The Impact of Geographic Shifts in International Sourcing on Global CO_2 emissions

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Abstract: In this paper we simulated the emission cost of geographic shift of international sourcing on global CO2 emissions for the period 1995-2011 by comparing the scenarios with and without geographic shift. Our simulations indicate that in 2011, had the share of trade by sourcing economy remained in the level of 1995, 2000, 2005 and 2008, global CO_2 emissions in production processes would have been 2.8 Gt, 2.0 Gt, 1.3 Gt and 540 Mt lower than the actual emissions. Although the outsourcing trend shifted from developed economies to developing economies has been slow downed after the international crisis in 2008, the overall emission costs have always been significantly positive. The further investigations by economy and industry show that such geographic shift mainly dominated by developed economies themselves, and occurred in high-tech industries such as productions of ICT goods and machinery, leading to positive emission cost in developing economies especially China. Our results addressed the urgency of eliminating in carbon emission intensity between developing and developed economies.
Keywords: geographic shift; international sourcing, developed economies, developing economies, CO_2 emissions.

Highlight:

There have been geographic shift of international sourcing from developed economies (e.g. USA, Japan and Asia four tigers) to developing economies (e.g. China) in 1995-2011.
The shift of outsourcing toward developing economies increased global CO_2 emissions by 2.8 Gt from 1995 to 2011.
Such shift is mainly dominated by the outsourcing of developed economies, leading to net emissions growth in developing economies.
By industry, the shift of sourcing in the productions of ICT goods and machinery led to the largest emission cost for 1995-2011.

1. Introduction

The last few decades have witnessed a fluctuated growth of international trade, with a strong boom from 5.17 trillion of merchandise exports in 1995 to 16.16 trillion in 2008, and a sharp fall after the economic crisis in 2009, and then a moderate recovery from 15.30 trillion US$ in 2010 to 19.00 trillion US$ in 2014 (WTO, 2015). Except for the period 2008-2009, the world merchandise exports have been grown in a much more higher rate than world gross domestic product (GDP) in recent decades (WTO, 2015). Meanwhile the pattern of world trade is also gradually changing. Lower trade cost and improved communication technology have fostered an increase in the internationalization of production, for which the productions are increasingly unbundled into different stages that are conducted in different economies/regions (Baldwin, 2011; Timmer et al., 2014; Draper, 2013). As a result, the growth of trade in the past decades has been characterized by a growth in intermediates trade (Hummels et al., 2001; Sturgeon and Gereffi, 2009; De Backer and

Yamano, 2012;), accompanied by a geographic shift of source regions (OECD, WTO and WB, 2014; AfDB, OECD and UNDP, 2014; WTO, 2015). The share of developing economies' exports in world totals increased from 26 per cent in 1995 to 44 per cent in 2014, while the share of developed economies' exports decreased correspondingly by 18 percentages (WTO, 2015). As Lehmann (2012) summarized, the center of global production and trade originated with the industrial revolution in Britain, after which has shifted to Western Europe (especially Germany), then to the U.S., and two decades after World War II to Japan, Asia's Four Tigers (especially South Korea and Taiwan), China, and now with a sign starting to move further to less developing economies in South Asia and Africa (see also, Stratfor, 2013; AfDB, OECD and UNDP, 2014).

In parallel to this boom in world trade, there has been a rapid growth in global Greenhouse Gas (GHG) emissions. The global CO_2 emissions has been accelerated from 21.84 Gigatonnes (Gt) in 1995 to 29.47 Gt in 2008, after which with a slight slow down to 28.97 Gt in 2009, and then rebound to 32.30 Gt in 2014 (IEA, 2015). The international trade not only brought a separation of consumptions and productions, and consequently carbon leakage (see, e.g. Wiedmann et al., 2007; Peters and Hertwich, 2008; Davis and Caldeira, 2010; Peters, 2010; Peters et al., 2011; Feng et al., 2013), but also led net growth of CO_2 emissions with its changing patterns (see, e.g. Arto and Dietzenbacher, 2014; Hoekstra et al., 2016; Malik and Lan, 2016). By decomposing the global GHG emissions, Arto and Dietzenbacher (2014), for example, has found that the changes in the structure of international trade increased global GHG emissions by 0.58 Gt CO_2 equivalents in the period 1995-2008. In a similar vein, Hoekstra et al. (2016) decomposed the effects of changes in the structure of international trade between different income groups of economies on their CO_2 emissions growth. Referring the sum of these effects as the emission cost of international sourcing (ECS), they found that the net global effects, the ECS, amounts to 18% of the total global CO_2-emissions growth (i.e. 1.1 Gt) over the period 1995-2007. Defining the outsourcing as imports of carbon emissions embodied commodities, Malik and Lan (2016) also discussed the changes of outsourcing trend and decomposed their contributions on global CO_2 emissions growth by region and commodity over the period 1990-2010.

In this paper, we adopt Hoekstra et al. (2016)'s idea, referring the structure of international trade as the "international sourcing", and plan to discuss the emission cost of the geographic shift of international sourcing. As aforementioned, the developing economies account for increasing share of global exports. The geographic shift of international sourcing therefore can be identified as a change of the purchases of intermediate and final goods from new source economies (very possibly developing economies) rather than from the previous trading partners (possibly developed economies) or producing domestically. Given the gap in energy efficiency and fuel mix between developing and developed economies, such geographic shift from developed economies (with higher energy efficiencies and somewhat greater reliance on clean energies) to developing economies (with lower energy efficiencies and much greater reliance on fossil fuels) would lead to additional global CO_2 emissions at the aggregate level. This is referred as emission cost of geographic shift in international sourcing in our paper.

Unlike the literatures that rely on structural decompositions analysis (SDA) to isolate the effects of changing trade pattern on global emissions growth (see, e.g. Arto and Dietzenbacher, 2014; Hoekstra et al., 2016; Malik and Lan, 2016), in this paper we adopted scenario analysis approach to quantify the emission cost of the geographic shift of international sourcing. The idea is to simulate the extent to which global emissions would have been lower when assuming that the global demand for goods remains in the absence of the geographic shift to developing economies. More specifically, for a specific year t1, we simulate the global CO_2 emissions assuming that the structure of international trade by sourcing country/region is replaced by the structure in year t0, and then compare the results with the actual global CO_2 emissions as a means of quantifying the emission cost of geographic shift in international sourcing for year t1.

Recent years have seen a proliferation of global multi-regional input-output tables (GMRIO) that are available to analyze the global value chains and emissions issues, such as Eora, EXIOBASE, OECD-ICIO, GTAP-MRIO (see Tukker and Dietzenbacher (2013) for an explicit review). To conduct the empirical analysis, this paper employed the inter-country input-output tables (ICIO) complied by OECD (OECD, 2014). One of the unique features of OECD-ICIO is that it distinguishes processing exports and normal productions for China and Mexico. It has been widely acknowledged that the production recipes and emission intensity of processing exports and normal productions is highly different, as a result a distinction of their activities in IO tables is necessary (see, e.g. Dietzenbacher et al., 2012; Su et al., 2013; Jiang et al., 2015 and 2016). Employing OECD-ICIO, our paper is also different with the literatures that use other GMRIO databases, by distinguishing the production chains of processing exports with the normal productions in China and Mexico.

The paper is organized as follows. In section 2 we introduce our methods and data sources; in section 3 we present our results of emission cost of the geographic shift of international sourcing, at both aggregate and individual region/industry level. Some policy-related implications of our findings are discussed in section 4.

