0.9	289	1.1	62.7	168	0.9	201	0.8	19.5	–9	–5.3	–88	–30.4
India	721	3.8	1,367	5.3	89.6	655	3.5	1,316	5.1	100.8	–66	–9.1	–51	–3.7
Indonesia	173	0.9	304	1.2	75.8	173	0.9	306	1.2	77.5	0	–0.1	3	0.8
Japan	1,024	5.4	1,021	4.0	–0.3	1,297	6.8	1,208	4.7	–6.8	273	26.6	187	18.3
Europe (EU-27)	**3,381**	**17.8**	**3,431**	**13.4**	**1.5**	**3,818**	**20.2**	**4,378**	**17.1**	**14.7**	**437**	**12.9**	**947**	**27.6**
Europe Advanced 15	2,638	13.9	2,757	10.8	4.5	3,199	16.9	3,682	14.4	15.1	561	21.3	926	33.6
of which: Germany	725	3.8	690	2.7	–4.8	939	5.0	862	3.4	–8.2	214	29.6	171	24.8
Europe Emerging 12	742	3.9	675	2.6	–9.1	619	3.3	696	2.7	12.5	–124	–16.7	21	3.2
NAFTA	**5,000**	**26.4**	**5,359**	**20.9**	**7.2**	**5,217**	**27.5**	**6,232**	**24.3**	**19.4**	**217**	**4.3**	**873**	**16.3**
United States	4,342	22.9	4,550	17.8	4.8	4,619	24.4	5,343	20.9	15.7	277	6.4	793	17.4
Canada	398	2.1	456	1.8	14.5	347	1.8	474	1.9	36.6	–51	–12.9	18	3.9
Mexico	260	1.4	353	1.4	35.9	251	1.3	415	1.6	65.1	–9	–3.4	61	17.4
Others	**5,375**	**28**	**7,381**	**29**	**221**	**5,029**	**27**	**6,914**	**27**	**243**	**–346**	**4**	**–467**	**20**
Brazil	175	0.9	274	1.1	56.4	205	1.1	334	1.3	62.6	30	17.3	60	22.0
Turkey	139	0.7	242	0.9	73.5	162	0.9	291	1.1	80.1	23	16.2	50	20.6
Russian Federation	1,412	7.5	1,515	5.9	7.3	1,033	5.5	1,116	4.4	8.0	–379	–26.8	–399	–26.3
Australia	271	1.4	369	1.4	36.2	266	1.4	399	1.6	49.9	–5	–1.8	30	8.1
Rest of the world	3,377	17.8	4,982	19.5	47.5	3,362	17.7	4,774	18.6	42.0	–15	–0.4	–208	–4.2
World	18,946	100	25,598	100	35.1	18,946	100	25,598	100	35.1	0	0	0	0

CO_2 = carbon dioxide, EU = European Union, NAFTA = North American Free Trade Agreement.
Notes: Emission in megatons (Mt). Share is in percentage of world total except for last columns (on CO_2 net transfers) which show the share in emission from production in the economy. Growth is the percentage change between 1995 and 2008. Europe Advanced 15 comprises Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. Europe Emerging 12 comprises Bulgaria, Cyprus, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. Detailed results for European countries are shown in Appendix Table A.2.
Source: Authors' computations based on World Input–Output Database, release November 2013.

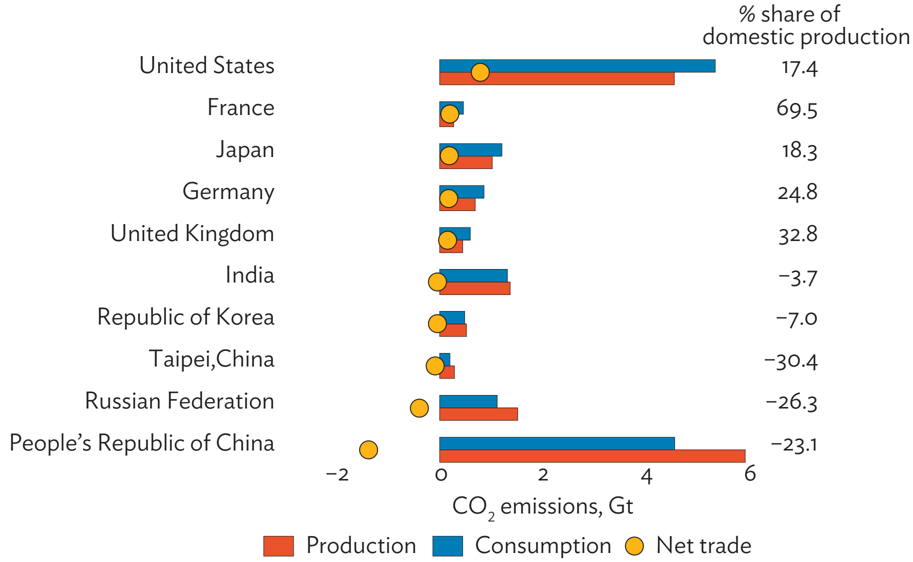
The central columns of Table 1 show that the attribution of CO_2 emissions differs when they relate to the location of consumption instead of production. For example, the People's Republic of China (PRC) consumed goods and services associated with 4,557 Mt of CO_2 emissions in 2008, which is nearly a quarter less than the emissions from production on Chinese territory during that year. The difference, equal to −1,366 Mt of CO_2, constitutes net emission transfers embodied in the PRC's goods and services exports. The final columns in Table 1 shows that the PRC's net emissions exports in 2008 had grown threefold, from −498 Mt of CO_2 in 1995. Despite the marked increase in net exports, the domestic share dominated total Chinese emissions: the amount of CO_2 associated with goods and services produced and consumed in the country were more than three times the size of net emissions exports that year. This reflects the staggering speed with which the PRC's economy expanded during the past 3 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 US dominate the opposite side of the emissions spectrum shown in Table 1, with CO_2 consumption significantly outweighing its production. Net emission transfers through international goods and services imports were sizable as a result and expanded between 1995 and 2008. More broadly, Table 1 suggests a pattern of emission transfers from production processes that take place in emerging economies and cater to consumer markets in the more advanced countries. Such evidence is all too familiar and has been documented at length in Davis and Caldeira (2010) and Peters et al. (2011) on the basis of GTAP data, as well as the trade analysis in Xu and Dietzenbacher (2014) based on the WIOD.[7]

The divide in net carbon transfers among advanced and emerging economies also emerges from Figure 1, ranking the five largest net carbon exporters and importers in 2008. Following the US as the main net importer of CO_2 are France, Japan, Germany, and the United Kingdom. Following the ranks of the PRC as the main net carbon exporter are other emerging economies such as the Russian Federation, and India, but also Taipei,China and the Republic of Korea. The US and the PRC dwarf all other economies 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 CO_2 exceed 23% for the PRC and 17% for the US. In some economies, this share is even higher. For example, the exceptionally large role of nuclear power generation lowers domestically produced CO_2 emission levels in France, so that CO_2 net imports account for nearly 70% of emissions produced domestically (Ahmad and Wyckoff 2003).

