Energy for Sustainable Development 25 (2015) 1–7

Contents lists available at ScienceDirect

Energy for Sustainable Development

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

Xuemei Jiang [a], Yifang Liu [b,*]

[a] Center for Forecasting Science, Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing, China
[b] School of Economics, Central University of Finance and Economics, Beijing, China

ARTICLE INFO

Article history:
Received 14 November 2012
Revised 1 December 2014
Accepted 2 December 2014
Available online xxxx

Keywords:
Slicing up the value chain
Carbon dioxide emissions
International fragmentation of production
Information and communication technology

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

* Corresponding author at: School of Economics, Central University of Finance and Economics, Haidian District, Beijing 100081, China. Tel.: +86 10 62611259.
E-mail address: liuyifang08@163.com (Y. Liu).

[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.

http://dx.doi.org/10.1016/j.esd.2014.12.001
0973-0826/

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).

Table 1
The inter-country input–output table, three countries.

		Intermediate use			Final use			Total output
		Country 1	Country 2	Country 3	Country 1	Country 2	Country 3	
Intermediate use	Country 1	Z^{11}	Z^{12}	Z^{13}	F^{11}	F^{12}	F^{13}	X^1
	Country 2	Z^{21}	Z^{22}	Z^{23}	F^{21}	F^{22}	F^{23}	X^2
	Country 3	Z^{31}	Z^{32}	Z^{33}	F^{31}	F^{32}	F^{33}	X^3
Value added		V^1	V^2	V^3				
Total input		X^1	X^2	X^3				

outputs in country r, the carbon emissions generated along production chains can be traced as:

$$\begin{bmatrix} E^1 \\ E^2 \\ E^3 \end{bmatrix} = \begin{bmatrix} CA^1 & 0 & 0 \\ 0 & CA^2 & 0 \\ 0 & 0 & CA^3 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{11}+F^{12}+F^{13} \\ F^{21}+F^{22}+F^{23} \\ F^{31}+F^{32}+F^{33} \end{bmatrix}. \quad (4)$$

According to Eq. (4), the carbon emission generated in country 1 due to all final demands of country 2 can be considered as the exported carbon dioxide emission from country 1 to country 2, that is:

$$e\_ex\left(F^{12}\right) = \begin{bmatrix} CA^1 & 0 & 0 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{12} \\ F^{22} \\ F^{32} \end{bmatrix}. \quad (5)$$

Similarly, the carbon emission generated in country 2 due to all final demands of country 1 can be considered as the imported carbon dioxide emission of country 1 from country 2, that is:

$$e\_im\left(F^{12}\right) = \begin{bmatrix} 0 & CA^2 & 0 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{11} \\ F^{21} \\ F^{31} \end{bmatrix}. \quad (6)$$

The carbon emissions embodied in the exports and imports of country 1 therefore are:

$$e\_ex\left(F^{1}\right) = \begin{bmatrix} CA^1 & 0 & 0 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{12}+F^{13} \\ F^{22}+F^{23} \\ F^{32}+F^{33} \end{bmatrix} \quad (7)$$

$$e\_im\left(F^{1}\right) = \begin{bmatrix} 0 & CA^2 & CA^3 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{11} \\ F^{21} \\ F^{31} \end{bmatrix}. \quad (8)$$

In an analogous way, let V^r denote the value-added in country r, and $\mathrm{VA}^r = V^r\left(\widehat{\mathrm{X}^r}\right)^{-1}$ denote the value added coefficient per unit of output in country r, the value-added obtained in the exports and imports of country 1 can be measured as:

$$v\_ex\left(F^{1}\right) = \begin{bmatrix} VA^1 & 0 & 0 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{12}+F^{13} \\ F^{22}+F^{23} \\ F^{32}+F^{33} \end{bmatrix} \quad (9)$$

$$v\_im\left(F^{1}\right) = \begin{bmatrix} 0 & VA^2 & VA^3 \end{bmatrix} \begin{bmatrix} B^{11} & B^{12} & B^{13} \\ B^{21} & B^{22} & B^{23} \\ B^{31} & B^{32} & B^{33} \end{bmatrix} \begin{bmatrix} F^{11} \\ F^{21} \\ F^{31} \end{bmatrix}. \quad (10)$$

Note that the equations so far only provide a stylized procedure for the calculations of value-added and embedded carbon emissions in trade, based on a simplified case with three economies and one sector. The linkages among sectors and economies in real world are much more complicated. The WIOD provides a real world account, by classifying the world economy into 41 economies and 35 sectors. In the case of WIOD, let $\widetilde{F^{rs}}$ indicate the final demand column where ICT manufacturing sector is filled with the ICT exports of final products from country r to country s and other sectors with zeros $\left(\text{i.e., } \widetilde{F^{rs}} = \left[0, \ldots, f^{rs}_{ICT}, 0, \ldots, 0\right]^T\right)$, VA^r and CA^r indicate the value-added coefficients and carbon emission coefficients of all sectors in country r, respectively, B^{rs} indicate the inter-sector intermediate uses from country r to country s, the carbon dioxide emission and value-added generated by exports and imports of ICT final products can be traced in a similar way as suggested by Eqs. (7)–(10), respectively.