2. **Methodology and Data**

2.1. Global Multi-Regional Input-Output (GMRIO) framework and data source

The global multiregional input-output model (GMRIO) has been widely accepted to trace the CO_2 emission footprint along the global production chains (see Wiedmann (2009) and Minx et al. (2010) for reviews and Malik et al. (2016) for recent applications). In the GMRIO framework, all CO_2 emissions in one specific region can be traced to the final demand of different regions, including their own final demand and demand from other regions. Table 1 presents the GMRIO framework employed in this paper. The diagonal matrices of intermediate use give the intra-regional intermediate deliveries. For example, the elements z_{ij}^{rr} of matrix $\mathbf{Z}^{\mathrm{rr}}$ give the intermediate deliveries from industry i in region r to industry j in region r, with i, j =1,…,m, where m is the number of industries, and r =1,…,n, where n is the number of regions. The non-diagonal matrices indicate inter-regional intermediate deliveries. For example, the elements z_{ij}^{rs} of matrix $\mathbf{Z}^{\mathrm{rs}}$ indicate the deliveries of products from industry i (=1,..,m) in region r (=1,..,n) for input use in industry j (=1,..,m) in region s (=1,..,n; $\neq r$). The matrices of final demand have a similar structure; they are divided by consumption (including consumption by households, governments and non-government organizations), $\mathbf{F}_{\mathrm{cons}}^{\mathrm{rs}}$($r$, s=1,...,n), and investment (for fixed capital formation), $\mathbf{F}_{\mathrm{inv}}^{\mathrm{rs}}$ (r, =1,...,n).

Table 1. The multi-regional input-output framework

			Intermediate Use			Final Use					Total Output
			Region 1	…	Region n	Region 1		…	Region n		
			Industry 1,.., m		Industry 1,…,m	Cons.	Inv.		Cons.	Inv.	
Intermediate Use	Region 1	industry	Z^{11}	…	Z^{1n}	F^{11}_{cons}	F^{11}_{inv}	…	F^{1n}_{cons}	F^{1n}_{inv}	X^{1}
	…	…	…	…	…			…		…	…
	Region n	industry	Z^{n1}	…	Z^{nn}	F^{n1}_{cons}	F^{n1}_{inv}	…	F^{nn}_{cons}	F^{nn}_{inv}	X^{n}
Value Added			V^{1}	…	V^{n}						
Total Inputs			X^{1}	…	X^{n}						

According to Table 1, we have row equilibrium in matrix notation as follows:

$$\begin{bmatrix} \mathbf{Z}^{11} & \cdots & \mathbf{Z}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{Z}^{n1} & \cdots & \mathbf{Z}^{nn} \end{bmatrix} + \begin{bmatrix} \mathbf{F}^{11} + \cdots + \mathbf{F}^{1n} \\ \cdots \\ \mathbf{F}^{n1} + \cdots + \mathbf{F}^{nn} \end{bmatrix} = \begin{bmatrix} \mathbf{X}^{1} \\ \vdots \\ \mathbf{X}^{n} \end{bmatrix} \quad (1)$$

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

$$\mathbf{A}^{\mathrm{rs}} = \mathbf{Z}^{\mathrm{rs}}(\widehat{\mathbf{X}^{\mathrm{s}}})^{-1} \quad (2)$$

where r, s=1,...,n, and $(\widehat{\mathbf{X}^{\mathrm{s}}})^{-1}$ denotes the inverse of a diagonal matrix of total outputs in region s.

Define the input coefficients matrix $\mathbf{A} = \begin{bmatrix} \mathbf{A}^{11} & \cdots & \mathbf{A}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{n1} & \cdots & \mathbf{A}^{nn} \end{bmatrix}$ where $\mathbf{A}^{\mathrm{rs}}$ is the input coefficient from region r to region s. Then, the Leontief inverse can be calculated as $\mathbf{B} = (\mathbf{I} - \mathbf{A})^{-1}$; that is, $\mathbf{B} = \begin{bmatrix} \mathbf{B}^{11} & \cdots & \mathbf{B}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{B}^{n1} & \cdots & \mathbf{B}^{nn} \end{bmatrix} = \begin{bmatrix} \mathbf{I} - \mathbf{A}^{11} & \cdots & -\mathbf{A}^{1n} \\ \vdots & \ddots & \vdots \\ -\mathbf{A}^{n1} & \cdots & \mathbf{I} - \mathbf{A}^{nn} \end{bmatrix}^{-1}$, where $\mathbf{I}$ 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 regions and sectors.

Using $\mathbf{E}^{\mathrm{r}}_{\mathrm{carbon}}$ to denote the matrix of production-based CO_2 emissions by sector in region r and $\mathbf{CA}^{\mathrm{r}} = \mathbf{E}^{\mathrm{r}}_{\mathrm{carbon}}(\widehat{\mathbf{X}^{\mathrm{r}}})^{-1}$ to denote the matrix of carbon emissions intensity per unit of output by sector in region r, the CO_2 emissions generated along global production chains can be traced as follows:

$$\begin{bmatrix} \mathbf{E}^{11} & \cdots & \mathbf{E}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{E}^{n1} & \cdots & \mathbf{E}^{nn} \end{bmatrix} = \begin{bmatrix} \widehat{\mathbf{CA}}^{1} & 0 & 0 \\ 0 & \cdots & 0 \\ 0 & 0 & \widehat{\mathbf{CA}}^{n} \end{bmatrix} \begin{bmatrix} \mathbf{B}^{11} & \cdots & \mathbf{B}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{B}^{n1} & \cdots & \mathbf{B}^{nn} \end{bmatrix} \begin{bmatrix} \mathbf{F}^{11} & \cdots & \mathbf{F}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{F}^{n1} & \cdots & \mathbf{F}^{nn} \end{bmatrix} \tag{4}$$

where the elements E_{io}^{rs} of matrix $\mathbf{E}^{rs}$ indicate the production-based emissions of industry *i* (=1,..,m) in region *r* (=1,..,n) led by the final demand type o (=cons, inv) in region *s* (=1,..,n). As aforementioned, our data base of GMRIO is OECD-ICIO. It covers 62 regions (34 OECD regions and 28 non-OECD regions) and 34 industries, and 1995, 2000, 2005, 2008, 2009, 2010 and 2011. In particular it distinguishes the productions of Mexico into global manufacturing (serving as processing productions) and non-global manufacturing (serving as domestic productions), and that of China into domestic needs, processing exports and normal exports. Therefore, we would have n=65 and m=34 for the intermediate deliveries, and $\mathbf{E}_{\text{carbon}}^{\text{r}}$ and $\mathbf{CA}^{\text{r}}$ (*r* =1,...,65) as a 1*34 vector, $\mathbf{A}^{\text{rs}}$ and $\mathbf{B}^{\text{rs}}$ (*r,s* =1,..,65) as 34*34 matrix, $\mathbf{A}$ and $\mathbf{B}$ as 2210*2210 matrix. For the final use, to simplify somewhat, we aggregate the consumptions and investment, then $\mathbf{F}^{\text{rs}}$ (*r* =1,..,65; *s* = 1,...,62) is a 34*1 vector, $\mathbf{F}$ is a 2210*62 matrix.

Regarding CO_2 emissions, we mainly rely on IEA's statistics on CO_2 emissions from fuel combustion, and reconcile them into the classification of OECD-ICIO table (IEA, 2014)[1]. With respect to the CO_2 emissions by production type for China and Mexico, we adopted the method of Jiang *et al.* (2016) to use intermediate energy in an input-output table to proportionally decompose the CO_2 emissions of China (and Mexico) by three (and two) production types. All of the China's (and Mexico's) disaggregation by production type are calibrated to ensure that a re-aggregation would result in an official release of IEA.

2.2. The emission cost of geographic shift in international sourcing

The shift of international sourcing geography not only influences worldwide input structures of trade in intermediate products, but also influences final demand patterns through trade in final products. The simulations used to capture the impact of shifting geography on global emissions were carried out by assuming the structure of international trade by sourcing in year t1 would be reverted back to the structure in year t0.

Our first step is therefore to isolate the structure of international trade, i.e. the pattern of international sourcing. In this paper, we follow the line with Xu and Dietzenbacher (2014), Arto and Dietzenbacher (2014), and Hoekstra et al. (2016), and decompose the **A**-matrix into technical coefficients and pattern of international sourcing. That is, define the total technical input coefficients of industry *j* (=1,...,34) in region *s* (=1,...,65) from industry *i* (*i*-input, *i* = 1,...,34) as $a_{ij}^{*s} = \sum_r a_{ij}^{rs}$. In matrix form, the technical input coefficients of region s would be $\mathbf{A}^{*s} = \begin{bmatrix} a_{11}^{*s} & \cdots & a_{1m}^{*s} \\ \vdots & \ddots & \vdots \\ a_{m1}^{*s} & \cdots & z_{mm}^{*s} \end{bmatrix}$ as a 34*34 matrix. Then, horizontally stack the $\mathbf{A}^{*s}$ matrices and further vertically stack the result 65

[1] That means, in this paper we only focus on the GHG emissions generated in the productions of goods and services. The GHG emissions from land use, forest, household activities by combustions of fossil fuels (e.g. driving cars or cooking) are excluded.

times, we would have $\mathbf{A}^* = \begin{bmatrix} \mathbf{A}^{*1} & \cdots & \mathbf{A}^{*n} \\ \vdots & \ddots & \vdots \\ \mathbf{A}^{*1} & \cdots & \mathbf{A}^{*n} \end{bmatrix}$ as a 2210*2210 matrix. $\mathbf{A}^*$ is the technical intermediate input coefficients irrespective of the sourcing region.