[7] CO_2 emission data differ across sources. Also the attribution of CO_2 emission to production and consumption differs depending upon the MRIO that is used (Peters 2012). Davis and Caldeira (2010), who use GTAP data and other environmental accounts, find that in 2004 about 6.2 gigaton CO_2 were emitted to produce goods that were ultimately consumed abroad. Based on our data, we find that in 2004 about 6.05 gigaton of CO_2 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. These differences partly originate from the way in which MRIOs are constructed, as discussed in the introduction.

Figure 1: Production, Consumption, and Net Trade in Carbon Dioxide Emissions, 2008



CO_2 = carbon dioxide, Gt = gigaton.
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.

Deeper insights about the bilateral patterns of trade-embodied emission transfers between pairs of economies are gained from a network perspective of the data. Figure 2 traces the network of the top 5% of bilateral CO_2 emission flows in 1995 and 2008. The size of the nodes relates to the magnitude of economies' total emissions trade balances; net exporters of CO_2 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 Figure 2 confirms the direction of net CO_2 transfers, from emerging to advanced countries. There are exceptions, such as Denmark and Turkey, which in 2008 were a net CO_2 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.[8]

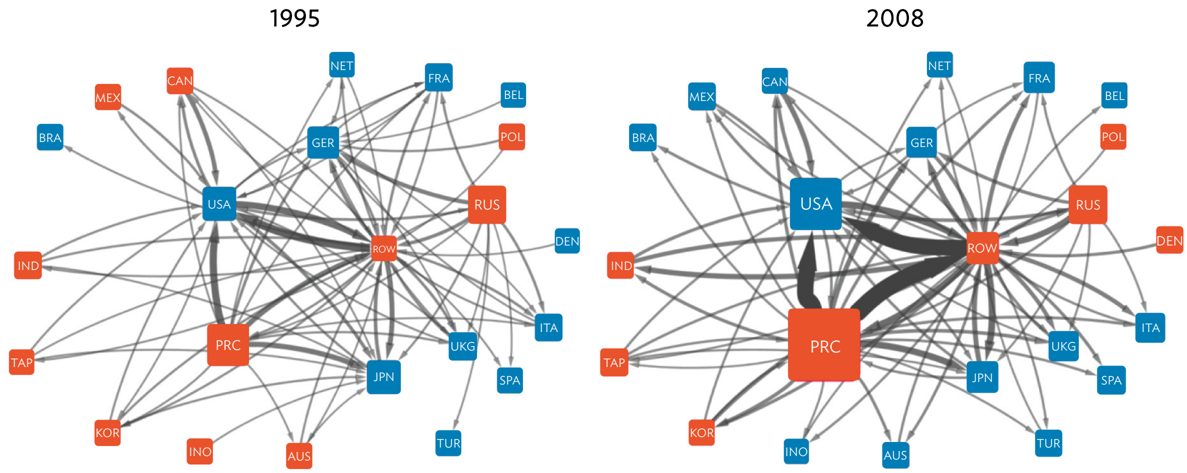
The width of vectors in 2008, in comparison to 1995, suggest that bilateral carbon transfers have strengthened over time, particularly between the PRC, the US, and the ROW. Bilateral transfers from the PRC to the US increased from 159 Mt in 1995 to 407 Mt in 2008. The PRC's transfers to the ROW grew fourfold to 440 Mt in 2008, while the ROW transfers to the US more than doubled in size to 383 Mt of CO_2. This reflects expanding global consumption of Chinese consumer goods and of the US oil imports from the ROW.

CO_2 transfers often involve intense bilateral relationships that run in both directions. Such is the case within NAFTA, where strong supply chain relationships between the US, Canada, and Mexico

[8] Indonesia recorded slightly positive net CO_2 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.

imply that plenty of CO_2 emissions are carried across national borders. Although less intensively, a similar pattern emerges in relation to Germany at the center of the European network. The Russian Federation gas exports constitute a key source of CO_2 transferred to the European countries. Asian developing economies' CO_2 net exports mainly involve Japan and the US as counterparts. For example, Indonesian exports—of natural gas predominantly—constitute a significant transfer of CO_2 for consumption in the Japanese economy.

Figure 2: Carbon Dioxide International Net Transfers



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 economies' total emissions trade balances. Net exporters (net producers) of emissions are shown in red and net importers (net consumers) in blue. The arrows indicate the direction of bilateral emissions flows and their width indicates the relative intensity.

Source: Authors' elaboration based on World Input–Output Database, release November 2013.

