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Original Article

Research on carbon emissions embodied in trade between China and South Korea

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ABSTRACT

With the signature of the free trade agreement, trade ties will develop rapidly between China and South Korea. Based on input–output model, this paper calculates and decomposes the embodied carbon emissions in the trade between China and South Korea from 2000 to 2010, analyses the reasons and gives some future advices. This paper suggests that the embodied carbon emissions surplus is not caused by trade surplus. It further points out that textile and leather industries, chemical manufacturing industries and metal manufacturing industries are three main sectors contributing to imported and exported embodied carbon emissions. In addition, the trade diversion between China and South Korea helps a lot in reducing the global carbon emissions and eases the pressure of carbon emissions in China. This paper also proposes that China should learn advanced technologies from South Korea and reduce carbon-intensive energy consumption in the future.

1. Introduction

Carbon emission, which is one of the core issues in the 2015 Paris Climate Conference, has been a growing problem around world. As the biggest carbon emitter, China of course has responsibility to control carbon emissions. However, due to the high level of foreign trade volume growth, China has emitted more carbon linked to production for export (Weber et al., 2008; Du and Zhang, 2012; Liu et al., 2015), which is called embodied carbon emissions. With the development of foreign trade, China faces a huge challenge of reducing carbon emissions.

Voluminous researches have been carried out on embodied carbon emissions, and the input–output model put forwarded by Leontief becomes the dominant research method (Leontief, 1936, 1941). Initially this method was used to analyze the relationship between inputs and outputs in economic field. By the 1960s, some researches began to apply this model to energy and environmental field (Daly, 1968; Isard et al., 1968; Ayres and Kneese, 1969; Leontief, 1970). Wyckoff and Roop's (1994) paper calculated the total carbon emissions embodied in manufactured imports of six OECD countries (Canada, France, Germany, Japan, United Kingdom and the United States), and the amount of carbon was 300 MtC, which was about 13% of the total carbon emissions.

Considering the different assumptions, the input–output model is usually divided into two types: single-regional input–output (SRIO) model (Shui and Harriss, 2006; Dietzenbacher and Mukhopadhyay, 2007; Li and Hewitt, 2008) and multi-regional input–output (MRIO) model (Kanemoto et al., 2012, 2013; Moran et al., 2013; López et al., 2013; Feng et al., 2013; Liu et al., 2015). For the MRIO model, Peters' (2008) paper treated it as two approaches: emissions embodied in bilateral trade (EEBT) approach and MRIO approach (Su and Ang, 2011; Jiang and Liu, 2013; Zhang et al., 2014). The EEBT approach only considers total direct trade between two regions concerned and employs SRIO tables of each region, while the MRIO approach considers the global production systems with MRIO table.

As one of the classical studies on this issue, the Pollution Haven Hypothesis (PHH) shows that developed countries tend to transfer energy-intensive production to developing countries with low salaries and energy costs (Copeland and Taylor, 1994, 2004), which turns the latter to be pollution haven. However, there are also some researches cannot confirm the PHH (Dietzenbacher and Mukhopadhyay, 2007; Li and Lu, 2010; Tan et al., 2013). Some previous researches on PHH in China's international trade also have different opinions. López et al.'s (2013) paper confirmed the

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existence of PHH between Spain and China while Tan et al.'s (2013) paper concluded that the PHH didn't hold in China–Australia trade. And Zhang et al.'s (2014) paper calculated national balance of CO_2 emissions in China and found that the PHH only holded in 2002. In addition, Arce et al.'s (2016) assessed the change of global carbon emissions occurring when China's trade is replaced by other developing country, which concludes that it will generate emissions savings.

Recently, there are more and more researches have analyzed embodied carbon emissions issues of China (Guan et al., 2009, 2014; Peters et al., 2010; Huang and Jiang, 2010; Feng et al., 2012, 2013; Lin et al., 2014; Yuan and Zhao, 2016). They concluded that a large proportion of China's carbon emissions was due to foreign consumption, which means China is a net exporter of embodied carbon emissions, and carbon emissions come mainly from energy-intensive industries (Ahmed and Wyckoff, 2003; Weber et al., 2008; Peters and Hertwich, 2008; Guan et al., 2009, 2014; Gao et al., 2011; Du and Zhang, 2012; Guo et al., 2012; Feng et al., 2013; Yang et al., 2013; Lin et al., 2014; Liu et al., 2014; Zhang and Tang, 2015). To decrease the emissions, China has to change the export structure, improve the energy use efficiency and technologies (Guan et al., 2009; Du et al., 2011; Tan et al., 2013; López et al., 2013; Zhang et al., 2014; Yuan and Zhao, 2016).