Let $c_{ij}^{rs} = a_{ij}^{rs} / a_{ij}^{*s}$ indicate the share sourced from region *r* (=1,...,65) in the input a_{ij}^{*s} in region *s* (=1,...,65), then in the matrix form, we would have $\mathbf{C}^{rs} = \begin{bmatrix} c_{11}^{rs} & \cdots & c_{1m}^{rs} \\ \vdots & \ddots & \vdots \\ c_{m1}^{rs} & \cdots & c_{mm}^{rs} \end{bmatrix}$ as a 34*34 matrix (where $\sum_r c_{ij}^{rs} = 1$), and $\mathbf{C} = \begin{bmatrix} \mathbf{C}^{11} & \cdots & \mathbf{C}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{C}^{n1} & \cdots & \mathbf{C}^{nn} \end{bmatrix}$ as a 2210*2210 matrix, to reflect the pattern of international sourcing. Then the A-matrix can be decomposed as

$$\mathbf{A} = \mathbf{C} \otimes \mathbf{A}^* \quad (5)$$

where $\otimes$ stands for the Hadamard product.

Moreover, we can split the **C**-matrix into sub-matrices for each region s (=1,...,65). Let $\mathbf{C}^{S} = \begin{bmatrix} 0 & \cdots & \mathbf{C}^{1s} & \cdots & 0 \\ \vdots & \ddots & \vdots & & \vdots \\ 0 & & \mathbf{C}^{ss} & & 0 \\ \vdots & & \vdots & \ddots & \vdots \\ 0 & \cdots & \mathbf{C}^{65,s} & \cdots & 0 \end{bmatrix}$, we would have $\mathbf{C} = \sum_s \mathbf{C}^{S}$. The Leontief inverse can be rewritten as:

$$\mathbf{B} = [\mathbf{I} - (\textstyle\sum_s \mathbf{C}^{S}) \otimes \mathbf{A}^*]^{-1} \quad (6)$$

In a similar fashion, the final demand can be decomposed into the determinants of total final demand and the pattern of sourcing. Let $y_i^{*s} = \sum_r y_i^{rs}$ indicate the total final demand in region *s* for output of industry *i* from all source cregions, $f_i^{rs} = y_i^{rs} / y_i^{*s}$ indicate the share sourced from region r (=1,...,65) in the final demand of region s (=1,...,65) for output in industry *i* (=1,...,34), and define the matrices correspondingly, the final demand can be decomposed as

$$\mathbf{F} = \left[\textstyle\sum_s \mathbf{F}^{S}\right] \otimes \mathbf{Y}^* \quad (7)$$

The second step is to introduce scenario analysis to quantify the emission cost. Letting subscript t1 denotes the year t1, actual emission (Scenario I) can be calculated as:

$$\begin{bmatrix} \mathbf{E}_{t1}^{11} & \cdots & \mathbf{E}_{t1}^{1n} \\ \vdots & \ddots & \vdots \\ \mathbf{E}_{t1}^{n1} & \cdots & \mathbf{E}_{t1}^{nn} \end{bmatrix} = \begin{bmatrix} \widehat{\mathbf{CA}}_{t1}^{1} & 0 & 0 \\ 0 & \cdots & 0 \\ 0 & 0 & \widehat{\mathbf{CA}}_{t1}^{n} \end{bmatrix} \cdot [\mathbf{I} - (\textstyle\sum_s \mathbf{C}_{t1}^{s}) \otimes \mathbf{A}_{t1}^*]^{-1} \cdot (\textstyle\sum_s \mathbf{F}_{t1}^{s}) \otimes \mathbf{Y}_{t1}^* \quad (8)$$

Scenario II assumes that the global final demands $\mathbf{Y}^*$, production technique $\mathbf{A}^*$ and emission intensity $\mathbf{CA}^r$ (r =1,...,65) remain unchanged, and the structure of international trade by sourcing region is replaced by those structure in year t0, then the production-based CO_2 emissions in

Scenario II can be calculated as:

$$\begin{bmatrix} \mathbf{E}_{t1}^{11}\_II & \cdots & \mathbf{E}_{t1}^{1n}\_II \\ \vdots & \ddots & \vdots \\ \mathbf{E}_{t1}^{n1}\_II & \cdots & \mathbf{E}_{t1}^{nn}\_II \end{bmatrix} = \begin{bmatrix} \widehat{\mathbf{CA}}_{t1}^{1} & 0 & 0 \\ 0 & \cdots & 0 \\ 0 & 0 & \widehat{\mathbf{CA}}_{t1}^{n} \end{bmatrix} \cdot [\mathbf{I} - (\sum_s \mathbf{C}_{t0}^{s}) \otimes \mathbf{A}_{t1}^{*}]^{-1} \cdot (\sum_s \mathbf{F}_{t0}^{s}) \otimes \mathbf{Y}_{t1}^{*} \quad (9)$$

The emission cost in region *r* and year t1 due to the geographic shift of international sourcing for the period t0-t1 would be:

$$ECS_{t1}^{r}\_II = \sum_s E_{t1}^{rs} - \sum_s E_{t1}^{rs}\_I \quad (10)$$

where $ECS_{t1}^{r}\_II > 0$ suggests that world incline purchase more intermediate or/and final products from region *r* (directly and indirectly), and vice versa. To sum up the $ECS_{t1}^{r}\_II$ over region *r* (=1,...,65) would give the global emission cost due to the geographic shift of international sourcing for the period t0-t1. At the aggregate level, $ECS_{t1}\_II > 0$ suggests that world inclines to purchase more intermediate or/and final products from economies with higher emission intensities (mostly developing economies). For example, China has been highly relied on coal as its primary energy input, as a result its CO_2 emission intentity per US$ GDP in constant price has been around 1.8-2.0 times of the world average (IEA, 2014). When China's exports account for more share of world total, that is, the world inclines to purchase more products (incl. intermediate and final products) from China rather than the economies with lower emission intensities, there is an additional CO_2 emissions so called as emission cost of sourcing (i.e. ECS).

The emission cost can also be traced by source region and product type. In Scenario III, we assume that the structure of international trade of intermediates in region *s* is replaced by those structure in year t0, and the others remain unchanged, then the production-based CO_2 emissions in Scenario III can be calculated as:

$$\begin{bmatrix} \mathbf{E}_{t1}^{11}\_III & \cdots & \mathbf{E}_{t1}^{1n}\_III \\ \vdots & \ddots & \vdots \\ \mathbf{E}_{t1}^{n1}\_III & \cdots & \mathbf{E}_{t1}^{nn}\_III \end{bmatrix}$$

$$= \begin{bmatrix} \widehat{\mathbf{CA}}_{t1}^{1} & 0 & 0 \\ 0 & \cdots & 0 \\ 0 & 0 & \widehat{\mathbf{CA}}_{t1}^{n} \end{bmatrix} \cdot \left\{\mathbf{I} - \left[\sum_{k=1,..,65;k\neq s}(\mathbf{C}_{t0}^{s} + \mathbf{C}_{t1}^{k})\right] \otimes \mathbf{A}_{t1}^{*}\right\}^{-1} \cdot (\sum_s \mathbf{F}_{t1}^{s}) \otimes \mathbf{Y}_{t1}^{*} \quad (11)$$