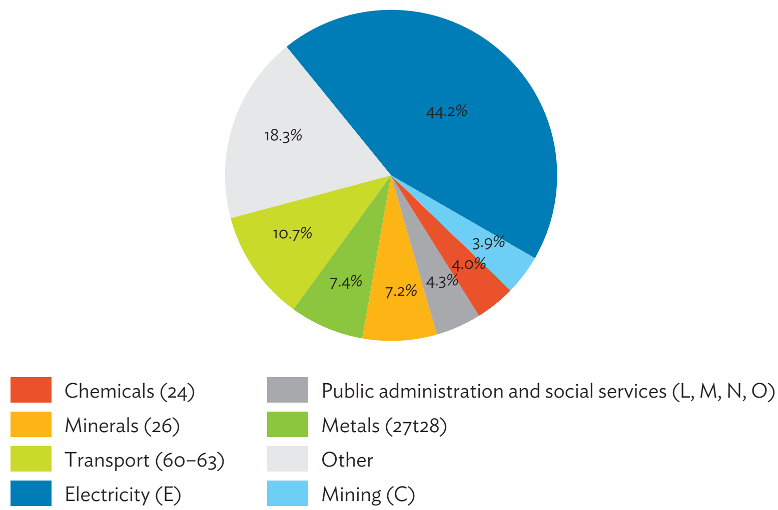
Which industries are the most polluting? Figure 3 breaks down WIOD-derived emissions transfers by industrial sectors. Electricity generation is the main culprit: it alone produced more than 44% of global emissions in 2008. Large shares are associated also with the metals, minerals, chemical, and mining sectors, as well as with transport, government, and social services.[9]

Alternative to tracing the origins of emissions associated with final goods consumption, using a forward-linkage approach as in Table 1, we now examine the origins of emissions associated with final products, irrespective of where they are being consumed. This is the GVC concept introduced by Timmer et al. (2014), and which Meng, Peters, and Wang (2015) refer to as a backward-linkage approach because it traces the emissions throughout the production stages leading up to a final good or service. For example, what are the origins of emissions that flow into the final assembly of *i*Phones in Longhua, PRC or of Porsche cars in Leipzig, Germany?

[9] Specifically, this share also includes water and gas, which the WIOD aggregates with electricity. Appendix Table A.1 lists the 35 sectors distinguished in the WIOD.

Table 2 applies the value chain approach to assess emissions per unit value of final output (we eliminate price effects in this analysis, further discussed in Section 4). In essence, this GVC approach provides a carbon label to products. For illustration, we compare the amount of CO_2 emissions associated with each $1 million of goods of electronic and automotive products where the final production stages was in the PRC, the Republic of Korea, Japan, and the US. For example, 3.38 kilotons (kt) of CO_2 were emitted globally in 1995 and 1.41 kt in 2008 to produce $1 million (in constant 1995 prices) worth of electronics final goods in the PRC. For comparison, in 2008 about 0.33 kt of CO_2 was emitted in the production network of electronic products that had their final assembly stage in the US.

Figure 3: Carbon Dioxide Emissions in 2008 by World Input–Output Database Sectors



Note: Industry codes in brackets (see Appendix Table A.1).
Source: Author's elaboration based on World Input–Output Database, release November 2013.

Table 2 suggests that electronic products finalized on the PRC's territory in 2008 generated twice the amount of emissions compared to value chains ending in the Republic of Korea, and more than three times those terminating in Japan and the US. A similar pattern emerges from emissions in the automotive supply chains. Meng, Peters, and Wang (2015) find that the key factors behind such country differences in the WIOD are variations in production techniques (see also Douglas and Nishioka 2012). For example, coal accounts for a larger portion of electricity generation in the PRC than in the US.

Table 2 further suggests that only a small share of carbon emissions is generated in countries operating upstream in the electronics and automotive supply chains with final stage of completion in the PRC. This would appear somewhat surprising in view of the PRC's heavy reliance on foreign parts and components imports for high-end consumer products (Dedrick, Kraemer, and Linden 2009). However, the high-end segment of electronic products does not represent the total basket of electronic products produced in the PRC (Timmer et al. 2014); most electronic products' domestic share of intermediate inputs is at least one half and the majority of emissions are therefore borne domestically. Moreover, some of the heaviest emission factors during production take place domestically, such as the combustion of imported fossil fuels for the generation of electricity.[10]

[10] Our analysis examines where the fuels were burned and the quantity of associated emissions. Davis et al. (2011) additionally examine the source and type of fossil fuel, which is beyond the scope and purpose of this paper.

Table 2: Carbon Dioxide Emissions in Product Global Value Chains

	PRC		Republic of Korea		Japan		United States	
	1995	2008	1995	2008	1995	2008	1995	2008
GVCs of electronic 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**
GVCs of transport 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**

GVCs = global value chains, PRC = People's Republic of China.
Notes: The figures indicate the amount of carbon dioxide in kilotons for each $1 million final output produced in constant 1995 prices.
Source: Authors' computations based on World Input–Output Database, release November 2013; and the World Input–Output Tables in previous years' prices, release December 2014.

Foreign suppliers of high-technology inputs for final assembly in the PRC, such as Japan and the Republic of Korea, are typically associated with relatively low emission intensity. This further explains the low share of foreign emissions associated with GVCs terminating in the PRC. By contrast, Table 2 shows that advanced countries saw foreign emissions along their value chains increase between 1995 and 2008. Advanced countries' offshoring of stages of carbon-intensive GVC production to emerging economies is compatible with this outcome and carbon leakage and global emissions would have risen as a result. However, to quantify the impact of GVCs on country and regional emission patterns, along with the effects of changing consumer demand and energy efficiency, a full GVC production-based analysis is needed. This we turn to next.

III. METHOD

The method we introduce here is an adaptation of the structural decomposition analysis introduced by Los, Timmer, and De Vries (2014) who study drivers in the skill structure of labor demand. Our accounting framework explains total emissions from production in country i ($CO_{2,i}$) as a function of: a column vector of emissions per unit of gross output in each of the n industries in each of the m countries ($\hat{\mathbf{g}}$); a final demand vector of n final products produced by each industry and supplied by m countries ($\mathbf{f}$); the Leontief inverse using the World Input–Output Tables $(\mathbf{I} - \mathbf{B})^{-1}$ to attribute to the final products the direct and indirect emissions along the GVCs;[11] and $\mathbf{u}_k$, which is an appropriately chosen summation vector:[12]

$$CO_{2,i} = \mathbf{u}_k \hat{\mathbf{g}}(\mathbf{I} - \mathbf{B})^{-1}\mathbf{f} \quad (1)$$

[11] The production of intermediate inputs often requires intermediate inputs itself and so forth. The indirect emissions from these additional input requirements are taken into account by using the Leontief inverse.