Let us illustrate the above measurements with iPod as an example. Assume the assembly of Y amount of iPod in China requires only three kinds of intermediate inputs, that are, hard disk drive (HDD) and display from Japan (X_1), the design and software from the U.S. (X_2), and metal products from China (X_3). If China exports all of the Y amount of iPod to Europe, Japan would obtain value-added from China's iPod exports by providing HDD and display (i.e. value-added in ICT manufacturing sector, $VA_{x1} \cdot X_1$); the U.S. would obtain value-added from China's iPod exports by providing design and software (i.e. value-added in ICT service sector, $VA_{x2} \cdot X_2$); China would obtain value-added from the

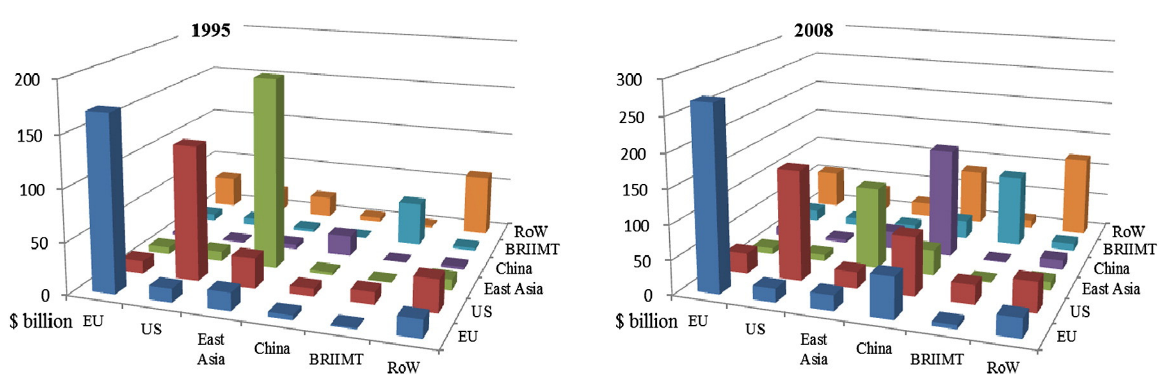

Fig. 1. International trade flow of ICT final products, 1995 and 2008.

provisions of metals (i.e. value-added in metal manufacturing sector, $VA_{x3} \cdot X_3$) as well as the assembly of iPod (i.e. value-added in ICT manufacturing sector, $VA_y \cdot Y = Y - X_1 - X_2 - X_3$). The value-added coefficients VA_{xi} of the supplying sectors in Japan, the U.S. and China are determined by outputs minus the intermediate inputs for each unit of output.[9] By describing all the trade flows across sectors and countries for both intermediate and final products, the inter-country input–output tables as shown in the WIOD allow us to trace the value-added generated along the production chain, to the ultimate final consumers. Given the emission coefficients CA_i, the carbon dioxide emission generated in the exports can be traced similarly.

Results

International trade of ICT products

Before presenting the results of value-added and carbon distributions, we first provide some basic descriptions of the world ICT commodity trade. In Fig. 1 we compare the trade flows of ICT final products (i.e. ICT products used as final demands) among six major economies in 1995 and 2008. The left axis indicates sourcing economies and the right axis indicates destination economies. For example, the exports from East Asia to the U.S. in 1995 was US dollar ($) 29 billion, much larger than the exports from the U.S. to East Asia at $ 9 billion. According to Fig. 1, the global outputs of ICT final products have grown from $ 755 billion in 1995 to $ 1684 billion in 2008,[10] among them the share of gross volume of exports (or imports) increased from 37.9% to 47.7%.