The emission cost in region *r* and year t1 due to the geographic shift of international sourcing pattern of intermediate in region *s* for the period t0-t1 would be:

$$ECS_{t1}^{r}\_III = \sum_s E_{t1}^{rs} - \sum_s E_{t1}^{rs}\_III \quad (12)$$

Similarly, in Scenario IV, we assume that the structure of international trade of final demand in region *s* is replaced by those structure in year t0, and the others remain unchanged, then the production-based CO_2 emissions in Scenario IV can be calculated as:

$$\begin{bmatrix} \mathbf{E}_{t1}^{11}\_IV & \cdots & \mathbf{E}_{t1}^{1n}\_IV \\ \vdots & \ddots & \vdots \\ \mathbf{E}_{t1}^{n1}\_IV & \cdots & \mathbf{E}_{t1}^{nn}\_IV \end{bmatrix}$$

$$= \begin{bmatrix} \widehat{\mathbf{CA}}_{t1}^{1} & 0 & 0 \\ 0 & \cdots & 0 \\ 0 & 0 & \widehat{\mathbf{CA}}_{t1}^{n} \end{bmatrix} \cdot \{\mathbf{I} - (\sum_s \mathbf{C}_{t1}^{s}) \otimes \mathbf{A}_{t1}^{*}\}^{-1} \cdot \left[\sum_{k=1,..,65;k\neq s}(\mathbf{F}_{t0}^{s} + \mathbf{F}_{t1}^{k})\right] \otimes \mathbf{Y}_{t1}^{*} \quad (13)$$

The emission cost in region *r* and year t1 due to the geographic shift of international sourcing pattern of final products in region *s* for the period t0-t1 would be:

$$ECS_{t1}^{r}\_IV = \sum_s E_{t1}^{rs} - \sum_s E_{t1}^{rs}\_IV \quad (14)$$

In addition, the emission cost can be traced by the changing sourcing pattern of industry. Let

$\mathbf{C}^{\mathrm{L}}$ indicate the share matrix of intermediate of *l*-th industry, filled with shares c_{kl}^{rs} (*k, s* =1,…,34; *r*=1,…,65) in the *l*-th (=1,…,34) industry and zeros for other industry *g* (≠ *l*), we would have $\mathbf{C} = \sum_{\mathrm{L}} \mathbf{C}^{\mathrm{L}}$. Similarly, let $\mathbf{F}^{\mathrm{L}}$ indicate the share matrix of final demand of *l*-th industry, the emission cost under Scenario V (structure of trade in intermediate and final products in industy *l* is replaced by those in year t0, and the others remain unchanged) can be quantified as:

$$\begin{bmatrix} \mathbf{E}_{\mathrm{t1}}^{11}\_\mathrm{V} & \cdots & \mathbf{E}_{\mathrm{t1}}^{1\mathrm{n}}\_\mathrm{V} \\ \vdots & \ddots & \vdots \\ \mathbf{E}_{\mathrm{t1}}^{\mathrm{n1}}\_\mathrm{V} & \cdots & \mathbf{E}_{\mathrm{t1}}^{\mathrm{nn}}\_\mathrm{V} \end{bmatrix} = \begin{bmatrix} \widehat{\mathbf{CA}}_{\mathbf{t1}}^{\mathbf{1}} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \widehat{\mathbf{CA}}_{\mathbf{t1}}^{\mathbf{n}} \end{bmatrix} \cdot$$

$$\left\{\mathbf{I} - \left[\textstyle\sum_{\mathrm{g}=1,\ldots,65;l\neq \mathrm{g}} (\mathbf{C}_{\mathrm{t0}}^{l} + \mathbf{C}_{\mathrm{t1}}^{\mathrm{g}})\right] \otimes \mathbf{A}_{\mathrm{t1}}^{*}\right\}^{-1} \cdot \left[\textstyle\sum_{\mathrm{g}=1,\ldots,65;l\neq \mathrm{m}} (\mathbf{F}_{\mathrm{t0}}^{l} + \mathbf{F}_{\mathrm{t1}}^{\mathrm{g}})\right] \otimes \mathbf{Y}_{\mathrm{t1}}^{*} \tag{15}$$

$$ECS_{t1}^{r}\_V = \textstyle\sum_s E_{t1}^{rs} - \sum_s E_{t1}^{rs}\_V \tag{16}$$

It should be noted that our method has different focus compared with the structural decompostions method such as Arto and Dietzenbacher (2014), and Hoekstra et al. (2016) employed, when isolating the impact of changing trade pattern on global emissions. To clarify our contribution, we use a two country model with one product to describe the difference between our method and that of SDA[2].

Assume China is country A and the developed world is country B. Use e_A^t and e_B^t to represent the emission intensity of country A and B in year t, s_A^t and s_B^t to represent share of country A and B in world demand in year t, y^t to represent the world total demands. The changing trade pattern could be reflected by the change of s_A^t and s_B^t, and we always have $s_A^t + s_B^t = 1$ for any specific year t.

For the period t0-t1, the SDA method in polar forms used by investigators such as Arto and Dietzenbacher (2014) and Hoekstra et al. (2016) would decompose global emissions growth from year t0 to t1 as:

$$\Delta E = e_A^{t1} \cdot s_A^{t1} \cdot y^{t1} + e_B^{t1} \cdot s_B^{t1} \cdot y^{t1} - e_A^{t0} \cdot s_A^{t0} \cdot y^{t0} + e_B^{t0} \cdot s_B^{t0} \cdot y^{t0} \tag{17}$$

$$= \tfrac{1}{2}[(e_A^{t1} - e_A^{t0}) \cdot s_A^{t1} \cdot y^{t1} + (e_A^{t1} - e_A^{t0}) \cdot s_A^{t0} \cdot y^{t0} + (e_B^{t1} - e_B^{t0}) \cdot s_B^{t1} \cdot y^{t1} + (e_B^{t1} - e_B^{t0}) \cdot s_B^{t0} \cdot y^{t0}]$$

$$+\tfrac{1}{2}[e_A^{t1} \cdot (s_A^{t1} - s_A^{t0}) \cdot y^{t0} + e_A^{t0} \cdot (s_A^{t1} - s_A^{t0}) \cdot y^{t1} + e_B^{t1} \cdot (s_B^{t1} - s_B^{t0}) \cdot y^{t0} + e_B^{t0} \cdot (s_B^{t1} - s_B^{t0}) \cdot y^{t1}]$$

$$+\tfrac{1}{2}[e_A^{t1} \cdot s_A^{t1} \cdot (y^{t1} - y^{t0}) + e_A^{t0} \cdot s_A^{t0} \cdot (y^{t1} - y^{t0}) + e_B^{t1} \cdot s_B^{t1} \cdot (y^{t1} - y^{t0}) + e_B^{t0} \cdot s_B^{t0} \cdot (y^{t1} - y^{t0})]$$

where the second terms gives the contributions of changing trade pattern. Given $s_A^t + s_B^t = 1$, we would have the impact of changing trade pattern on global emissions growth as:

$$E_{\Delta S} = \tfrac{1}{2}[(e_A^{t1} - e_B^{t1}) \cdot \Delta S_A \cdot y^{t0} + (e_A^{t0} - e_B^{t0}) \cdot \Delta S_A \cdot y^{t1}] \tag{18}$$

In contrast, our paper quantified the global emission cost due to the changing trade pattern as:

$$ECS_{t1} = e_A^{t1}(s_A^{t1} - s_A^{t0})y^{t1} + e_B^{t1}(s_B^{t1} - s_B^{t0})y^{t1} = (e_A^{t1} - e_B^{t1}) \cdot \Delta S_A \cdot y^{t1} \tag{19}$$

The two methods give very relevant (as both of them are related to e_A^t, e_B^t, ΔS, etc.) but different results. Where SDA method addresses the temporal change, for which the changing trading shares are weighted by the spatial gap of emission intensity and total final demand for both year t0 and t1; our method only concerns the spatial difference and total final demand in year t1.

3. Results

3.1. The global emissions cost of geographic shift in international sourcing, 1995-2011

In figure 1 we first compare the "actual" global CO_2 emissions (our Senario I meansured by eq. 8) with an alternative scenario II (measured by eq. 9) for the period 1995-2011. The alternative

[2] See Lenzen (2016) for a recent review of SDA applications in energy use and carbon emissions under GMRIO framework.

scenario II assumes that the pattern of international sourcing, i.e. structure of international trade for both intermdiate and final products, were replaced by the pattern in one specific previous year while the others remain unchanged. For example, the brown line indicated as "1995 structure" gives the simulated emissions for 2000-2011 when the structure of trade remains as it did in 1995, and the world final demand are as same as it did in 2000-2011. The difference between Scenario I and Scenario II (with structure for different year) is the so-called emission cost of the geographic shift in international sourcing (ECS).