[12] See chapter 13 of Miller and Blair (2009) for an introduction to structural decomposition analysis. Matrices are indicated by boldfaced capital letters (e.g. B), vectors are columns by definition and are indicated by boldfaced lowercase letters (e.g. q), and scalars (including elements of matrices or vectors) are indicated by italicized letters (e.g. $CO_{2,i}$). A prime indicates transposition (e.g. $\mathbf{u}'_k$). A hat (e.g. $\hat{\mathbf{g}}$) indicates a diagonal matrix, which on its diagonal has the elements of the vector (e.g. g). The symbol ∘ stands for the "Hadamard product," obtained by cell-by-cell multiplication (i.e., W = X ∘ Y implies that $w_{ij} = x_{ij}y_{ij}$, for all i and j). $\mathbf{u}_k$ is a summation vector which contains ones in the cells associated with the industries in the focal country i. All other elements of $\mathbf{u}_k$ are zero.

Various factors drive a country's CO_2 emissions over time. These are changes in environmental energy intensity, which determine $\hat{g}$. Also, there are changes to factors with a bearing on the GVCs' input–output structures, such as a relocation of intermediates production stages, which will affect emissions through the term $\hat{g}(I - B)^{-1}$ in Equation (1). Finally, changes to final demand, such as shifts in consumption patterns or the relocation of final assembly stages, are reflected in vector f.

In turn, the final demand vector of products f in Equation (1) can be broken down into three components: (i) the total final demands by each of the *m* countries, expressed by vector $\hat{c}$; (ii) the final demand shares of each of the *n* products, subsumed in matrix S* by stacking *m* identical *n*x*m*-matrices; and (iii) the final trade coefficients, defined as *m* countries' shares in country *j's* demand for a product, in matrix T stacking *m* *n*x*m*-matrices. Also included is u, an *m*-elements summation vector consisting of ones:

$$\mathrm{f} = [\mathbf{T}^* \circ (\mathbf{S}^* \cdot \hat{\mathbf{c}})]\mathbf{u} \quad (2)$$

Equation (2) may be thought of as being influenced by three factors determining the global demand for goods and services and thus the CO_2 emissions associated with their production. Firstly, total final demand is affected directly by a countries' income: when gross domestic product grows, so does total final demand. Secondly, changing consumers' preferences affect the composition of consumption bundles through so-called Engel effects. For example, rising per capita incomes may affect over time the consumption bundle of, say, Chinese consumers, increasing their demand for meat and cars. Thirdly, shifts in consumer preferences affect countries' market shares over time. Together, these three factors affect the relative size of each of the *mxn* GVCs operating in the global economy and, with it, the amount of CO_2 they emit.

Apart from final demand and the international trade in intermediate and final goods and services it generates, global emissions will reflect technological factors determining the energy intensity of production, as well as by changes in the type and composition of activities countries are specializing in. To quantify these effects, note that the amount of global emissions (g^w) associated with the production per unit value of each of the *mn* final products is given by $g^{w'} \equiv g'(I - B)^{-1}$ (see Table 2 in the previous section for several country-product examples). Since the WIOD includes data on the *mn* industries and their CO_2 emissions as well as on the *mn* GVCs these emissions relate to, we are able to compute a *mn*x*mn*-matrix that contains the shares of each of the *mn* industries in total emissions per unit of final demand produced by any of the *mn* GVCs. In such a matrix R, rows represent the industries and columns the GVCs in which emissions originate:

$$R = \{\hat{g}(I - B)^{-1}\}(\hat{g}^w)^{-1} \quad (3)$$

We can now substitute Equations (2) and (3) into (1) and express it in relation to a time period 0 and country *i*:

$$CO_{2,i0} = \mathrm{u}'_k \mathrm{R}_0 \hat{\mathrm{g}}^w_0 [\mathrm{T}^*_0 \circ (\mathrm{S}^*_0 \cdot \hat{\mathrm{c}}_0)]\mathrm{u}. \quad (4)$$

Equation (4) can be expressed in terms of a change in country *i*'s CO_2 emissions between two discrete time periods, 0 and 1, which allows us to disentangle five components that account for such a change:[13]

$$CO_{2,i1} - CO_{2,i0} = u_k' R_1 \hat{g}_1^w [T_1^{*} \circ \ (S_1^* \cdot \hat{c}_1)]u - u_k' R_0 \hat{g}_0^w [T_0^{*} \circ \ (S_0^* \cdot \hat{c}_0)]u =$$

$$u_k' \langle R_1 - R_0 \rangle \hat{g}_1^w [T_1^{*} \circ \ (S_1^* \cdot \hat{c}_1)]u + \tag{5a}$$

$$u_k' R_0 \langle \hat{g}_1^w - \hat{g}_0^w \rangle [T_1^{*} \circ \ (S_1^* \cdot \hat{c}_1)]u + \tag{5b}$$

$$u_k' R_0 \hat{g}_0^w [\langle T_1^* - T_0^* \rangle \circ \ (S_1^* \cdot \hat{c}_1)]u + \tag{5c}$$

$$u_k' R_0 \hat{g}_0^w [T_0^{*} \circ \ (\langle S_1^* - S_0^* \rangle \cdot \hat{c}_1)]u + \tag{5d}$$

$$u_k' R_0 \hat{g}_0^w [T_0^{*} \circ \ (S_0^* \cdot \langle \hat{c}_1 - \hat{c}_0 \rangle)]u \tag{5e}$$

The decomposition in Equation (5) isolates the partial effects of each of the five determinants, which jointly are exhaustive of the total change in a country's emissions. The individual elements of this equation are interpreted in Table 3. Their bearing on a country's total CO_2 emissions from production is explained in terms of supply chain trade, GVC emission intensity, and consumption.

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

[13] The decomposition analysis represented by Equations (5a–5e) is not a unique solution. It alters with the choice of weights applied to the individual expressions and can give rise to 120 (5*!*) possible decompositions (see Dietzenbacher and Los 1998). The results presented in the next section are an arithmetic average over Equations (5a–5e) 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 roughly corresponds to the average of the two polar decompositions.