In addition, several researches have conducted a hypothetical scenario analysis to analyze the difference between the carbon emissions in trade and the hypothetical emissions in no-trade scenario (Shui and Harriss, 2006; Li and Hewitt, 2008; Liu et al., 2010; Tan et al., 2013; Zhang and Hong, 2013). Some researches show that international trade has increased global carbon emissions, including US–China Trade (Shui and Harriss, 2006), and UK–China Trade (Li and Hewitt, 2008). And other researches show that it has decreased global emissions, including Japan–China Trade (Liu et al., 2010), Australia–China Trade (Tan et al., 2013) and China Mainland–Taiwan Trade (Zhang and Hong, 2013).

China and South Korea have signed a free trade agreement (FTA) in Seoul on June 1st, 2015. According to the agreement, they will eliminate tariffs gradually on 90 percent of all goods within 20 years, which can promote the development of bilateral trade. Since the establishment of diplomatic ties in 1992, the relationship between China and South Korea has become closer. According to the report of Ministry of Commerce of the People's Republic of China (MOFCOM, 2015), the trade volume reached to \$235.40 billion in 2014, demonstrating a 2.8% increase over 2013. To be specific, the export volume from South Korea to China was \$145.33 billion, and the volume from China to South Korea was \$90.07 billion, which showed an increase of 8.5%. At present, China becomes South Korea's largest trading partner, export markets and source of imports. Korea becomes China's the third-largest trading partner, behind the US and Japan.

The development of bilateral trade between China and South Korea has accelerated the transfer of production and consumption of their goods, and as a result, it leads to the redistribution of carbon emissions. In recent years, the export volume from China to South Korea has grown rapidly. In this regard, it is necessary to conduct a further study on carbon emissions embodied in Sino-South Korea trade and offer some suggestions.

In this paper, we choose the EEBT approach to calculate embodied carbon emissions, and the reasons are as follows. On one hand, this research analyzes the impacts of direct trade in two regions, rather than considering the global production chains, which indicates the EEBT approach is more suitable. On the other hand, this paper is to provide an overview of carbon emissions embodied in Sino-South Korea trade under the background of FTA, which means MRIO approach is too complex.

The rest of the paper is organized as follows. Section 2 introduces the methodology and data source. Section 3 presents the further analyses and discussion on the results, which includes input–output analysis, decomposition analysis and hypothetical scenario analysis, followed by conclusions and policy implications in Section 4.

2. Methodology and data

2.1. Input–output model

This paper employs I–O Model to calculate carbon emissions (Leontief, 1936, 1941; Miller and Blair, 1985; Dietzenbacher and Mukhopadhyay, 2007; Lenzen et al., 2010; Su and Ang, 2011), which can be expressed as:

$$x = Ax + y \tag{1}$$

where x represents the total output, A represents the matrix of domestic input coefficients, and y represents the final consumption. And we can get:

$$x = (I - A)^{-1} y \tag{2}$$

where $(I - A)^{-1}$ is the domestic Leontief inverse matrix that shows the requirement of total production for per unit of final consumption and I is identity matrix. In addition, we defined $e = (b_1, b_2, \cdots, b_i)$ as the vector of emissions coefficients of sectors, so b_i, the carbon emissions that sector i produces per unit of goods, can be formulated as follows:

$$b_i = \sum_{k=1}^{m} f_k \frac{s_{ik}}{g_i} \tag{3}$$

where f_k represents the carbon emissions coefficient by using energy k, and there are m kinds of energy, g_i represents the goods produced in sector i, and s_{ik} is the consumption of energy k in sector i.

Therefore, the "consumption-based" carbon emissions using the EEBT approach embodied in the export from China to South Korea, c_a, can be expressed as:

$$c_a = e_s (I - A)^{-1} a \tag{4}$$

where e_s represents the row vector of carbon emissions coefficients of Chinese sectors, $(I - A)^{-1}$ is Leontief Inverse Matrix based on Chinese I–O table, and a represents the trade volume that China export to South Korea. In addition, the carbon emissions embodied in the trade that China imports from South Korea can be expressed as:

$$c_d = e_s' (I - A)^{-1'} d \tag{5}$$

where d means the trade volume that South Korea export to China, e_s' represents the vector of carbon emissions coefficients of South Korean sectors, and $(I - A)^{-1'}$ is calculated by South Korean I–O table.