In 1995, East Asia was the largest exporter, accounting for 26.2% of the global exports of ICT final products. It was followed by the EU-27 (20.8%), the U.S. (18.2%) and China (6.8%). In 2008, China was the largest exporter, accounting for 38.7% of global exports of ICT final products, followed by the EU (16.3%), East Asia (13.8%) and the U.S. (10.4%). With respect to imports, the U.S. remained to be the largest importer of ICT final products, accounting for 32.5% and 28.0% of global imports of ICT final products in 1995 and 2008, respectively. The advanced economies (i.e. the EU plus the U.S. and East Asia) have always been the major consumers of ICT final products. In 2008, advanced economies accounted for 55.1% of global imports, while China and BRIIMT together only accounted for 17.7%.

The productions of ICT final products highly depend on ICT components and parts as intermediates.[11] In Fig. 2 the flows of ICT components (i.e. ICT products used as intermediates) among six main economies are compared for 1995 and 2008. The gross outputs of ICT components witnessed a fast growth from $ 1174 billion in 1995 to $ 2872 billion in 2008, among them the share of global exports (or imports) increased from 27.7% to 37.4%. Unlike ICT final products, the exports of ICT components remained to be led by advanced economies. East Asia has always been the largest exporter of ICT components, accounting for 26.2% and 25.2% of global exports in 1995 and 2008. With respect to imports, the U.S. was the largest recipient (32.5% in global imports) and China was the smallest recipient (3.9%) in 1995, in 2008 China has become the largest recipient (24.3%) and the share of the U.S. dropped to 14.1%. East Asia's share in imports dropped from 10.4% to 9.7%, while EU's share fell from 18.1% to 15.1%. The BRIIMT share increased slightly from 7.3% to 8.1%. It should be noted that foreign-funded enterprises in China accounted for about 70% of China's total exports of ICT final products in 2008. It is very possible that the widespread multinational enterprises and their "own" trade, which imported a great amount of intermediate inputs from their home country to assemble the exported ICT final products in China, actually determined the changing patterns.

Value-added generated by the trade of ICT final products

Fig. 3 describes how value-added generated in the trade of ICT final products across economies in 1995 and 2008, based on Eqs. (9) and (10). The rows describe the value-added generated in exports, and the columns describe that in imports. The value-added export from East Asia to the U.S., for example, was $ 38 billion in 1995, much larger than the value-added export from the U.S. to East Asia at $ 15 billion. The patterns of value-added embodied in trade by economy are quite similar with the trade pattern shown in Fig. 1. China has been significantly benefited by involving in the global production chain of ICT final products. The value-added which China received from the exports of ICT final products expanded from $ 19 billion in 1995 to $ 249 billion in 2008, with an annual growth rate at 19.9%.[12] The emerging economies BRIIMT also expanded quite fast, as its annual growth rate of value-added by the exports of ICT final products was 9.7% during 1995–2008, much faster than that of the EU (5.9%), the U.S. (3.7%) and East Asia (3.6%).

With respect to value-added imports, the U.S. and the EU have always been major contributors. In 1995, the U.S. contributed to 28.9% of value-added in global imports of ICT final products, while it was followed by the EU (19.3%), East Asia (12.5%) and China (4.3%). In 2008, the contributions from China increased into 11.1%, and advanced economies (the EU plus the U.S. and East Asia) still accounted for 51.47%. Emerging economies have obtained increasing economic benefits from the international trade of ICT final products, for which the demand is mainly driven by advanced economies.

All of above results are conducted in absolute term, it should be noted that the patterns in percentage term are slightly different. In 2008, the value-added generated by the exports of ICT final products was $ 911 billion, among them China obtained 27.4%. This share is smaller than the contribution of China in terms of the global exports of ICT final products as suggested by Fig. 2 (i.e. 38.7%). In contrast, the shares of value-added which advanced economies (i.e. the EU, East Asia and the U.S.) received from exports are larger than their contributions in exports. This indicates that China still received less value-added per unit of exports than advanced economies in 2008.

Carbon dioxide emissions embodied in the trade of ICT final products

In a similar vein, Fig. 4 describes how carbon dioxide generated in the international trade of ICT final products in 1995 and 2008, based on Eqs. (7) and (8). The carbon dioxide emissions linked to the international exports (or imports) of ICT final products increased from 199 million tonnes to 656 million tonnes during 1995–2008. Among them, the carbon emission generated in China increased most rapidly, from 85 million to 374 million tonnes with an annual growth rate at 11.1%. This was followed by East Asia (with annual growth rate at 5.8%), BRIIMT (4.4%) and the EU (1.5%). U.S. carbon emission due to ICT exports even decreased, with an annual rate at −1.5%. In general, the growths of carbon embodied in the international trade of ICT final products were slower than that of value-added, especially for emerging economies. This implies that the worldwide upgrade in terms of

[9] We can further assume that the production of X_1 amount of HDD and display in Japan requires ICT components from Taiwan (Z_1) and South Korea (Z_2). Then we would have: (a) the value-added of HDD and display in Japan is $VA_{x1} \cdot X_1 = X_1 - Z_1 - Z_2$; (b) Taiwan and South Korea will also be benefited from China's exports of Y amount of iPod to Europe, with value-added at $VA_{z1} \cdot Z_1$ and $VA_{z2} \cdot Z_2$, respectively. The outputs of ICT component production in Taiwan and South Korea can be further decomposed into the supplying sectors, and so on.