Table 3: The Determinants of Change in an Economy's Total Carbon Dioxide Emissions

Determinant	Equation (5) term	Descriptive examples
Global value chains trade	5a. Relocation of intermediates production	Japanese hard disk drive production facilities and related carbon emissions move to Thailand. The PRC starts sourcing certain electronic parts domestically, instead of relying on US imports.
	5c. Changes in the location of final assembly	Laptop assembly and related emissions moves from Taipei,China to the PRC, due to lead firms' strategic search of locational advantages or changes in consumer preferences.
GVC emission intensity	5b. Changes in the amount of emissions generated along the GVC	Asian GVCs centered on the PRC's assembly and other supplying economies increase the energy efficiency of production over time. Emissions fall as a result.
Consumption	5d. Changes in the consumption bundle	Consumer preference shifts toward products that are more energy-intensive along their GVCs. Relative demand for these products increases and so do the emissions by economies involved in these GVCs.
	5e. Changes in consumption levels	Expanding GDP increases the demand for final goods and the emissions associated with their production.

GDP = gross domestic product, GVCs = global value chains, PRC = People's Republic of China, US = United States.
Source: Authors' compilation.

IV. CONSUMPTION, TECHNOLOGY, AND SUPPLY CHAIN TRADE AS DRIVERS OF CARBON DIOXIDE EMISSIONS

To eliminate the impact of price effects, we compute Equation (5) in terms of volumes, rather than current values. Specifically, we use the World Input–Output Tables in previous years' prices and apply a suitable chaining technique.[14]

Table 4 summarizes the results of the decomposition analysis for a select group of economies and regions. Shown are total emissions in 1995 and 2008—equal to the total emissions from production in Table 1—as well as the five factors accounting for the change in emissions between the two periods. Changes in consumption levels—in the third last column—are further broken down into changes in domestic and foreign consumption levels.

[14] We use the World Input–Output Tables in previous years' prices, released in December 2014 (www.wiod.org). Because output prices typically increase over the years due to inflation, emissions per unit of gross output in the vector **g** and hence, the relative importance of the various drivers would be biased if output values in current prices were 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 Equation (5).This chaining technique is also used and further explained in de Haan (2001) and Xu and Dietzenbacher (2014).

Table 4: Global Value Chains Carbon Dioxide Emissions Accounting

				Change in emissions accounted for by changes in:						
				Trade		Technology	Consumption			
Location of Production	Total Emissions 1995	Total Emissions 2008	Change in Emissions 2008 Minus 1995	Location of Intermediate Stages	Location of Final Assembly	GVC Emissions	Consumption Preferences	Global Consumption Levels	o/w domestic	o/w foreign
Asia	5.191	9.426	4.235	631	739	−2.231	142	4.954	4.221	733
People's Republic of China	2.723	5.923	3.200	550	673	−1.706	89	3.594	3.216	379
Republic of Korea	372	522	149	19	19	−91	3	199	120	79
Taipei,China	178	289	111	37	5	−57	23	104	42	62
India	721	1.367	646	14	36	−226	44	779	704	75
Indonesia	173	304	131	26	20	−15	0.01	100	65	35
Japan	1.024	1.021	−3	−14	−13	−136	−17	178	74	104
Europe	3.381	3.431	51	−287	−40	−899	−43	1.319	828	492
Europe Advanced 15	2.638	2.757	119	−199	−79	−546	−4	946	549	397
of which: Germany	725	690	−34	−24	−1	−173	2	162	60	102
Europe Emerging 12	742	675	−68	−87	39	−353	−40	373	279	95
NAFTA	5.000	5.359	359	−426	−137	−1.040	−347	2.309	2.018	290
United States	4.342	4.550	208	−381	−131	−909	−307	1.935	1.745	190
Canada	398	456	58	−18	2	−99	−28	200	125	75
Mexico	260	353	93	−27	−8	−33	−11	173	148	25
Others	1.997	2.399	402	−74	−66	−585	−197	1.324	1.012	312
Brazil	175	274	99	14	4	−7	−3	90	71	19
Turkey	139	242	102	36	7	−34	−6	99	83	16
Russian Federation	1.412	1.515	103	−101	−63	−527	−166	961	720	241
Australia	271	369	98	−24	−14	−16	−21	174	138	36
Rest of the world	3.377	4.982	1.605	156	122	−1.018	468	1.877	1.382	495
World	18.946	25.598	6.651	−0.01	619	−5.774	24	11.783		

GVC = global value chain, NAFTA = North American Free Trade Agreement.
Notes: Emission in megatons (Mt). Share is in percentage of world total. Growth is the percentage change between 1995 and 2008. Europe Advanced 15 comprises Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom. Europe Emerging 12 comprises Bulgaria, Cyprus, Czechoslovakia, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. Detailed results for European countries are shown in Appendix Table A.3.
Source: Authors' computations based on World Input–Output Database, release November 2013; and the World Input–Output Tables in previous years' prices, release December 2014.

Take the case of the PRC, the largest emitter of CO_2 emissions in the final year of our analysis. Total CO_2 emissions more than doubled, from 2,723 Mt in 1995 to 5,923 Mt in 2008. The relocation of intermediate and final stages of production accounted for 550 Mt and 673 Mt respectively, or roughly a third of the increase in Chinese emissions, totaling 3,200 Mt. However, Table 4 also shows that these supply chain trade-related effects are countered by a massive 1,706 Mt reduction in emissions due to technological improvements, which reduced the energy and carbon intensity of GVC production in the period from 1995 to 2008. This finding reflects a marked fall in the PRC's energy intensity of production, which is known to have outstripped steady advances also in other regions and the world as a whole, although it is still at higher levels than in advanced economies.