2.2. Hypothetical scenario analysis

c_a and c_d mentioned above are under the circumstance of the existence of Sino-South Korea trade. However, some researches show that once there is no trade in bilateral trade, countries have to produce imports domestically (Shui and Harriss, 2006; Li and

Hewitt, 2008; Tan et al., 2013). Therefore, we hypothesize a no-trade scenario between China and South Korea, and we can get:

$$c_{China} = e_s(I-A)^{-1}d \tag{6}$$

$$c_{Korea} = e_s'(I-A)^{-1'}a \tag{7}$$

As a result, if there is no trade between China and South Korea, then the global carbon emissions will increase c_{net}, which can be described as:

$$c_{net} = c_{China} + c_{Korea} - c_a - c_d \tag{8}$$

if $c_{net} > 0$, the trade will decrease the global emissions, otherwise, it will increase the emissions.

2.3. Structural decomposition analysis

In order to have a better understanding of factors that influence carbon emissions embodied in Sino-South Korea trade, this paper uses structural decomposition analysis to have a further study on the embodied carbon emissions (Torvanger, 1991; Zhang et al., 2009; Feng et al., 2012; Tan et al., 2013; Lenzen, 2016). The formula to calculate embodied carbon emissions we mentioned above are as follows:

$$c = e(I-A)^{-1}q \tag{9}$$

where q means the column vector of the total import volume or total export volume of sectors, and we had it deformed:

$$c = e(I-A)^{-1}pv \tag{10}$$

where p represents the vector $\left(\frac{q_1}{v}, \frac{q_2}{v} \cdots \frac{q_i}{v}\right)$, $\frac{q_i}{v}$ means the proportion of the import volume of sector i in the total import volume (or the export volume of sector i in the total export volume). And we define $\Delta c(\Delta e)$, $\Delta c[\Delta(I-A)^{-1}]$, $\Delta c(\Delta p)$, $\Delta c(\Delta v)$ that represent the effect of carbon emissions coefficients, intermediate technology, trade structure and trade scale on embodied carbon emissions, and we assume that 0 means the value of base period and 1 means the value of report period. So the decomposition formula can be expressed as follows:

$$\Delta c = \Delta c(\Delta e) + \Delta c[\Delta(I-A)^{-1}] + \Delta c(\Delta p) + \Delta c(\Delta v) \tag{11}$$

where,

$$\Delta c(\Delta e) = 1/2[\Delta e(I-A)^{-1}{}_0 p_0 v_0 + \Delta e \times (I-A)^{-1}{}_1 p_1 v_1] \tag{12}$$

$$\Delta c[\Delta(I-A)^{-1}] = 1/2[e_1 \Delta(I-A)^{-1} p_0 v_0 + e_0 \Delta(I-A)^{-1} p_1 v_1] \tag{13}$$

$$\Delta c(\Delta p) = 1/2[e_1(I-A)^{-1}{}_1 \Delta p v_0 + e_0(I-A)^{-1}{}_0 \Delta p v_1] \tag{14}$$

$$\Delta c(\Delta v) = 1/2[e_1(I-A)^{-1}{}_1 p_1 \Delta v + e_0(I-A)^{-1}{}_0 p_0 \Delta v] \tag{15}$$

2.4. Data

In this paper, the RMB exchange rate is adopted from Annual Report of the State Administration of Foreign Exchange (SAFE, 2011), and China's CPI is from China Statistical Year book published by the National Bureau Statistics of the People's Republic of China (NBSC, 2011). KRW exchange rate and South Korea's CPI are retrieved from Annual Report of the Bank of Korea (BOK, 2011). The input–output table and the trade volume of two countries are based on OECD Database (OECD, 2000, 2005, 2010), and we select the I–O data and trade volume in 2000 year as the base period, which means the data in 2005 and 2010 are adjusted. The carbon emissions coefficients of energy are calculated based on 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The energy consumption of China is from China Statistical Year book published by NBSC (NBSC, 2011) and the data of South Korea is from Year book of Energy Statistics published by Korea Energy Economics Institute (KEEI, 2011). In addition, we adjusted them into 11 sectors due to the different sector classification of input–output table, bilateral trade volume and energy consumption (see Table 1).

3. Results and discussion

In this section, we calculate the embodied carbon emissions and discuss the effects of carbon emissions between Sino-South Korea trade, which is conducted by the methodology mentioned above.