[10] Due to data availability, all volumes in this paper are in current prices without specifications. According to world development indicators published by world bank, the world GDP deflator from 1995 to 2008 is 1.86, while advanced countries generally have much lower GDP deflators than emerging countries. The real growth rates of global ICT outputs and exports would be smaller than current nominal growth rates, but still positive.

[11] According to WIOD, in 2008, about half inputs of ICT final products are ICT components and parts, other major inputs include metal, ICT services and business services.

[12] Unless specified, the growth rates in this paper are nominal growth rates. According to world bank, the annual GDP deflators of the EU, the U.S., Japan and China in 1995–2008 were 2.8%, 2.0%, −0.9% and 2.9%. There are still considerable growths in terms of value-added for both advanced and emerging economies in constant prices.

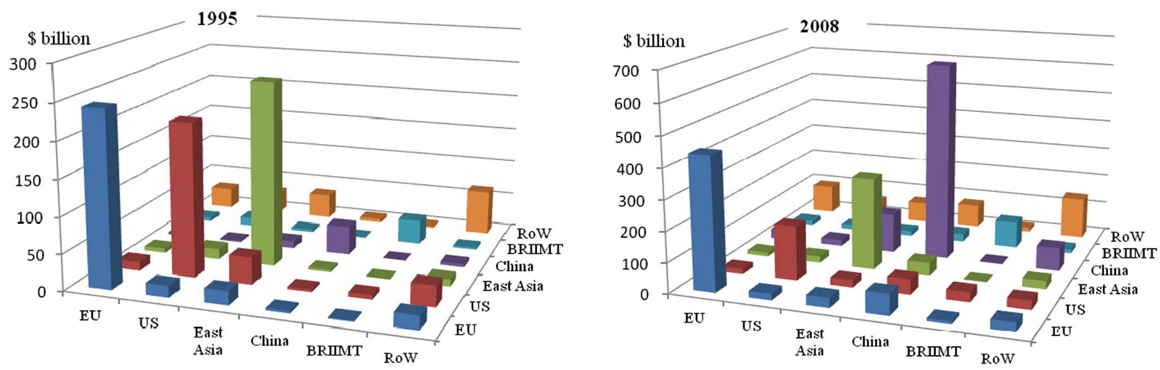

Fig. 2. International trade flow of ICT components, 1995 and 2008.

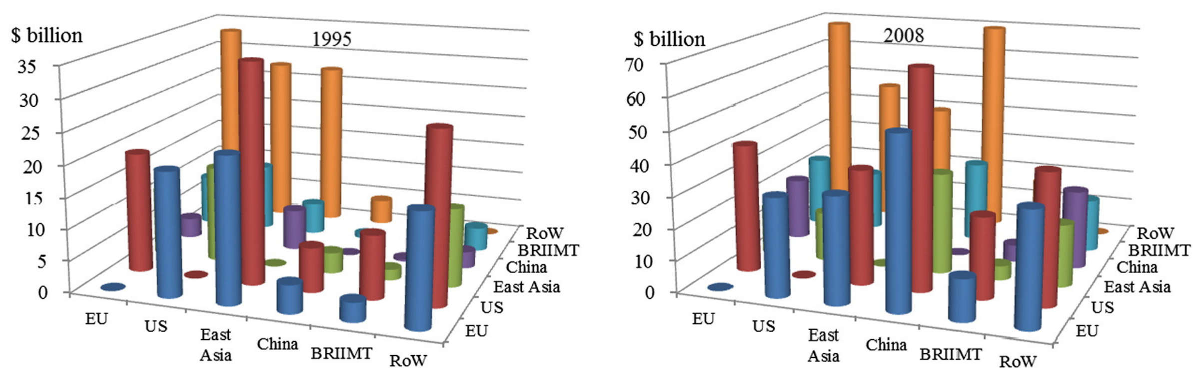

Fig. 3. Value-added in international trade, 1995 and 2008.

carbon-intensity-related technologies has seriously reduced the global carbon emissions linked to each unit of ICT outputs/exports.