Per capita gross domestic product in the PRC nearly tripled between 1995 and 2008 (IMF 2015). Consumption by Chinese citizens grew as a result. Rising levels of domestic consumption account for the largest change of CO_2 emissions in the PRC since 1995 and equal to 3,216 Mt in 2008. At 379 Mt, the foreign share of changes from consumption is sizable. Jointly with the GVC trade effects of intermediate and final assembly relocation, this adds up to 1,602 Mt of emissions that may be ascribed largely to foreign determinants of Chinese territorial emissions.[15] However, more than 90% of the consumption-related increase in Chinese carbon emissions is accounted for by an increase in Chinese domestic consumption. That is, decomposition analysis shows the expansion of domestic consumption to bear twice as heavily on Chinese CO_2 emissions growth than do supply chain trade and foreign consumption.[16] Table 4 also suggests that variations in the composition of consumption play a relatively minor role in the PRC and elsewhere. The preference of Chinese consumers shifted toward the consumption of goods that embody more emissions, but this effect added merely 89 Mt to the country's CO_2 emissions.[17]

Consumption accounts for the largest share of emission growth also for the other Asian emerging economies. Except India, a large country itself, foreign consumption in smaller economies tends to play a relatively larger role than in the PRC. Technological advance partly offset emission growth in all the Asian economies. The relocation over time of GVC intermediates production and assembly raised emissions in these economies too, but relative magnitudes suggest that they were less important than in the PRC. Japan stands out among Asian and other countries, in that it slightly reduced territorial CO_2 emissions by 2008. Technological efficiency, production relocation, and other factors more than outweigh the upward pressure on carbon emissions from changes in consumption levels.

The EU only slightly increased its CO_2 emissions 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, displays a drop in carbon emissions, helped by the offshoring of intermediate stages of production, substantial technological gains, and moderate changes in final assembly activities. Interestingly, the EU's 12 emerging economies as a group also experienced a fall in CO_2 emissions, due to strong technological gains and the relocation and declining importance of (partly heavy industry) intermediate stages of production.

---

15 Note these emissions attributed to foreign factors are qualitatively close to the net transfers from trade reported in Table 1, but deviates because the concepts and methods are substantially different.

16 This confirms the results of scenario analysis in Guan et al. (2008).

17 The change in emissions is also in part due to shifts in the consumption bundle of foreign consumers toward products in which the PRC is active in its GVC. The majority of the change, however, is accounted for by changes in the consumption bundle in the PRC itself. Detailed results are available upon request.

The US and NAFTA more broadly experienced a substantial increase in CO_2 emissions driven mainly by higher levels of domestic consumption, which was less than offset by other factors. Interestingly, Mexico's emissions lowered due to the offshoring of both intermediate and assembly GVC processes, despite the importance of its maquiladora trade with the US and likely in reflection also of the rise of the PRC 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 CO_2 levels in 1995, emissions in the Russian Federation grew by less than other countries' in this aggregate, mainly because of high offsets by the GVC trade effects. The ROW aggregate is associated with a 1,605 Mt increase in CO_2 emissions, mostly accounted for by domestic consumption and a net increase in intermediates production and assembly.

Finally, for the world as a whole, the last row of Table 4 shows that emissions growth was propelled by a rapid rise in global consumption levels. The increase in global CO_2 emissions would have been almost twice as high if not for the rapid improvement in energy efficiency. Within the world aggregate, the net effects from relocation of intermediate stages are nearly balanced. This suggests that the relocation of production stages across economies did not contribute to CO_2 emissions in the aggregate, in contrast to the product examples discussed in Section 2. But it is evident that in the aggregate, the final assembly stages have moved toward economies that emit more greenhouse gasses per unit of output.

Ensuing from this analysis is a picture akin to the network graph in Figure 2, which shows international CO_2 emission transfers increase mainly in connection with the PRC, the US, and the ROW, in reflection of the fragmentation and internationalization of production and the concomitant rise in consumption, both in the advanced and the emerging world.

V. CONCLUDING REMARKS

Climate policy negotiations typically involve commitments about the reduction of greenhouse gas emissions that take place within national borders. However, the rise of GVCs has dramatically changed the nature of production and international trade, blurring the attribution of ultimate responsibility for CO_2 emissions. This paper implemented a novel method that accounts for supply chain trade, technology, and consumption as the drivers of territorial CO_2 emissions.

Our findings suggest that emissions expanded mainly because of rising levels of domestic consumption between 1995 and 2008. A substantial share of rising emission levels in emerging economies is explained by increased participation in global production networks and serving expanding foreign consumption. However, even for emerging economies that rapidly integrated in global production networks, such as the PRC and to a lesser extent India and Indonesia, the increase of CO_2 emissions between 1995 and 2008 is mainly on account of rising levels of domestic consumption. For all the 40 advanced and emerging economies that we analyzed, we find evidence that energy efficiency improved dramatically, effectively stemming against the spike in emissions from higher consumer demand.

Our analysis is grounded in a relatively simple model that has its limitations. It is an ex post accounting exercise in which final demand is considered exogenous. The various drivers of changes in a country's CO_2 emissions are "proximate sources" that are not necessarily independent. Further analysis in a more encompassing framework is needed to uncover the deeper determinants. Future research may also seek to apply the method introduced here to other environmental factors, such as land, water, and waste for a more encompassing assessment of humanity's footprint (Hoekstra and Wiedmann 2014). Furthermore, considerable scope remains for World Input–Output Tables to expand country coverage and improve data quality, for example, by explicitly incorporating information about the separate production processes of firms that produce for the domestic and foreign markets (Timmer et al. 2015). Distinguishing processing exports from regular exports and domestic use would improve the reliability of estimated carbon leakage in relation to the PRC and other economies heavily involved in global production networks. Also, major changes are taking place in the sourcing of fossil fuels, and increasingly, electricity is generated from renewable sources. More recent data is needed to analyze the implications of these changes.

APPENDIX

Table A.1: World Input–Output Database List of Sectors or Industries

#	ISIC rev 3.1	Label
1	AtB	AGRICULTURE, HUNTING, FORESTRY, AND FISHING
2	C	MINING AND QUARRYING
3	15t16	FOOD , BEVERAGES, AND TOBACCO
4	17t18	Textiles and textile
5	19	Leather, leather and footwear
6	20	WOOD, AND OF WOOD AND CORK
7	21t22	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 NONMETALLIC MINERAL
12	27t28	BASIC METALS AND FABRICATED METAL
13	29	MACHINERY, NEC
14	30t33	ELECTRICAL AND OPTICAL EQUIPMENT
15	34t35	TRANSPORT EQUIPMENT
16	36t37	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	Other inland transport
24	61	Other water transport
25	62	Other air transport
26	63	Other supporting and auxiliary transport activities, activities of travel agencies
27	64	POST AND TELECOMMUNICATIONS
28	J	FINANCIAL INTERMEDIATION
29	70	Real estate activities
30	71t74	Renting of machinery and 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

Source: World Input–Output Database, release November 2013.