3.1. Embodied carbon emissions based on EEBT approach

As shown in Table 2, we can find that embodied carbon emissions that China Exported to South Korea was 46.56 Mt in 2000 and 132.24 Mt in 2005, and then it reached to 142.62 Mt in 2010. We can see that the average annual growth rate (AAGR) was 23.21% in the former five years (2000–2005) and 1.52% in the latter five years (2005–2010). Meanwhile, the imported embodied carbon emissions from South Korea to China increased from 26.68 Mt in 2000 to 46.31 Mt in 2005, and then it reached 68.70 Mt in 2010. By comparison, we can conclude that the AAGR of the exported embodied carbon emissions experienced a big decrease while the AAGR of the imported embodied carbon emissions were stable. However, the exported carbon emissions were still bigger than the imported emissions due to the large base of exported embodied carbon emissions.

Some previous researches show that trade surplus is the main reason that leads to the embodied carbon emissions surplus between China and OECD countries (López et al., 2013; Tan et al., 2013). In order to find out whether it can also explain in Sino-South Korea trade or not, we have compared the trade volume. As shown in Table 2, the trade volume that China exported to South Korea was $11.29 billion in 2000, $32.84 billion in 2005 and $55.64 billion in 2010. Meanwhile, the imported volume was $18.46 billion in 2000, $52.56 billion in 2005, and $85.41 billion in 2010. It is shown that China had a trade deficit with South Korea, so we can conclude that the trade surplus was not the reason for embodied carbon emissions surplus in Sino-South Korea (because there is a trade deficit in Sino-South Korea trade).

Table 1
Classification of the sectors.

No.	Sectors	No.	Sectors
1	Agriculture, hunting, forestry and fishery	7	Chemical manufacturing industries
2	Mining and quarrying	8	Non-metallic mineral manufacturing industries
3	Food, beverages and tobacco	9	Metal manufacturing industries
4	Textiles and leather industries	10	Other manufactures
5	Wood and wood products	11	Other sectors
6	Paper, printing and publishing		

Table 2
Total embodied carbon emissions and trade volume.

	2000	2005	2010	AAGR	
				2000–2005	2005–2010
Embodied carbon emissions China exported to South Korea (million tons)	46.56	132.24	142.62	23.21%	1.52%
Embodied carbon emissions China imported from South Korea (million tons)	26.68	46.31	68.70	11.67%	8.21%
Trade volume China exported to South Korea[a] (billion dollar)	11.29	32.84	55.64	23.81%	11.12%
Trade volume China imported from South Korea[a] (billion dollar)	18.46	52.56	85.41	23.28%	10.20%

[a] The data are adjusted for inflation based on year 2000.
Source: Own elaboration from OECD database.

By comparison, China emitted more carbon dioxide than South Korea when they produce goods with same value. For example, China exported $11.29 billion products and emitted exported embodied carbon 46.56 Mt in 2000, which means that China emitted 4.12 thousand tons per million US dollars on average. However, South Korea only emitted 1.45 thousand tons per million US dollars on average in 2000. This is due to the fact that coal and some other carbon-intensive energy accounted for a large proportion in the China's energy consumption structure, which also reflects the difference of energy utilization rate and technology gap between China and South Korea. This result can also be found in Liu et al.'s paper (2015).

Given that emissions coefficients may be one of reasons that lead to embodied carbon surplus, we compare them by sectors with data in 2000 as an example (see Table 3). We can see that South Korea had more environmental emissions coefficients than China in most sectors in 2000. Compared with previous studies, Liu et al.'s paper (2010), López et al.'s paper (2013) and Tan et al.'s paper (2013) had similar conclusions that Japan, Spain and Australia have lower emissions coefficients than China.

From the perspective of sectors. The coefficients of sectors 1, 4 and 8 in China had absolute environmental advantage than in South Korea while they were relatively close in sectors 3, 5 and 10. And we find that sectors 1 and 4 are primary industries (Agriculture, hunting, forestry, fishery, textiles and leather industries), so the difference of coefficients may be explained by the diversity of mechanization in two countries. To be precise, these two sectors in South Korea were more mechanized than those in China, in this way, they required more energy consumption in South Korea, which led to the more carbon emissions and the higher coefficients. In addition, the coefficients of other sectors were lower in South Korea with respect to China, because of the more consumption of carbon-intensive energy (especially for coal) in China. And it is consistent with López et al.'s paper (2013), which presented that the difference of coefficients were explained by the increase in the consumption of coal in China.

Combined with trade data, we can find that China imported and exported goods were mainly from sectors 4, 7, 9 and 10 (high coefficients sectors). However, the import volume in these sectors were much larger than export volume, which can contribute more imported embodied emissions from South Korea. In addition, China exported more goods than South Korea only in some low coefficients sectors except sector 2 (such as sectors 1 and 3).