The patterns of carbon imports are quite similar with the patterns of value-added, for which advanced economies are major contributors. Advanced economies are the main consumers of ICT final products. We then turn our attention to the comparisons in relative term. In 1995, advanced economies accounted for 65.2% of the global exports of ICT final products, while they received 71.2% of value-added in the exports and were responsible for 32.3% of carbon emissions due to the exports. In 2008, the shares of advanced countries were 40.4%, 50.1% and 19.8%, respectively in exports, value-added and carbon terms. Advanced economies emitted less carbon in producing ICT final products than did emerging economies, but received more added value than emerging economies, even though exports of final products was about equal between the two categories of economies.

Trade balance in value-added and carbon emissions

Comparing the value-added generated by exports and imports, we can analyze the trade balance in value-added term, as shown in the left of Fig. 5. In 1995, East Asia had the largest trade surplus in value-added term (i.e. $ 56 billion), while the U.S. had the largest trade deficit ($ 11 billion). In 2008, China surpassed East Asia and had the largest trade surplus in value-added term ($ 149 billion), while the U.S. remained with the largest trade deficit ($ 88 billion). The trade surplus of East Asia increased from $ 56 billion to $ 76 billion. In brief, China is still the largest beneficiary in terms of value-added balance.

If we compare the carbon emissions generated by exports and imports, advanced economies are found to be net importers while China and other emerging economies are net exporters. This is in line with the literatures which study carbon embodied in international

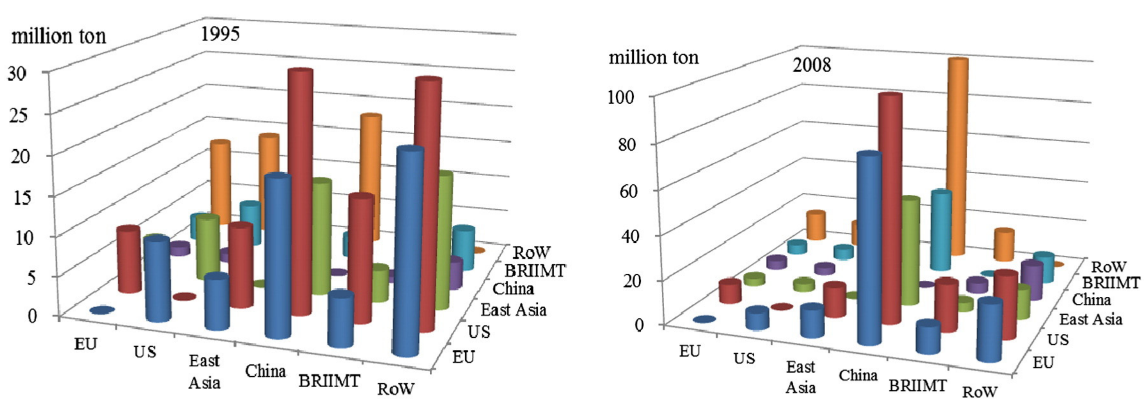

Fig. 4. Carbon dioxide emissions embodied in international trade, 1995 and 2008.

