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Global value chain, trade and carbon: Case of information and communication technology manufacturing sector

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ABSTRACT

This paper investigates the slicing up the value chain and the accompanied carbon dioxide emissions linked to the international trade of global information and communication technology (ICT) manufacturing sector, the most dynamic and globally dispersed sector in the world economy. Based on an inter-country input–output database WIOD, we trace the changes of value-added and the carbon dioxide emissions that are embodied in the international trade of ICT final products in 1995–2008. The results show that the emerging economies are largely benefited by involving in global ICT productions, for which advanced economies have always been major consumers and importers. Although the emerging economies experienced much faster upgrades in carbon-intensity-related technologies, in 2008 the advanced economies still emitted less carbon dioxide and obtained more added value than emerging economies, for identical amount of exports of ICT final products.

Introduction

In recent years, two interrelated important phenomena in international trade have attracted a great deal of interests by researchers, policy makers and general public. The first one is the slicing up the value chain, where the production processes are sliced into many stages in different locations, including different countries[1]. As a result, the international trade is increasingly dominated by the trade in parts and components. It then has been argued explicitly that standard trade statistics on final products do not give accurate information anymore about the actual value which a country adds in the global production process, especially for a country which has to import a large amount of intermediate inputs to assemble its exports, such as China. Instead of traditional trade statistics, the domestic value-added contents (DVA) in global trade have gradually become a focus not only for academia (see, e.g. Chen et al., 2004; Lau et al., 2006; Koopman et al., 2012, 2014), but also for governmental agencies and international organizations, such as WTO, OECD and UNCTAD[2].

The second phenomenon is the carbon dioxide emission embodied in international trade. Carbon emission embodied in international trade has been extensively measured since it causes a geographic separation between the carbon content of goods consumed in a country and the carbon emitted by a country in the production of goods (see, e.g. Davis and Caldeira, 2010; Peters et al., 2011; Boitier, 2012). Peters et al. (2011), for example, estimated that total CO_2 emissions embodied in global international trade have increased from 4.3 Gt CO_2 in 1990 (20% of global CO_2 emissions from fuel combustion) to 7.8 Gt in 2008 (26% of global CO_2 emissions from fuel combustion).

Yet in both the academic and policy literature, the phenomena of domestic value added (DVA) and carbon embodied in trade have been studied quite separately, with various methods and data sources. Most of the carbon literature has focused on the argument on consumer/producer responsibilities, that is, the carbon dioxide emissions associated with the production of goods should be attributed, in emission inventories, to the country in which the goods are consumed, rather than the country in which they are produced. Attributing emissions to the producer, it is thus argued, amounts to an unfair assignment of responsibility to producers, which are often the developing countries or emerging economies (Ahmad and Wyckoff, 2003; Davis et al., 2011; Boitier, 2012; Kanemoto et al., 2012). In contrast, there are also

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[1] Although the term “slicing up the value chain” originated with Krugman (1996), there are many other terms for the same phenomenon. The most frequent in the literature include: delocalisation (Leamer, 1996), intra-product specialization (Arndt, 1997), disintegration (Feenstra, 1998), global production sharing (Yeats, 1998), outsourcing (Grossman and Helpman, 2002), international fragmentation of production (Jones and Kierzkowski, 1990), and vertical specialization (Hummels et al., 2001). See Deardorff's Glossary of International Economics, available at http://www.personal.umich.edu/~alandear/glossary/.

[2] See a joint report initiated by OECD, WTO and UNCTAD (2013), Implications of Global Value Chains for Trade, Investment, Development and Jobs, at http://www.oecd.org/trade/G20-Global-Value-Chains-2013.pdf.

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sound bases for current "producer responsibilities", mainly due to the argument that the country which receives economic benefits from exports is supposed to be responsible for the carbon emission linked to exports (Ashton and Wang, 2003). This viewpoint, however, fails to take into account the benefits actually received by the exporting country. Though the literature on global value chain generally suggests that the emerging countries are poorly compensated by specializations in the assembling, testing and packaging activities, most of them are concluded based on case study at firms' or products' level.[3] There is very little literature providing both measurements on value added and the carbon embodied in international trade, based on an authoritative database. It would be misleading to attribute emissions to a country without considering the value added by various countries in the value chain and without considering the emissions caused at each stage in the value chain.

In this paper, we plan to trace value-added and carbon dioxide emissions generated in the entire global production chain of Information and Communication Technology (ICT) manufacturing sector.[4] Arto et al. (2014) compared embedded carbon emissions and jobs from trade, by introducing jobs generated from trade to indicate economic benefits. The amount of jobs however highly depends on labor productivity, which varies across sectors and countries. Instead of jobs, we use domestic value-added (DVA) as the indicator of economic benefit in this paper.

The ICT manufacturing sector is selected as typology case for the following three reasons. Firstly, ICT manufacturing sector is a typical high-fragmented sector, for which productions of different stages are geographically dispersed. Linden et al. (2011) found that more than 70% of value-added generated by iPod's exports from China is captured by the U.S., Japan, Korea and Taiwan. Secondly, the exports of ICT products persistently account for 15% of the global commodity exports in the past decade (Vogiatzoglou, 2009)[5] and therefore it is a very representative tradable good. Thirdly, the input materials of ICT products have significant embedded carbon contents (Fettweis and Zimmermann, 2008).