As shown in Table 4, sector 10 contributed the greatest carbon emissions both in exported and imported carbon emissions, this is because that the carbon emissions of all the other manufactures except sectors 7, 8 and 9 are calculated to sector 10.

For the detail sectors (except sectors 10 and 11), the top three sectors of exported embodied carbon emissions of China were sectors 9, 7 and 4. And it is similar with some previous studies (Guan et al., 2009; Gao et al., 2011; Guo et al., 2012; Zhang and Hong, 2013; Zhang and Tang, 2015). The proportion of carbon emissions by these sectors over total exported carbon emissions respectively were 20.73%, 17.45%, 14.19% in 2000, and reached to 28.76%, 17.34%, 8.76% in 2005 and 23.33%, 16.91%, 5.81% in 2010. We can find that the exported carbon emissions by these sectors had a down trend over the ten years, which reflects that the exported products structure have become diversified. For other sectors, they contributed little to carbon emissions in these years.

Imported embodied carbon emissions in 2000 and 2005 were mostly from sectors 9, 7 and 4, and the proportion of carbon emissions by these sectors over total imported embodied carbon emissions were 45.35%, 12.44%, 6.19% in 2000, and decreased to 33.30%, 7.90%, 2.16% in 2005. In addition, the top three sectors of imported embodied carbon emissions were sector 9, 7 and 3 in 2010, which occupied 15.01%, 5.27% and 4.97% of the total carbon emissions. And the rest of sectors have contributed little to carbon emissions.

According to the imported and exported embodied carbon emissions, we can conclude that metal manufacturing industries, chemical manufacturing industries and textiles and leather industries were the top three industries that led to the huge

Table 3
Emissions coefficients of sectors (e) and trade in year 2000.

		e (China)[a]	e (South Korea)[a]	China exports[b]	South Korea exports[b]
1	Agriculture, hunting, forestry and fishery	0.09	0.37	932.33	28.73
2	Mining and quarrying	0.99	0.07	813.54	9.28
3	Food, beverages and tobacco	0.10	0.07	712.79	121.63
4	Textiles and leather industries	0.09	0.17	2541.47	3033.98
5	Wood and wood products	0.06	0.09	154.21	53.30
6	Paper, printing and publishing	0.36	0.20	54.53	404.23
7	Chemical manufacturing industries	1.61	0.86	1193.20	6805.89
8	Non-metallic mineral manufacturing industries	1.06	1.39	171.81	143.57
9	Metal manufacturing industries	1.27	1.06	1345.69	1899.43
10	Other manufactures	0.04	0.05	3368.54	5916.49
11	Other sectors	0.75	0.35	4.68	37.44

[a] Unit (Kt/per million US dollar).
[b] Unit (million US dollar).
Source: Own elaboration.

Table 4
Embodied carbon by sectors from year 2000–2010.

Sector	2000		2005		2010	
	ECE[a]	ICE[b]	ECE[a]	ICE[b]	ECE[a]	ICE[b]
1	1.70	0.02	1.86	0.03	0.64	0.10
2	4.21	0.004	8.55	0.01	3.25	0.03
3	1.50	0.09	2.55	0.11	2.46	3.42
4	6.61	2.88	11.58	1.65	8.29	1.27
5	0.50	0.04	0.72	0.01	0.52	0.004
6	0.20	0.36	0.48	0.15	0.65	0.14
7	8.12	12.22	22.93	16.41	24.12	10.31
8	1.14	0.33	—[c]	0.29	4.97	1.73
9	9.65	5.05	38.03	7.84	33.28	3.62
10	12.90	5.64	45.48	19.69	64.39	47.93
11	0.02	0.03	0.06	0.14	0.03	0.16
Grand total	46.56	26.68	132.24	46.31	142.62	68.70

[a] Exported carbon emissions, million tons.
[b] Imported carbon emissions, million tons.
[c] The data in year 2005 of sector 8 from OECD I–O table was categorized into sector 7, so the embodied carbon emissions of sector 8 below also was categorized into sector 7.
Source: Own elaboration.

embodied carbon emissions in Sino-South Korea trade. Combined with trade volume presented in Table 3 (data in 2000), we can see that the export volume of these three sectors were less than import volume. However, the exported carbon emissions of these three sectors were greater than the imported carbon emissions, which reveals that the main reason for the huge exported embodied carbon emissions was not the huge export volume, but the technology gap and the difference of the energy consumption structure. Differently, the large imported embodied carbon emissions were caused by the large import volume. This result differs from some previous studies (Liu et al., 2010; López et al., 2013; Tan et al., 2013; Deng, 2014), which concluded that the main reason that China being a net exporter of embodied carbon emissions is owing to trade surplus.