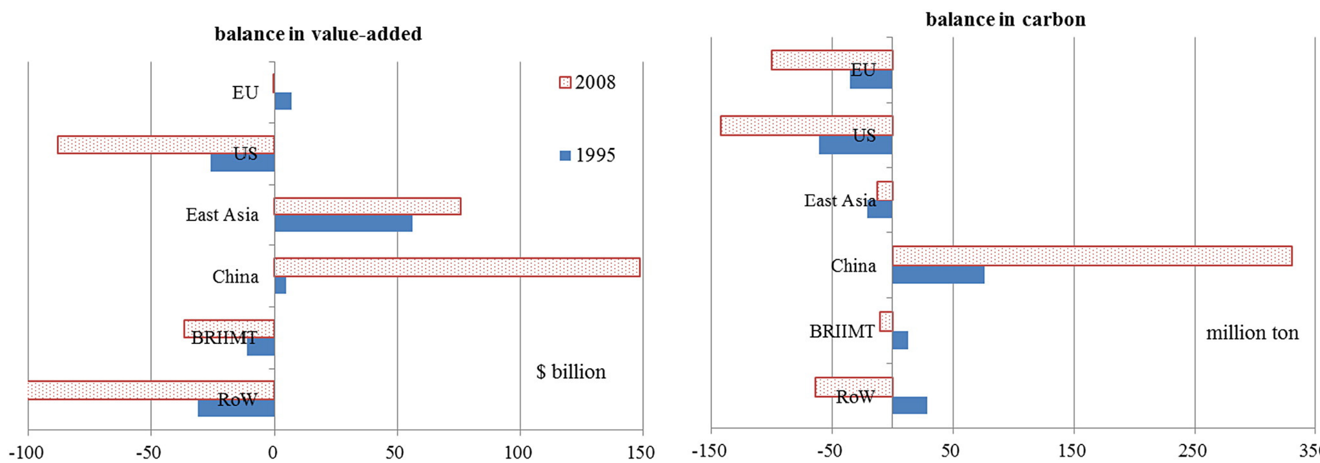

Fig. 5. Balance in value-added and carbon terms, 1995 and 2008.

trade at country level (see, e.g. Davis and Caldeira, 2010; Peters et al., 2011; Boitier, 2012). It should be noted that the changes of trade balance in carbon term (as shown in the right of Fig. 5) differ with that in value-added term (as shown in the left of Fig. 5). East Asia had carbon deficit against value-added surplus in 1995 and 2008. BRIIMT had carbon surplus against value-added deficit in 1995. Although China showed surplus in both value-added and carbon terms, the growth of carbon surplus from 1995 to 2008 is slower than that of value-added surplus. Similarly, the growth of carbon deficit of the U.S. is also slower than that of value-added deficit. All of these results again reflect that advanced economies emitted less carbon dioxide in producing ICT goods, but obtained more value-added than emerging economies for identical exports.

Discussion of results: impacts of slicing up the value chain

Given the finding that advanced economies emitted less carbon dioxide but obtained more value-added than emerging economies, in this section we introduce three indicators in relative terms to compare the performance by economy. They are:

(a) Value-added coefficients per unit of exports in ICT final products (abbreviated as value-added coefficients hereafter). Dividing the value-added in the exports of country 1 as shown in Eq. (9) by the exports of country 1, that is, $v\_ex(F^1)/F^1$, for example, we can obtain the value-added coefficients for country 1.
(b) Carbon dioxide emissions per unit of exports in ICT final products (abbreviated as carbon intensity per exports hereafter). Dividing the carbon emission embodied in the exports of country as shown in Eq. (7) by the exports of country 1, that is, $e\_ex(F^1)/F^1$, for example, we can obtain the carbon intensity per exports for country 1.
(c) Carbon dioxide emissions per unit of value-added (abbreviated as carbon intensity per value-added). For example, dividing the carbon emission linked to exports as shown in Eq. (7) by the value-added linked to exports as shown in Eq. (9), that is, $e\_ex(F^1)/v\_ex(F^1)/F^1$, we can obtain the carbon intensity per value-added for country 1.

Table 2 summarizes the results for the six major economies. Note that we provide two additional rows of “World ICT” and “World economy” as the references. The results of “World ICT” are the weighted average of six major economies for the world ICT productions. The “World economy” shows the results for the entire world including all agriculture, manufacturing, utility and services sectors. According to SNA (2008), the value-added (i.e. GDP), would equal to the sum of final demands if we treat the world as a single economy. Therefore, we would have identical values for the carbon intensity per value-added and the carbon intensity per export, that are obtained by dividing the world carbon dioxide emission by the world GDP in 1995 and 2008.[13]

For advanced economies, in 1995–2008 the value-added they obtained per unit of exports in ICT final products increased, while carbon dioxide emission they emitted for each unit of exports decreased. East Asia is the only exception with increased carbon intensity in exports. This is very possibly caused by the price deflations in Japan during 1995–2008, considering that the carbon intensity of Japan remained almost unchanged simultaneously.[14] The carbon intensities in exports of China and BRIIMT decreased much faster than the EU and the U.S., implying either more rapid technological upgrades of carbon control in emerging economies, or the shift of production of lower carbon intensity goods from developed countries to developing countries (also known as the “Pollution Haven Hypothesis” in the literature; see, for example, Cole, 2004; He, 2006; Levinson and Taylor, 2008). Meanwhile, the value-added which China received from each unit of exports in ICT final products considerably decreased.

In the last two columns, we compared the carbon emissions which the economy emitted when receiving per unit of value-added from the exports of ICT final products. For example, if China exported $ 1000 of ICT final products in 2008, it would gain $ 857 domestic value-added and emitted 1.28 tons of carbon dioxide. With same $ 1000 of exports in ICT final products, the U.S. would gain $ 1608 DVA but emitted only 0.41 tons of carbon dioxide. In general, advanced economies emitted only 0.21–0.37 tons of carbon dioxide when receiving $ 1000 value-added, while the emerging countries emitted 0.88–1.50 tonnes of carbon dioxide while receiving the same value-added.