The empirical analysis in this paper is based on the World Input–Output Database (WIOD) which provides time-series of inter-country input–output tables for 40 countries (Dietzenbacher et al., 2013).[6] Due to its clear description of inter-country and inter-sector flows along global production process, the input–output technique has been widely accepted to measure both DVA (see Koopman et al. (2014) for a review) and the carbon embodied in international trade (see Wiedmann (2009) and Wiedmann et al. (2011) for a review). To highlight the analysis, we focus the measurements in six major economies: EU-27, the United States, East Asia (including Japan, South Korea and Taiwan), China, a group of selected emerging economies BRIIMT (Brazil, Russian Federation, India, Indonesia, Mexico and Turkey) and RoW (Rest of World). Following the definition of ICT sector by OECD (2002), we considered sector 14 in WIOD (Electrical and Optical Equipment) as the ICT manufacturing sector. Although the WIOD presents time series for 1995 through 2009[7], our analysis only covers the period from 1995 to 2008, in 2009 the global financial crisis obscured the developments of ICT manufacturing fragmentation that we are looking for.

[3] Examples include Antras (2003, 2005), Antras and Helpman (2004), Grossman and Helpman (2004, 2005), McLaren (2000), Feenstra and Hanson (2005), and Feenstra and Spencer (2005). See Spencer (2005) for an excellent survey.

[4] Ever since 1998, OECD member countries agreed to define the ICT sector as a combination of manufacturing and services industries that capture, transmit and display data and information electronically (OECD, 2002).

[5] See Vogiatzoglou (2009), based on the World Trade Organization international trade database.

[6] The project was funded by the European Commission, Research Directorate General as part of the 7th Framework Programme, Theme 8: Socio-Economic Sciences and Humanities.

[7] The inter-country input–output database of WIOD actually covers period 1995–2011, but the carbon emission accounts are released only for period 1995–2009.

Methodology

For the sake of simplicity, in this section the methodology is described using the simplest case with three regions and one sector. Table 1 outlines the scheme of an inter-country input–output table with three countries. In a similar way with single-country input–output table, Z describes the intermediate uses, F describes the final use (incl. consumption, investment and changes in inventories), V describes the value-added (incl. compensations of employees, production taxes, depreciation of fixed capital and net operation profits),[8] X indicates the total outputs and superscript r $(=1,2,3)$ represents the country. For example, Z^{13} represents the intermediate use from country 1 to country 3.

According to Fig. 1, we have row equilibrium in matrix notation as:

$$\begin{bmatrix} Z^{11} & Z^{12} & Z^{13} \\ Z^{21} & Z^{22} & Z^{23} \\ Z^{31} & Z^{32} & Z^{33} \end{bmatrix} + \begin{bmatrix} F^{11}+F^{12}+F^{13} \\ F^{21}+F^{22}+F^{23} \\ F^{31}+F^{32}+F^{33} \end{bmatrix} = \begin{bmatrix} X^1 \\ X^2 \\ X^3 \end{bmatrix}. \tag{1}$$

The direct input coefficients then can be obtained by normalizing the columns in IO table, that is:

$$A^{rs} = Z^{rs}\left(\widehat{X^s}\right)^{-1} \tag{2}$$

where $r, s = 1, 2, 3$, and $\left(\widehat{X^s}\right)^{-1}$ denote the inverse of a diagonal matrix of total outputs in country s.

Define input coefficient matrix $A = \begin{bmatrix} A^{11} & A^{12} & A^{13} \\ A^{21} & A^{22} & A^{23} \\ A^{31} & A^{32} & A^{33} \end{bmatrix}$ with A^{rs} is the input coefficient from country r to country s, the Leontief inverse can be calculated as $B = (I - A)^{-1}$, that is, $B = \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} = \begin{bmatrix} I-A^{11} & -A^{12} & -A^{13} \\ -A^{21} & -A^{22} & -A^{23} \\ -A^{31} & -A^{32} & -A^{33} \end{bmatrix}^{-1}$, where I is the identity matrix with diagonal elements as ones and non-diagonal elements as zeros. The Leontief inverse describes both the direct and indirect linkages across countries and sectors. For example, assuming country 1 increased its imports from country 2 ΔF^{21} as final demand (i.e. country 2 increases its exports to country 1), all countries would increase their outputs to satisfy the extra demand, that is

$$\Delta X = (I - A)^{-1} \cdot \Delta F = \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} 0 \\ \Delta F^{21} \\ 0 \end{bmatrix}. \tag{3}$$

Country 1 and country 3 would also be benefited from the increase of final demands in country 2, even though their own final demands were unchanged. The benefits which country 3 received from the increase of final demand in country 2 ($B^{32} * \Delta F^{21}$) are determined by the extent to which country 3 relies on intermediate goods from country 2 to produce its own products, i.e. the degree of B^{32}.

Using E^r denotes the carbon emission in country r, and $CA^r = E^r\left(\widehat{X^r}\right)^{-1}$ denotes the carbon emission coefficient per unit of

[8] Note the value-added can be obtained by deducting the cost of intermediate use from gross output, that are $V^j = X^j - \sum_i Z^{ij}$. This is the so-called production approach that national account measures Gross Domestic Product (GDP) (SNA, 2008).