Table A.2: Total Carbon Dioxide Emissions in European Countries, 1995 and 2008

	Carbon Dioxide Production					Carbon Dioxide Consumption					Carbon Dioxide Net Transfers			
	1995		2008			1995		2008			1995		2008	
	Emissions	Share	Emissions	Share	Growth	Emissions	Share	Emissions	Share	Growth	Emissions	Share	Emissions	Share
Austria	44	0.23	54	0.21	24	78	0.41	86	0.34	10	35	79	32	59
Belgium	101	0.53	96	0.38	–4	103	0.54	127	0.50	23	2	2	31	32
Bulgaria	57	0.30	49	0.19	–14	35	0.18	37	0.15	8	–22	–39	–11	–23
Cyprus	4	0.02	7	0.03	60	8	0.04	12	0.05	64	3	73	5	77
Czech Republic	107	0.56	101	0.40	–5	90	0.47	97	0.38	8	–17	–16	–4	–4
Germany	725	3.83	690	2.70	–5	939	4.96	862	3.37	–8	214	30	171	25
Denmark	64	0.34	100	0.39	56	65	0.34	66	0.26	1	1	2	–34	–34
Spain	203	1.07	261	1.02	28	238	1.26	365	1.43	53	35	17	105	40
Estonia	17	0.09	16	0.06	–6	13	0.07	14	0.06	12	–4	–24	–1	–9
Finland	53	0.28	57	0.22	6	56	0.30	68	0.27	21	3	6	12	20
France	284	1.50	273	1.07	–4	384	2.03	462	1.81	20	100	35	189	70
United Kingdom	451	2.38	449	1.75	0	499	2.63	596	2.33	20	48	11	147	33
Greece	75	0.40	93	0.37	24	92	0.48	143	0.56	56	16	22	49	53
Hungary	48	0.25	46	0.18	–5	50	0.26	57	0.22	13	2	4	11	24
Ireland	26	0.14	32	0.12	24	28	0.15	54	0.21	93	3	10	23	71
Italy	360	1.90	378	1.48	5	434	2.29	509	1.99	17	74	20	131	35
Lithuania	13	0.07	13	0.05	2	14	0.07	21	0.08	50	1	7	8	57
Luxembourg	6	0.03	3	0.01	–53	6	0.03	7	0.03	15	0	–5	4	135
Latvia	9	0.05	8	0.03	–7	10	0.05	13	0.05	37	1	10	5	61
Malta	2	0.01	2	0.01	22	3	0.02	3	0.01	12	1	57	1	44
Netherlands	154	0.81	169	0.66	10	157	0.83	186	0.73	19	3	2	17	10
Poland	314	1.66	290	1.13	–8	255	1.35	281	1.10	10	–59	–19	–10	–3
Portugal	46	0.24	53	0.21	15	54	0.28	67	0.26	25	7	16	14	26
Romania	120	0.64	90	0.35	–25	101	0.53	103	0.40	2	–20	–17	13	14
Slovakia	40	0.21	37	0.14	–8	29	0.15	37	0.15	31	–11	–28	1	2
Slovenia	11	0.06	15	0.06	36	13	0.07	19	0.08	51	2	17	5	31
Sweden	47	0.25	49	0.19	5	66	0.35	84	0.33	27	19	41	34	69
World	18.946	100	25.598	100	35	18.946	100	25.598	100	35	0	0	0	0

Notes: Emission in megatons (Mt). Share is in percentage of world total except for last columns (on CO_2 net transfers) which show the share in emission from production in the country. Growth is the percentage change between 1995 and 2008.
Source: Authors’ computations based on World Input–Output Database, release November 2013.

Table A.3: Global Value Chains Carbon Dioxide Emissions Accounting for European Countries

				Change in Emissions Accounted for by Changes in:						
				Trade		Technology	Consumption			
Location of Production	Total Emissions 1995	Total Emissions 2008	Change in Emissions 2008 Minus 1995	Location of Intermediate Stages	Location of Final Assembly	GVC Emissions	Consumption Preferences	Global Consumption Levels	o/w domestic	o/w foreign
Austria	44	54	10	4	2	–9	–1	15	6	9
Belgium	101	96	–4	–20	–2	–16	–2	36	11	25
Bulgaria	57	49	–8	–8	–3	–29	6	26	15	11
Cyprus	4	7	3	0	0	–1	1	3	3	1
Czech Republic	107	101	–5	–10	8	–42	0	39	23	16
Germany	725	690	–34	–24	–1	–173	2	162	60	102
Denmark	64	100	36	24	0	–15	–2	29	9	20
Spain	203	261	58	–17	–3	–44	2	119	93	26
Estonia	17	16	–1	–1	9	–8	–14	13	10	3
Finland	53	57	3	–5	–1	–17	1	25	14	11
France	284	273	–11	–58	11	–52	–14	101	61	40
United Kingdom	451	449	–2	–69	–42	–93	2	201	141	60
Greece	75	93	18	–6	–21	–19	21	43	40	3
Hungary	48	46	–2	–2	1	–16	–6	20	13	7
Ireland	26	32	6	–5	1	–11	2	19	14	5
Italy	360	378	18	–3	–17	–50	–10	98	52	45
Lithuania	13	13	0	0	0	–8	–1	9	6	3
Luxembourg	6	3	–3	–4	0	–1	0	2	1	1
Latvia	9	8	–1	0	0	–6	–1	6	4	1
Malta	2	2	0	0	0	0	0	1	1	0
Netherlands	154	169	15	–7	–3	–26	–7	58	25	34
Poland	314	290	–24	–37	22	–163	–17	171	139	32
Portugal	46	53	7	–2	–2	–11	2	20	14	6
Romania	120	90	–30	–25	–3	–60	–5	62	50	12
Slovakia	40	37	–3	–7	5	–20	0	19	11	8
Slovenia	11	15	4	0	0	–2	–1	6	4	2
Sweden	47	49	3	–7	–2	–8	0	19	8	10

GVC = global value chain.
Notes: Emission in megatons (Mt). Share is in percentage of world total. Growth is the percentage change between 1995 and 2008.
Source: Authors' computations based on World Input–Output Database, release November 2013.