Summary

Based on a harmonized inter-country input–output database WIOD, we explore the patterns and their changes of value-added distributions and the carbon emission responsibilities linked to global ICT trade in 1995–2008. In the process, both direct effects due to the productions of regional/national own exports and indirect effects due to the downstream productions of the intermediate inputs of other region/country's exports are considered. The results show that the increasing role of emerging economies in international fragmentation of production has considerably changed the patterns of global ICT trade market. China and other emerging economies significantly expanded their shares in

[13] The comparisons of carbon intensity by value-added confirmed our point in the introduction that ICT manufacturing sector has significant embedded carbon contents.
[14] According to EIA, the carbon intensity of Japan dropped from 0.27 to 0.26 ton/thousand $ in 1995–2008.

Table 2
Comparisons of value-added coefficients and carbon intensities, by economy.

	Value-added coefficient		Carbon intensity per export (ton/thousand $)		Carbon intensity per value-added (ton/thousand $)	
	1995	2008	1995	2008	1995	2008
EU	1.254	1.362	0.498	0.297	0.397	0.218
U.S.	1.453	1.608	0.752	0.410	0.517	0.255
East Asia	1.331	1.583	0.369	0.591	0.277	0.373
China	1.019	0.857	4.401	1.281	4.319	1.496
BRIIMT	1.173	1.355	2.083	1.195	1.775	0.881
RoW	0.980	1.276	1.323	0.873	1.350	0.684
World ICT	1.228	1.209	1.046	0.871	0.851	0.720
World economy	–	–	0.665	0.426	0.665	0.426

obtaining value-added from the international exports of ICT final products. In 1995, China only obtained 5.6% of value-added generated in the international exports of ICT final products, by 2008, this share had increased to 27.4%. The expansion of emerging economies, especially China, decreased the share of total value added by advanced economies. The value-added share of advanced economies (i.e. the EU plus the U.S. and East Asia) has dropped from 71.2% to 50.1%. Meanwhile, advanced economies, especially the U.S. have always been the main importers. The advanced economies accounted for about 55%–60% of the global imports of ICT final products and contributed to 50%–60% of the corresponding value-added (i.e. value-added in global end–use ICT imports) from 1995 through 2008. It is undoubted that emerging economies especially China are largely benefited by involving in the ICT productions, for which advanced economies have always been major consumers.

If we consider the carbon emissions embodied in trade, the trend is somewhat different. We found that emerging economies decreased carbon intensity, expressed as emissions per unit of value-added, more rapidly than advanced economies during the period 1995–2008. During that entire period, however, the emission intensity in advanced economies was always less than the intensity in emerging economies and the value-added by advanced economies was greater than that of emerging economies. From a perspective of global climate mitigation, the upgrades of carbon control and production technologies in emerging countries are in particular required.

Acknowledgment

The paper acknowledges funding from the National Natural Science Foundation of China (Project Number: 71103176 & 71003115). The authors are grateful to one associate editor and one anonymous reviewer for their valuable comments. The authors are in particular grateful for the scrutiny of the manuscript and the very constructive suggestions by Editor Daniel B. Jones.