3.2. Hypothetical carbon emissions in a no-trade scenario

As we mentioned above, if there is no trade between China and South Korea, two countries have to produce imports domestically, and then we calculate the hypothetic embodied carbon emissions in a no-trade scenario (see Figs. 1–3). As shown in Fig. 1, exported carbon emissions in bilateral trade was larger than the hypothetic emissions if these goods were produced in South Korea, which means South Korea has reduced carbon emissions. Instead, it increased carbon emissions in China and emitted 33.07 Mt (in 2000), 104.39 Mt (in 2005) and 73.70 Mt (in 2010) more carbon in the worldwide compared with no-trade scenario. As shown in Fig. 2, embodied carbon emissions imported from South Korea to China were lower than the hypothetic emissions if these goods were produced domestically. So we can conclude that the imports from South Korea helped China to reduce emissions while it increased emissions in South Korea, and it reduced 66.98 Mt (in 2000), 183.49 Mt (in 2005) and 167.77 Mt (in 2010) carbon around the world.

From the perspective of total embodied carbon emissions (see Fig. 3), we calculate the total embodied carbon emissions and total hypothetic emissions in a no-trade scenario. We can see that the total embodied carbon emissions in the bilateral trade were lower than the hypothetic emissions in a no-trade scenario ($c_{net} > 0$). And c_{net} was 33.91 Mt (in 2000), 79.00 Mt (in 2005) and 94.07 Mt (in 2010) respectively, which means total carbon emissions would decrease in the worldwide due to the bilateral trade. It can be explained that large numbers of carbon-intensive goods from South Korea to China could help China reduce the consumption of energy in production. This result is consistent with some previous studies (Liu et al., 2010; Tan et al., 2013; Zhang and Hong, 2013). However, it differs from some studies (Li and Hewitt, 2008; Du et al., 2011; López et al., 2013), they implied that global emissions would decrease if there is no bilateral trade.

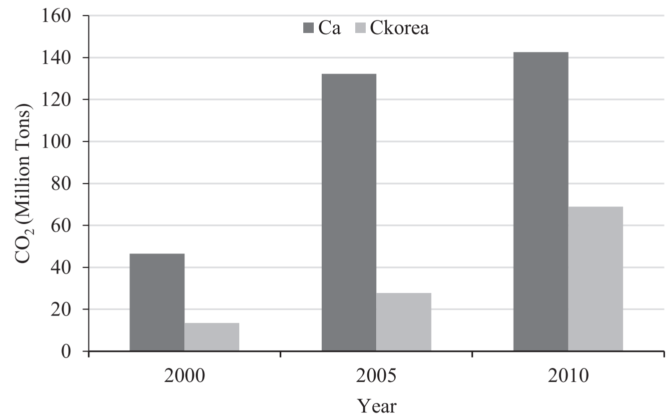

Fig. 1. Embodied carbon emissions China exported to South Korea and hypothetic carbon emissions if exports were produced in South Korea.
Source: Own elaboration.

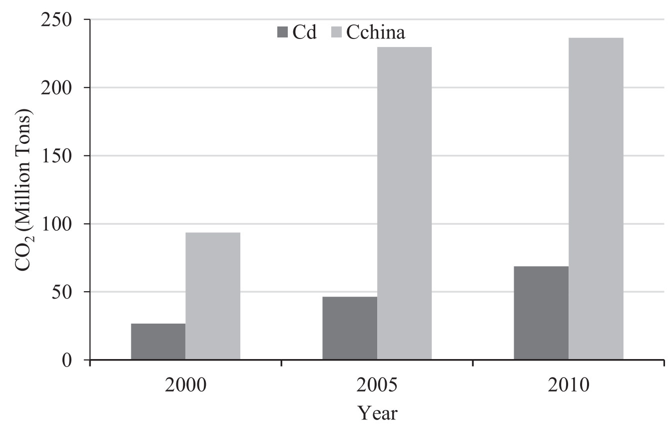

Fig. 2. Embodied carbon emissions China imported from South Korea and hypothetic carbon emissions if imports were produced in China.
Source: Own elaboration.

