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.

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 gases. 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 gases 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
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 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.wiiod.org.

We briefly introduce notation and the derivation of production and consumption accounts (see Peters (2008) for a detailed exposition). Let \( g = 1, \ldots, G \) index the 35 industries, and let \( i \) and \( j \) index the 40 countries plus the RoW region distinguished in the WIOTs. Let \( f \) be the \( G \times 1 \) vector of CO2 emissions from each country-industry with typical element, \( f(g) \), the CO2 emissions per unit of gross output of industry \( g \) in country \( i \). 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 \( \epsilon_{ij} \) 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 \( z_i \) be a \( G \times 1 \) vector denoting country j’s usage of intermediate inputs from country i. The \( G \times 1 \) vector of output \( y_i \) from country i is split between consumption and intermediate inputs:

\[
y_i = \sum_j (\epsilon_{ij} + z_i)
\]

Next, let \( a_{ij}(g,h) = z_{i}(g,h)/y_{i}(h) \) 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 ≠ j). Hence, \( a_{ij} \) 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 \( A \) with dimensions \( G \times GN \) that tracks the movement of intermediate inputs across countries and industries:

\[
A = [A_{11} A_{12} \ldots A_{1N} \\
A_{21} A_{22} \ldots A_{2N} \\
\vdots \vdots \ddots \vdots \\
A_{N1} A_{N2} \ldots A_{NN}]
\]

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 \( A \) summarizes the flows of all intermediate goods and using this we can rewrite the stacked market clearing conditions from Eq. (1) as

\[
[\begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_N
\end{bmatrix} = [\begin{bmatrix}
    A_{11} & A_{12} & \cdots & A_{1N} \\
    A_{21} & A_{22} & \cdots & A_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    A_{N1} & A_{N2} & \cdots & A_{NN}
\end{bmatrix} \begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_N
\end{bmatrix}] + \begin{bmatrix}
    c_{11} & c_{12} & \cdots & c_{1N} \\
    c_{21} & c_{22} & \cdots & c_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    c_{N1} & c_{N2} & \cdots & c_{NN}
\end{bmatrix} \begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_N
\end{bmatrix} + \begin{bmatrix}
    \epsilon_{11} & \epsilon_{12} & \cdots & \epsilon_{1N} \\
    \epsilon_{21} & \epsilon_{22} & \cdots & \epsilon_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    \epsilon_{N1} & \epsilon_{N2} & \cdots & \epsilon_{NN}
\end{bmatrix} \begin{bmatrix}
    1 & 1 & \cdots & 1
\end{bmatrix}
\]

Below the following will be useful:

\[
C = [\begin{bmatrix}
    c_{11} & c_{12} & \cdots & c_{1N} \\
    c_{21} & c_{22} & \cdots & c_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    c_{N1} & c_{N2} & \cdots & c_{NN}
\end{bmatrix} \begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_N
\end{bmatrix} + \begin{bmatrix}
    \epsilon_{11} & \epsilon_{12} & \cdots & \epsilon_{1N} \\
    \epsilon_{21} & \epsilon_{22} & \cdots & \epsilon_{2N} \\
    \vdots & \vdots & \ddots & \vdots \\
    \epsilon_{N1} & \epsilon_{N2} & \cdots & \epsilon_{NN}
\end{bmatrix} \begin{bmatrix}
    1 & 1 & \cdots & 1
\end{bmatrix} = \begin{bmatrix}
    y_1 \\
    y_2 \\
    \vdots \\
    y_N
\end{bmatrix}
\]

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

\[
y = (I-A)^{-1}C \epsilon
\]

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

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).
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