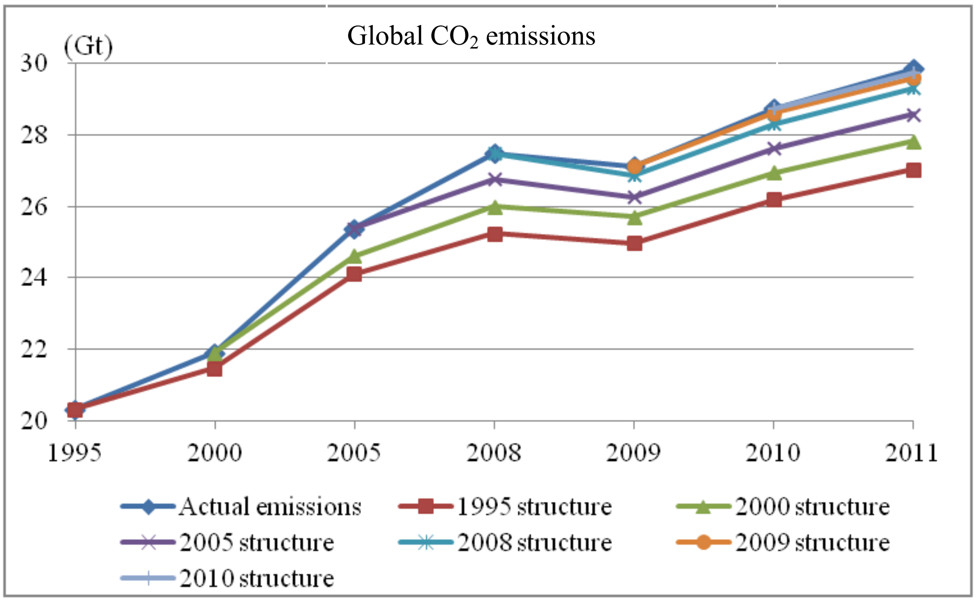

Figure 1. The global emissions with and without geographic shift of international sourcing (Scenario I and II, assuming structures of international trade in different years are adopted)

Figure 1 indicates that the global emissions would be reduced if the structure of trade in the previous years were adopted. This is not surprising, given the facts that the share of developing economies' exports in world trade has significant increased (WTO, 2015), and the emission intensity of OECD economies is around 38%-41% lower than that of non-OECD economies (IEA, 2014). Specifically, our simulations indicate that, in 2011, had the structure of trade remained in the level of 1995, global CO_2 emissions in production processes would have been 27.04 Gt rather than the "actual" (Scenario I) level of 29.85 Gt.[3] In other words, the emission cost of the geogrpahic shift in international outsourcing toward developing economies increased the annual global CO_2 emissions, in 2011, by 2.81 Gt from 1995 to 2011. If the structure of trade in recent years, 2000, 2005, 2008, etc., were adopted, the emissions cost are still positive, but the amount would become smaller. For example, if the trade structure of 2010 were adopted, the global CO_2 emissions in 2011 would have been 29.74 Gt, lower the actural emissions by 110 Mt.

Our simulations of ECS are larger than the literatures using SDA method. For example, Arto and Dietzenbacher (2014) identified that the changes in the structure of international trade increased global GHG emissions by 0.58 Gt CO_2 equivalent in the period 1995-2008; Hoekstra et al. (2016) found that the net global effects of changing source were up to 1.1 Gt over the period 1995-2007. For the period 1995-2008, our simulations indicate that if the trade structure of 1995 were adopted, the

[3] In this paper we only focused on the CO_2 emissions generated in productions process of goods and services, and excluding the emissions by household activities,

global CO_2 emissions in 2008 would have been 25.25 Gt, lower the actural emissions by 2.23 Gt. Recalling the comparisons of fomulars between our method and SDA (eq. 18 vs. eq. 19), the difference is generated from

$$ECS_{t1} - E_{\Delta S} = \frac{1}{2}(e_A^{t1} - e_B^{t1}) \cdot \Delta S_A \cdot (y^{t1} - y^{t0}) + \frac{1}{2}[(e_A^{t1} - e_B^{t1}) - (e_A^{t0} - e_B^{t0})] \cdot \Delta S_A \cdot y^{t1}$$

As aforementioned, the emission intensity gap among OECD and non-OECD economies remain at a relatively stable level for the period 1995-2011. The huge diffrence of our results with SDA literature thus is attributable to the significant increase of global final demand. Therefore SDA may underestimate the impact of geographic shift of sourcing on the global CO_2 emissons, when focusing on the temporal changes from t0 to t1.

3.2. The regional emissions cost of geographic shift in international sourcing, 1995-2011

If we further divide the entire period 1995-2011 into four intervals, that is, 1995-2000, 2000-2005, 2005-2008 and 2008-2011, the emission increase due to the georaphic shift of sourcing are 416 Mt, 768 Mt, 707 Mt and 540 Mt, respectively (Fig. 1). The ECS grows especially during 2000-2008. In figure 2 we present the national emission cost due to the geographic shift of global sourcing pattern, i.e. structure of global inter-country trade for the four intervals, and the total emission cost for the entire period 1995-2011 as measured by $ECS_{t1}^{r}\_II$ in eq. 10 for each region *r*. Positive cost suggested that the economy increasingly involve in the international sourcing of carbon-intensive products (incl. intermediate and final products) from other economies over the period. Negative cost suggested that the economy involve in the international sourcing to a less extent over the period. Note that the total cost for the period 1995-2011 does not necessarily equal to the sum of emissions cost of four sub-intervals.

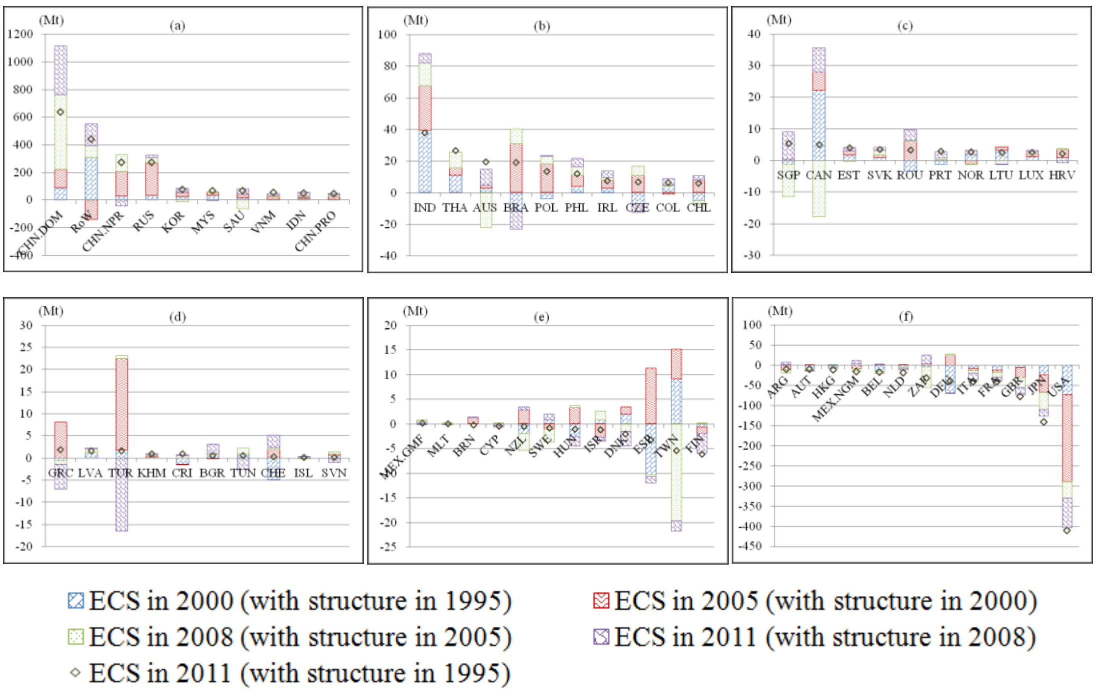

Figure 2. The regional emissions cost of geographic shift in international sourcing (ECS), 1995-2011. Refer to appendix table A for the abbreviation of region.