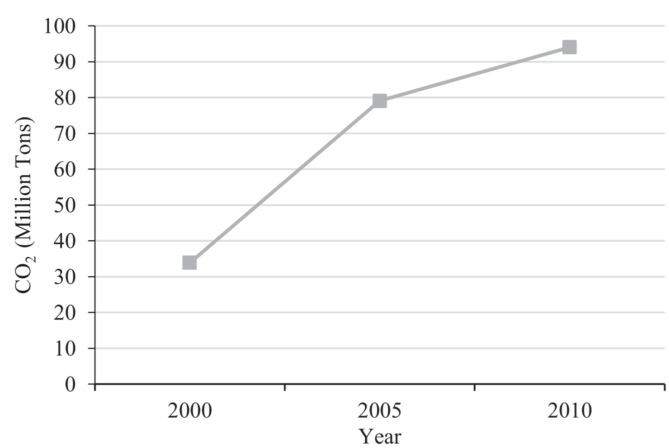

Fig. 3. Net carbon emissions (c_{net}).
Source: Own elaboration.

Recently, China and South Korea have signed a free trade agreement (FTA). It mentioned that the tariffs will be eliminated gradually on 90 percent of all goods within 20 years, which of course will promote the development of bilateral trade.

Given that FTA can have positive impacts on exports in both countries, it could lead to two different situations of the global carbon emissions in terms of trade diversion. One situation is there still leave a trade deficit, in this way, China imports more goods from South Korea rather than produces domestically, which will reduce large numbers of emissions in the world due to more environmental emissions coefficients in South Korea we have analyzed above. The other situation is on the opposite way, which means export volume of China is increased more so that there is a trade surplus in Sino-South Korea trade, and it may increase the global carbon emissions because of a big export volume of carbon-intensive goods from China to South Korea.

Pollution haven hypothesis implies that the carbon-intensive industries would be transferred from developed countries to developing countries due to the lower environment standard and lower costs (Copeland and Taylor, 1994), which has been confirmed in some studies (He, 2006; López et al., 2013; Liu et al., 2015). However, we do not find result or evidence to confirm the existence of PHH, and it is similar with Tan et al.'s paper (2013). The result can be explained by other factors rather than environment standard.

One factor is small domestic market in South Korea and its economic growth has to rely on exports. As we all know, South Korean economy has grown rapidly in the past 50 years, and many Koreans believe it results from the industrial policy that limits imports and encourages exports (Holcombe, 2013). According to the data of Korea Customs Service (KCS) cited in the China Country Trade Report (MOFCOM, 2015), the exported volume from South Korea to China occupied about 25% of the total exported volume in 2014, which means China is a huge market as for South Korea. In this way, South Korea transfer more exports to China.

The other factor is massive production of chemical industries, metal manufacturing industries and other carbon-intensive industries. In the past 50 years, these heavy industries got a boost in South Korea due to the economic growth, which led to large output. However, the domestic market is small so that they exports these goods to other counties (especially to China). As a result, numbers of carbon-intensive goods were transferred to China over these years (also can be proved in Table 3).

3.3. Structural decomposition analysis

In this section, we use SDA method mentioned above to make further investigation on the factors which influence exported and imported embodied carbon emissions.

As shown in Fig. 4, the carbon emissions coefficients contributed to a reduction of exported carbon emissions, which facilitated to reduce 99.03 Mt in ten years (20.80 Mt in the former five years and 78.23 Mt in the latter five years). And it helped total exported carbon emissions reduced to 10.39 Mt from 2005 to 2010. In this regard, we can conclude that China adjusted energy consumption structure by the decline of carbon-intensive energy consumption in the latter five years, which led to the decrease of carbon emissions coefficients (especially for the carbon-intensive industries), and it had a significant impact on reducing carbon emissions. Differently, intermediate technology, trade structure and trade scale were the three factors responsible for the increase in exported carbon emissions, and trade scale was a dominate factor which increased 87.70 Mt of exported carbon emissions from 2000 to 2005 and 75.51 Mt from 2005 to 2010. Followed by that were intermediate technology and trade structure, and they made exported carbon emissions increased 19.93 Mt and 11.95 Mt respectively over ten years.

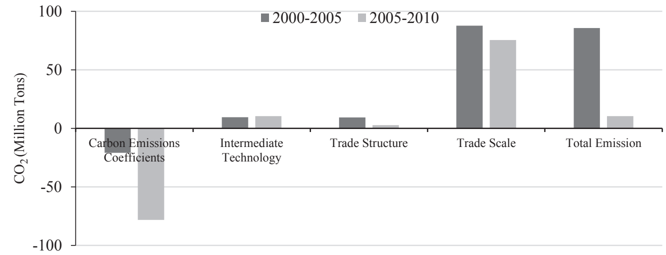

Fig. 4. Decomposition analysis of exported carbon emissions from year 2000–2010. *Source*: Own elaboration.