References

Ahmad N, Wyckoff A. Carbon dioxide emissions embodied in international trade of goods. OECD Science, Technology and Industry Working Paper 15; 2003.
Antras P. Firms, contracts, and trade structure. Q J Econ 2003;118:1375–418.
Antras P, Helpman E. Global sourcing. J Polit Econ 2004;112:552–80.
Arndt S. Globalisation and the open economy. N Am j Econ Financ 1997;8:71–9.
Arto I, Rueda-Cantuche JM, Andreoni V, Mongelli I, Genty A. The game of trading jobs for emissions. Energy policy 2014;66:517–25.
Ashton J, Wang X. Equity and climate: in principle and practice. Beyond Kyoto: advancing the international effort against climate change. Washington, DC: Pew Center on Global Climate Change; 2003.
Boitier B. CO_2 emissions production-based accounting vs. consumption, insights from the WIOD databases. Final WIOD Conference: Causes and Consequences of Globalization, Groningen, the Netherlands; 2012. [May].
Chen, X., Cheng, L., Fung, F.C. and Lau, L. J. (2004). The Estimation of Domestic Value-Added and Employment Induced by Exports: An Application to Chinese Exports to the United States, mimeo, Stanford University.
Cole MA. Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. Ecol Econ 2004;48:71–81.
Davis SJ, Caldeira K. Consumption-based accounting of CO_2 emissions. Proc Natl Acad Sci 2010;107(12):5687–92.
Davis S, Peters G, Caldeira K. The supply chain of CO_2 emissions. Proc Natl Acad Sci 2011;108:18554–9.
Dietzenbacher E, Los B, Stehrer R, Timmer M, de Vries G. The construction of world input–output tables in the WIOD projects. Econ Syst Res 2013;25:71–98.
Feenstra RC. Integration of trade and disintegration of production in the global economy. J Econ Perspect 1998;14(4):31–50.
Feenstra RC, Hanson G. Ownership and control in outsourcing to China: estimating the property-rights theory of the firm. Q J Econ 2005:729–61. [May].
Feenstra, R.C. and Spencer, B. (2005). Contractual versus Generic Outsourcing: The Role of Proximity," University of British Columbia, mimeo.
Fettweis G, Zimmermann E. ICT energy consumption — trends and challenges. The 11th International Symposium on Wireless Personal Multimedia Communications (WPMC 2008), Sep., 2008, Lapland, Finland; 2008.
Grossman GM, Helpman E. Integration versus outsourcing in industry equilibrium. Q J Econ 2002;117:85–120.
Grossman GM, Helpman E. Managerial incentives and international organization of production. J Int Econ 2004;63:237–62.
Grossman GM, Helpman E. Outsourcing in a global economy. Rev Econ Stud 2005;72:135–60.
He J. Pollution haven hypothesis and environmental impacts of foreign direct investment: the case of industrial emission of sulfur dioxide (SO2) in Chinese provinces. Ecol Econ 2006;60(1):228–45.
Hummels D, Ishii J, Yi K. The nature and growth of vertical specialisation in world trade. J Int Econ 2001;54:75–96.
Jones RW, Kierzkowski H. The role of services in production and international trade: a theoretical framework. In: Jones RW, Krueger AO, editors. The political economy of international trade: essays in honor of Robert E. Baldwin. Cambridge, MA: Blackwell; 1990.
Kanemoto K, Lenzen M, Peters G, Moran D, Geschke A. Frameworks for comparing emissions associated with production, consumption, and international trade. Environ Sci Technol 2012;46(1):72–179.
Koopman R, Wang Z, Wei SJ. Estimating domestic content in exports when processing trade is pervasive. J Dev Econ 2012;99:178–89.
Koopman R, Wang Z, Wei SJ. Tracing value-added and double counting in gross exports. Am Econ Rev 2014;104(2):459–94.
Krugman P. Does third world growth hurt first world prosperity? Harv Bus Rev 1996;72:113–21.
Lau LJ, Chen X, Cheng LK, Fung KC, Sung Y, Yang C, et al. A new type of input–holding–output model of the non-competitive imports type capturing China's processing exports. Chin Soc Sci 2006;31:35–54.
Leamer EE. The effects of trade in services, technology transfer and delocalisation on local and global income inequality. Asia Pac Econ Rev 1996;2:44–60.
Levinson A, Taylor MS. Unmasking the pollution haven effect. Int Econ Rev 2008;49(1):223–54.
Linden G, Kraemer KL, Dedrick J. Innovation and job creation in a global economy: the case of Apple's iPod. J Int Commer Econ 2011;3(1):223–39.
McLaren J. Globalization and vertical structure. Am Econ Rev 2000;90:1239–54.
OECD. The OECD definition of the ICT sector. available at http://www.oecd.org/internet/ieconomy/2771153.pdf, 2002.
Peters GP, Minx J, Weber CL, Edenhofer O. Growth in emission transfers via international trade from 1990 to 2008. Proc Natl Acad Sci 2011;108(21):8903–8.
European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank (2009), System of National Accounts 2008 (SNA, 2008), New York, 2009.
Spencer B. International outsourcing and incomplete contracts. Sauder School of Business, University of British Columbia; 2005.
Vogiatzoglou K. Determinants of export specialization in ICT products: a cross-country analysis. INFER working paper 2009.3, Greece; 2009.
Wiedmann T. A review of recent multi-region input–output models Used for consumption-based emission and resource accounting. Ecol Econ 2009;69:211–22.
Wiedmann T, Wilting M, Lenzen M, Lutter S, Viveka P. Quo vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis. Ecol Econ 2011;65:15–26.
Yeats AJ. Just how big is global production sharing? Policy Research Working Paper 1871. The World Bank; 1998.