During 1995-2011, USA shrunk its share in international sourcing the most, while it is followed by Japan and United Kingdom. The emission of USA, Japan and UK in 2011 assuming the structure of international outsourcing were as same as that in 1995, would have been respective 411 Mt, 141 Mt and 78 Mt larger. These economies reduce their share in the international sourcing, especially for carbon-intensive products. In contrast, China expanded its share in international sourcing the most for the same period 1995-2011, while it is followed by Russia and Korea. Without the increase of involvement in the international sourcing, China's emissions would have been 953 Mt lower in 2011. The emission costs of Russia and Korea were also very large, at 273 Mt and 77 Mt, respectively.

In general, most developed economies shrunk their shares in international sourcing, such as most EU15 economies, showing negative emissions cost from 1995 to 2011. There are also exceptions, such as Australia and Canada, the so-called resource-rich developed economies show strong involvement in sourcing by exporting raw materials and resources, and therefore show positive emissions cost (see also Malik and Lan, 2016). In contrast, most developing economies expanded their shares in international sourcing, showing positive emissions cost. Among them, Southeast Asia (e.g. Malaysia, Vietnam, Indonesia, Thailand and Philippines), Latin America (e.g. Brazil, Columbia, Chile), East Europe economies (e.g. Poland, Czech Republic, Estonia) and Saudi Arabia have relatively strong performance, with the emissions costs larger than 5 Mt for the period 1995-2011.

Note that there are also significant temporal changes across four sub-periods. After the entry into WTO, China has largely expanded its share in international sourcing, even after the international financial crisis in 2008. This is reflected as positive and growing ECS of China for all sub-periods. By production type, the non-processing exports of China have expanded significantly in 2000-2008 (with ECS at 297 Mt), and then experienced shrink in post-crisis era 2008-2011 (with ECS at -47 Mt); while the domestic productions of China have continuously expanded its market share ever since 2005 (with ECS at 542 Mt and 353 Mt in 2005-2008 and 2006-2011). To a lesser extent, Southeast Asia economies such as Malaysia, Vietnam, Indonesia, Thailand and Philippines also expanded their share in international sourcing continuously during 1995-2011, showing positive emission costs in all four sub-periods. The Latin America and East Europe developing economies mainly experienced expansions of sourcing during 2000-2008, while after crisis they experienced drops, showing ECS turning to negative in 2008-2011. Clearly China still outperformed the South Asia and Latin America economies in terms of recession as a recipient of outsourcing in the post-crisis era, at least during the study period 2008-2011.

Most developed economies, such as USA, Japan, UK, France and Italy experienced continuous shrink in international sourcing shares for the period 1995-2011. Germany is one of the exceptions as it has expanded its share in 2000-2008 showing positive ECS. The Asia four tigers have expanded shares mainly before 2005, ever since then they started to shrink, while Taiwan and Hong Kong continuously drop their shares from 2005 to 2011, and Korea and Singapore firstly experienced a drop in 2005-2008 and then a rebound in 2008-2011. This is in line with the observations of Lehman (2012) that international sourcing firstly moves from developed world to Asia's Four tigers and then to China. Unfortunately, until 2011 there is no evident sign that international sourcing center has moved further to less developing economies.

3.3. The global emissions cost of geographic shift in international sourcing by sourcing region, 1995-2011

In figure 3 and 4 we present the ECS of trade in intermediate and final products by sourcing region for the entire period 1995-2011, that are measured by the summation $\sum_r ECS_{t1}^{r}\_III$ in eq. 12 and $\sum_r ECS_{t1}^{r}\_IV$ in eq. 14 respectively. Positive cost suggested the region purchase more products, especially carbon-intensive products from economies with low emission intensities (mainly developed economies) rather than economies with high emission intensities (mainly developing economies). In contrast, negative cost suggested the region purchase more products from economies with high emission intensities rather than economies with low emission intensities. As most developed economies shrunk shares in global trade in general, there are more outsourcing regions showing positive ECS rather than regions showing negative ECS. To simplifying the analysis, we only present the top regions with the highest and the lowest ECSs. We also divide the emission costs into domestic, OECD economies and non-OECD economies' emission costs, where their summation is the global emission cost.

The regions showing negative ECS are mostly large developing economies, including China, Russia, India and Saudi Arabia (fig. 3). When using more domestic rather than imported intermediates, their changing pattern of sourcing decreased their own emissions, and increased the emissions in other OECD and non-OECD economies for the entire period 1995-2011. Because their intensities are higher than OECD economies and most-OECD economies, such temporal changes brought negative ECS for the global emissions.

Most developed economies show positive ECS for the entire period 1995-2011. By outsourcing intermediates to other economies, especially non-OECD economies, they brought positive ECS for the global emissions. Among them, USA, Japan, Germany, France, Italy and Korea have often been the top outsourcing economies, showing relatively high ECS for each of the four intervals. These large developed economies dominated the trend of international sourcing pattern through a variety of ways, e.g. offshoring, FDI and multi-national co-operations (MNCs). To seek lower labor cost they have outsourced their intermediates and final products into developing economies, for which the global emissions had been increased.

The three types of productions of China show different dynamics in terms of intermediate use. Processing exports increasingly use imported materials from non-OECD economies rather than OECD economies for the period 2000-2011, and has showed considerable positive ECS. In contrast, non-processing exports tend to use more domestically produced intermediates rather than imports (either from OECD or non-OECD economies), and leading to negative ECS for the period 1995-2011. The domestic productions firstly use more domestic intermediates to replace imports until 2005, and then started to use more domestic intermediates and imports from OECD economies, showing considerable positive ECS in the post-crisis era 2008-2011. The increasing requirement on imports from OECD economies might be driven by the upgrading of Chinese manufacturing from labo-intensive toward high-tech products, while the growing requirement on domestic intermediates might be driven by infrastructure and housing constructions China initiated especially after the international crisis in 2008 (see also Jiang et al., 2016).

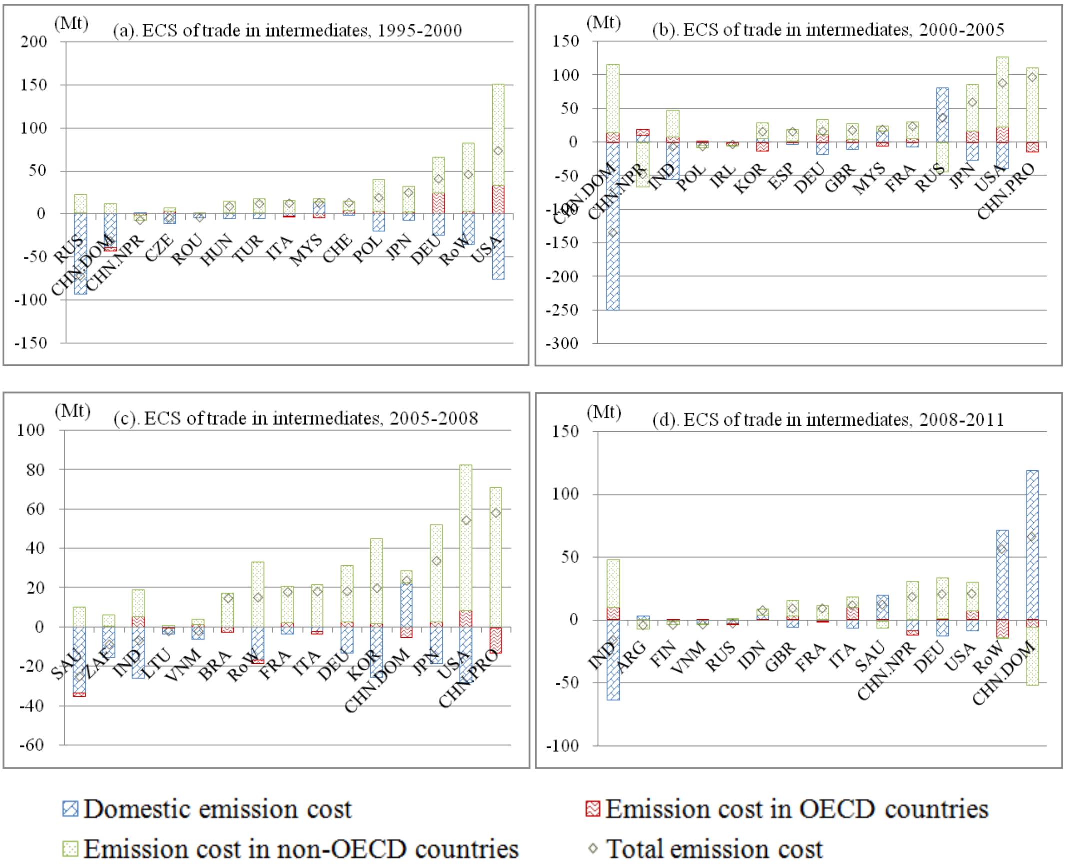

Figure 3. The emission cost of geographic shift of sourcing in intermediate products, by sourcing region, 1995-2011