REFERENCES

Ahmad, N. and A. Wyckoff. 2003. Carbon Dioxide Emissions Embodied in International Trade of Goods. OECD Science, Technology and Industry Working Papers 2003/15. OECD Publishing.

Arto, I. and E. Dietzenbacher. 2014. Drivers of the Growth in Global Greenhouse Gas Emissions. *Environment Science and Technology*. 48 (10). pp. 5388–94.

Asian Development Bank (ADB). 2015. *Asian Development Outlook 2015.* Manila.

Baldwin, R. 2014. The Development and Future of Factory Asia. In B. Ferrarini and D. Hummels, eds. *Asia and Global Production Networks*. Cheltenham, UK: Edward Elgar.

Davis, S. J. and K. Caldeira. 2010. Consumption-based Accounting of CO2 Emissions. Proceedings of the National Academy of Sciences of the United States of America (PNAS). 107 (12). pp. 5687–92.

Davis, S. J., G. P. Peters, and K. Caldeira. 2011. The Supply Chain of CO_2 Emissions. Proceedings of the National Academy of Sciences of the United States of America (PNAS). 108 (45). pp. 18554–59.

de Haan, M. 2001. A Structural Decomposition Analysis of Pollution in the Netherlands. *Economic Systems Research.* 13 (2). pp. 181–96.

Dedrick, J., K. L. Kraemer, and G. Linden. 2009. Who Profits From Innovation In Global Value Chains?: A Study Of The Ipod And Notebook Pcs. *Industrial and Corporate Change.* 19 (1). pp. 81–116.

Dietzenbacher, E. and B. Los. 1998. Structural Decomposition Techniques: Sense and Sensitivity. *Economic Systems Research.*10 (4). pp. 307–23.

Douglas, S. and S. Nishioka. 2012. International Differences in Emissions Intensity and Emissions Content of Global Trade. *Journal of Development Economics.* 99 (2). pp. 415–27.

Ferrarini, B. and D. Hummels. 2014. Asia and Global Production Networks: Implications for Trade, Incomes and Economic Vulnerability. In B. Ferrarini and D. Hummels, eds. *Asia and Global Production Networks: Implications for Trade, Incomes and Economic Vulnerability.* Cheltenham, UK: Edward Elgar.

Genty, A., I. Arto, and F. Neuwahl. 2012. Final Database of Environmental Satellite Accounts: Technical Report on Their Compilation. WIOD Deliverable 4.6. http://www.wiod.org/publications/source_docs/Environmental_Sources.pdf

Guan, D., K. Hubacek, C. L. Weber, G. P. Peters, and D. M. Reiner. 2008. The Drivers of Chinese CO_2 Emissions from 1980 to 2030. *Global Environmental Change.* 18 (4). pp. 626–34.

Hoekstra, A. Y. and T. O. Wiedmann. 2014. Humanity's Unsustainable Environmental Footprint. *Science.* 344 (6188). pp. 1114–17.

Intergovernmental Panel on Climate Change (IPCC). 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C. B., V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K. L. Ebi, Y. O. Estrada, R. C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, and L. L. White (eds.)] Cambridge, UK and New York, NY: Cambridge University Press. 1132 pp.

International Monetary Fund (IMF). 2015. World Economic Outlook April 2015 database. https://www.imf.org/external/pubs/ft/weo/2015/01/weodata/index.aspx (accessed 15 May 2015)

Johnson, R. C. and G. Noguera. 2012. Accounting for Intermediates: Production Sharing and Trade in Value Added. *Journal of International Economics.* 86 (2). pp. 224–36.

Kander, A., M. Jilborn, D. D. Moran, and T. O. Wiedmann. 2015. National Greenhouse-Gas Accounting for Effective Climate Policy on International Trade. *Nature Climate Change.* 5 (5). pp. 431–35.

Los, B., M. P. Timmer, and G. J. De Vries. 2014. The Demand for Skills 1995-2008: A Global Supply Chain Perspective. OECD Economics Department Working Papers No. 1141. Paris: OECD Publishing.

Meng, B., G. Peters, and Z. Wang. 2015. Tracing CO_2 Emissions in Global Value Chains. IDE Discussion Paper No. 486. Institute of Developing Economies.

Miller, R. E. and P. D. Blair. 2009. *Input-Output Analysis: Foundations and Extensions*. Second Edition. Cambridge: Cambridge University Press.

Peters, G. 2012. Carbon Footprints and the Role of International Trade in Climate Policy. Keynote address at the final WIOD conference, University of Groningen. April 2012. Slides available at http://www.wiod.org/new_site/project/conferences.htm#final

Peters, G. P., J. C. Minx, C. L. Weber, O. Edenhofer. 2011. Growth in Emission Transfers via International Trade from 1990 to 2008. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS). 108 (21). pp. 8903–08.

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

Timmer, M. P., A. A. Erumban, B. Los, R. Stehrer, G. J. De Vries. 2014. Slicing Up Global Value Chains. *Journal of Economic Perspectives.* 28 (2). pp. 99–118.

Wiedmann, T. O. 2009. A Review of Recent Multi-region Input-Output Models Used for Consumption-based Emission and Resource Accounting. *Ecological Economics.* 69 (2). pp. 211–22.

World Bank. 2015. World Development Indicators, April 2015. http://databank.worldbank.org accessed online 5 May 2015.

Xu, Y. and E. Dietzenbacher. 2014. A Structural Decomposition Analysis of the Emissions Embodied in Trade. *Ecological Economics.* 101. pp.10–20.

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

This paper examines the changes in territorial carbon dioxide emissions due to changes in energy intensity within global production networks, supply chain participation, and domestic and foreign consumption. It finds that a substantial share of emissions growth in emerging economies is explained by higher participation in global production networks that serve expanding foreign consumption. However, even for countries that most rapidly integrated in global production networks, such as the People's Republic of China, rising domestic consumption accounts for the bulk of territorial emissions. Improved energy efficiency partially stemmed the spike in emissions from higher consumer demand.

About the Asian Development Bank

ADB's vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region's many successes, it remains home to the majority of the world's poor. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

ADB

ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org