The ECS of sourcing in final products show very similar pattern as that of intermediates. Few large developing economies such as India, Russia and Saudi Arabia show negative ECS because of the sourcing in final demands moves toward domestic productions for the period 1995-2008. In contrast, the large developed economies such as USA, Japan and Germany still possess the biggest positive ECS by outsourcing final consumptions toward developing economies.

In spite of the similarity, the ECS patterns of sourcing in final products has difference with that of intermediates. China turned to use more domestic intermediates but less imports from both OECD and non-OECD economies in 2008-2011. In terms of final products, however, China turned to use more final products from non-OECD economies but less final products from OECD economies. Korea turned to use more intermediates but less final products from OECD economies for the period 2005-2011. This reflected a change of consumer preference.

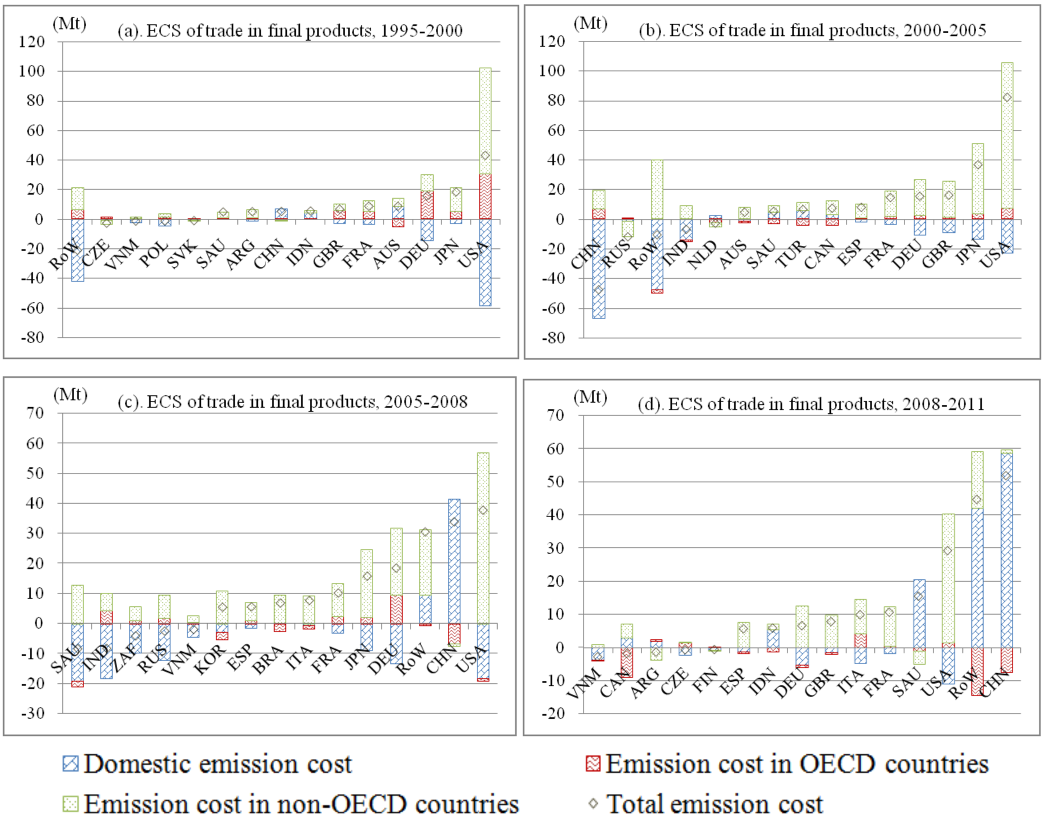

Figure 4. The emission cost of geographic shift of sourcing in final products, by sourcing region, 1995-2011

At the aggregate level, the ECS due to the changing sourcing in intermediates has been keeping growing from 1995 to 2008, at 246 Mt for 1995-2000, 285 Mt for 2000-2005, 323 Mt for 2005-2008; then it dropped to 268 Mt for 2008-2011. In contrary, the ECS due to the changing sourcing in final products has been keeping growing even in the post-crisis era, at 147 Mt for 1995-2000, 181 Mt for 2000-2005, 200 Mt for 2005-2008, and 232 Mt for 2008-2011[4]. As aforementioned, the trade pattern in intermediates is highly dominated by an active shift of developed economies toward low labor costs through offshoring and MNCs. Against the background of high unemployment rate and sluggish demand, many developed economies may turn to purchase more intermediates domestically after the crisis. As a result it is observed a much smaller domestic ECS for the sourcing of intermediates of developed economies for the period 2008-2011 than the previous sub-periods (fig. 3). The purchase of final products however is to a great extent dominated by the consumer preference, and thus is less influenced by the crisis.

3.4. The global emissions cost of geographic shift in international sourcing, by industry, 1995-2011

In figure 5 we present the global emission cost due to the geographic shift of international sourcing pattern by industry for the four intervals (measured by $\sum_r ECS_{t1}^r\_IV$ in eq. 16). Positive

[4] The aggregate ECS of trade in intermediates do not equal to the summation as shown in figure 3 because the decomposition of A-matrix is non-additive. The aggregate ECS of trade in final products however equals to the summation as shown in figure 4 because the decomposition of final demand is additive.

cost suggested that worldwide the industry purchase more intermediates or final products from regions with low emission intensities (mainly developed economies) rather than regions with high emission intensities (mainly developing economies). Again, as most developed economies shrunk shares in global trade in general, only very few industries show negative ECS, and the degrees are relatively small (less than 1.5 Mt for each intervals). To simplifying the analysis, we only presents the top ten industries with the highest positive ECS.

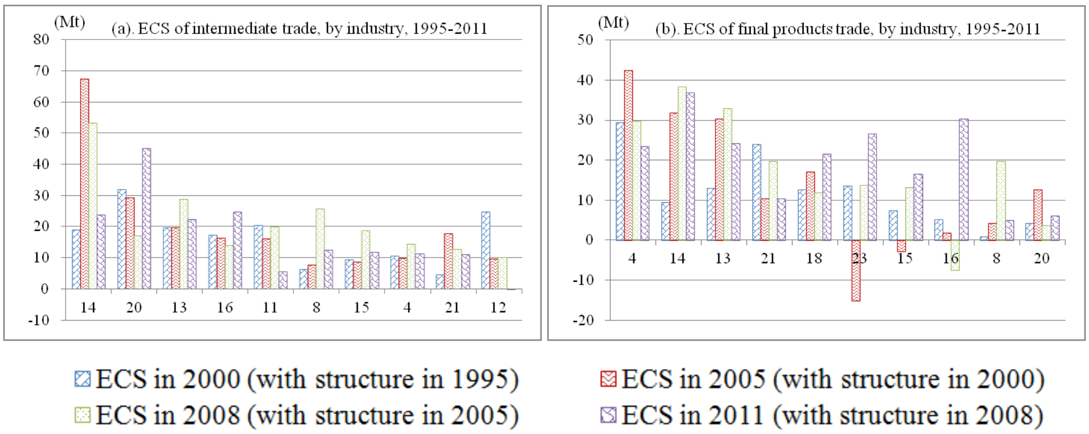

Figure 5. The emission cost of geographic shift of sourcing, by industry, 1995-2011. Refer to appendix table A for industry code.

The geographic shift of international sourcing in ICT goods (ind. 14) and machinery (ind. 13) brought the largest ECS in terms of both intermediates and final products. The geographic shift of sourcing pattern of intermediate and final products in ICT goods and machinery together lead to increases of 61 Mt, 149 Mt, 153 and 81 Mt CO_2 emissions for the four intervals 1995-2000, 2000-2005, 2005-2008, and 2008-2011. A closer investigation shows that China has played increasing role as a recipient of sourcing: the geographic shift of sourcing in ICT goods and machinery together has increased China's emissions by 5 Mt, 115 Mt, 184 Mt and 72 Mt for the correspondingly four intervals. Although ICT goods and machinery are "clean" high-tech products themselves, the productions of their raw materials emit considerable CO_2. From a perspective of production chains, the geographic shift of their productions from developed economies toward China has led global CO_2 emissions to increase significantly (see also Jiang and Liu, 2015).

The geographic shift of sourcing in the productions of textiles (ind. 4), chemical products (ind. 8), vehicle (ind. 16) and electrical products (ind. 15) also bring considerable increase of global emissions, showing positive ECS. Among them, the shift of sourcing pattern of chemicals and vehicles mainly occur in the intermediates, leading to ECS at around 25-40 Mt together for each sub-period in 1995-2011. The shift of sourcing pattern of textiles and electrical products mainly occur in the final products, leading to ECS at around 37-43 Mt for the sub-period in 1995-2011. In addition, the shift of sourcing in basic and fabricated metals (ind. 11 and 12), and constructions mainly occur in intermediates, while the shift of wholesale (ind. 21), transport and storage (ind. 23) mainly occur in final products.

4. Summary and policy implications

In this paper we discussed the impact of geographic shift of international sourcing on global CO_2 emissions by adopting scenario analysis assuming the geographic shift did not occur for the period 1995-2011. Our simulations indicate that, in 2011, had the share of trade by sourcing economy remained in the level of 1995, global CO_2 emissions in production processes would have been 27.04 Gt rather than the "actual" level of 29.85 Gt. In other words, the emission cost of the geogrpahic shift in international outsourcing toward developing economies increased the annual global CO_2 emissions, in 2011, by 2.81 Gt from 1995 to 2011.

Our resuls of emission cost of sourcing (ECS) are much higher than the literatures that use SDA to isolate the impact of changing patter of outsourcing, such as Arto and Dietzenbacher (2014) and Hoekstra et al. (2016) which arrive at around 0.5-1.0 Gt of emission cost. This is because that our ECS is purely decided by the emission intensity gap among developed and developing economies and final demand level in year t1, while SDA is decided by the temporal change of emission intensity gap and final demand for the period t0-t1. Given the relative stable emission intensity gap and booming increase of final demand for the period 1995-2011, it is not surprising that our results arrive at a much higher ECS.

We also discuss from and to which country/region the ECS is generated. In general, the developed economies increasingly outsourced their productions, especially carbon-intensive intermediates into developing economies. As a result, we observed positive ECS in developing economies and negative ECS in developed economies. By industry, the so-called high-tech products such as ICT goods, machinery and electrical products, compose the largest share of ECS. Although the productions of high-tech products are relatively "clean" in terms of emission intensity, their production chain of raw materials and the related geographic shift toward developing economies especially China has considerably increased the global CO_2 emissions.

Our findings on the ECS of geographic sourcing shift provide important implications on global climate change mitigations. While the climate change mitigation has become a consensus, there are a lot of challenges to limit the global GHG emissions avoiding an exceed of 2°C global warming (see also Peters et al., 2015; Malik and Lan, 2016). In the process, the geographic shift from developed economies to developing economies that aimed at lower labor costs, intensify the challenges. The emission intensity gap between developed and developing economies sustained, or even slightly increased over time. In 1995 the average CO_2 emission intensity per GDP using purchasing power parities (PPP) of OECD economies in 1995 was 0.44 kg CO_2 / US dollar in 2005 prices, 38.0% lower than that of non-OECD economies at 0.70 kg CO_2 / US dollar in 2005 prices; until 2011, the emission intensity gap has increased to 41%, when that of OECD and non-OECD economies are 0.33 and 0.55 kg CO_2 / US dollar in 2005 prices (IEA, 2014). Although the geographic shift toward developing economies has slow downed because of the international crisis in 2008, it is definitely not over. China still outperformed other economies by increasing share in outsourcing until 2011. In addition, there are signs that the international sourcing are moving toward even less-developing economies in South Asia and Africa to seek lower labor cost (Stratfor, 2013; AfDB, OECD and UNDP, 2014).

Therefore, against the background of continuous geographic shift of sourcing and sustained emission intensity gap, the global climate change mitigation requires stronger energy technology breakthroughs, especially ones developed by or transferable to the developing world. Such breakthroughs may include to make possible globally scalable low carbon energy supply, for all the high-tech or carbon-intensive industries. Without such breakthroughs significant global GHG mitigation will be very difficult to achieve.

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Appendix table A. Region and Industry list

No.	Abbr.	Region	Group	No.	Industry
1	AUS	Australia		1	Agriculture, hunting, forestry and fishing
2	AUT	Austria		2	Mining and quarrying
3	BEL	Belgium		3	Food products, beverages and tobacco
4	CAN	Canada		4	Textiles, textile products, leather and footwear
5	CHL	Chile		5	Wood and products of wood and cork
6	CZE	Czech Republic		6	Pulp, paper, paper products, printing and publishing
7	DNK	Denmark		7	Coke, refined petroleum products and nuclear fuel
8	EST	Estonia		8	Chemicals and chemical products
9	FIN	Finland		9	Rubber and plastics products
10	FRA	France		10	Other non-metallic mineral products
11	DEU	Germany		11	Basic metals
12	GRC	Greece		12	Fabricated metal products
13	HUN	Hungary		13	Machinery and equipment, nec
14	ISL	Iceland		14	Computer, Electronic and optical equipment
15	IRL	Ireland		15	Electrical machinery and apparatus, nec
16	ISR	Israel		16	Motor vehicles, trailers and semi-trailers
17	ITA	Italy		17	Other transport equipment
18	JPN	Japan		18	Manufacturing nec; recycling
19	KOR	Korea	OECD	19	Electricity, gas and water supply

20	LUX	Luxembourg		20	Construction
21	MEX.NGM	Mexico Non-Global Manufacturing		21	Wholesale and retail trade; repairs
22	MEX.GMF	Mexico Global Manufacturing		22	Hotels and restaurants
23	NLD	Netherlands		23	Transport and storage
24	NZL	New Zealand		24	Post and telecommunications
25	NOR	Norway		25	Financial intermediation
26	POL	Poland		26	Real estate activities
27	PRT	Portugal		27	Renting of machinery and equipment
28	SVK	Slovak Republic		28	Computer and related activities
29	SVN	Slovenia		29	R&D and other business activities
30	ESP	Spain		30	Public admin. and defence; compulsory social security
31	SWE	Sweden		31	Education
32	CHE	Switzerland		32	Health and social work
33	TUR	Turkey		33	Other community, social and personal services
34	GBR	United Kingdom		34	Private households with employed persons
35	USA	United States			
36	ARG	Argentina	non-OECD		
37	BGR	Bulgaria			
38	BRA	Brazil			
39	BRN	Brunei Darussalam			
40	CHN.DOM	China Domestic sales only			
41	CHN.PRO	China Processing			
42	CHN.NPR	China Non processing goods exporters			
43	COL	Colombia			
44	CRI	Costa Rica			
45	CYP	Cyprus			
46	HKG	Hong Kong SAR			
47	HRV	Croatia			
48	IDN	Indonesia			
49	IND	India			
50	KHM	Cambodia			
51	LTU	Lithuania			
52	LVA	Latvia			

53	MLT	Malta		
54	MYS	Malaysia		
55	PHL	Philippines		
56	ROU	Romania		
57	RUS	Russian Federation		
58	SAU	Saudi Arabia		
59	SGP	Singapore		
60	THA	Thailand		
61	TUN	Tunisia		
62	TWN	Chinese Taipei		
63	VNM	Viet Nam		
64	ZAF	South Africa		
65	RoW	Rest of the world		