Compared to exported embodied carbon emissions, we can find that there were only two factors, trade scale and intermediate technology, that contributed to an increase in imported carbon emissions (see Fig. 5). And trade scale had a greater impact than intermediate technology, which increased 39.68 Mt of imported carbon emissions in the former five years and 27.69 Mt in the latter five years, while intermediate technology only contributed 3.71 Mt and 6.71 Mt to imported carbon emissions. In contrast, carbon emissions coefficients and trade structure contributed to a reduction of imported carbon emissions, and the impact of the carbon emissions coefficients were more obvious, which helped imported carbon emissions to reduce 31.05 Mt in ten years. At the same time, trade structure helped imported carbon emissions reduce only 4.17 Mt in total.

Based on the above analysis, we can conclude that intermediate technology and trade scale were two factors responsible for the increase of exported and imported carbon emissions. And carbon emissions coefficients could help reduce both exported and imported carbon emissions. In contrast, trade structure increased exported carbon emissions, while it reduced imported carbon emissions.

Compared exported and imported carbon emissions, we can find that intermediate technology had a difference on exported and imported carbon emissions. Under the circumstance of trade deficit in Sino-South Korea trade, intermediate technology increased more exported carbon emissions than imported carbon emissions unexpectedly, which means that South Korea had more advanced intermediate technology than China. Therefore, we have to introduce technologies in the future of the development of Sino-South Korea free trade zone. Carbon emissions coefficients had a difference degree on exported carbon emissions in two periods, which contributed a reduction of 20.80 Mt and 78.23 Mt in the former and latter five years, and it means China used less carbon-intensive energy, increased energy utilization and changed energy consumption structure to reduce carbon emissions from 2005 to 2010. In this regard, exported carbon emissions had a great reduction during this period and its increment was less than the increment of imported carbon

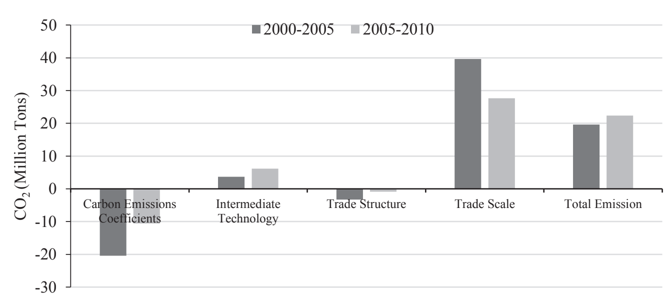

Fig. 5. Decomposition analysis of imported carbon emissions from year 2000–2010. *Source*: Own elaboration.

emissions. We can conclude that low carbon emissions coefficients were the most important measure for carbon reduction, so it is necessary to reduce carbon-intensive energy consumption and use more green energy. In addition, trade structure contributed an increase in exported carbon emissions and a reduction in imported carbon emissions, which means China produced more carbon-intensive goods for Korea and Korea produced comparatively clean goods for China. Therefore, China has to adjust exported products structure by exporting less carbon-intensive goods in the future.

4. Conclusion

In this paper, we have calculated the carbon emissions embodied in Sino-South Korea trade based on the EEBT approach. Further, we estimate the emissions in the trade and hypothetical emissions in no-trade scenario and compare them to find how the trade influence the global emissions. Finally, we have structural decomposition analysis. And the following part is our main takeaways from this study:

Firstly, China had an embodied carbon emissions surplus with South Korea, although there was a trade deficit in Sino-South Korea trade. Secondly, large trade volume of sectors 4, 7, 9 and 10 (carbon-intensive industries) were responsible for the increase of exported and imported carbon emissions. Thirdly, South Korea had more environmental carbon emissions coefficients in comparison with China, which means South Korea will emit less carbon when producing products with the same value. Therefore, the global carbon can be reduced due to more carbon-intensive goods were transferred from South Korea to China in terms of trade diversion. Last but not least, trade scale was a dominant factor that led to the increase of embodied emissions while carbon emissions coefficients could benefit a lot in reducing emissions. However, trade structure only contributed a decrease of emissions in South Korea.

Based on the conclusion, it should be noted that China should adjust export structure by reducing carbon-intensive goods and take full advantage of the bilateral trade platform to introduce advanced technologies from South Korea. From the perspective of domestic production, we expect that China could use less carbon-intensive energy and improve energy utilization to lower the carbon emissions coefficients, especially for carbon-intensive sectors.

Some policy implications can be drawn from the results presented above. Firstly, the embodied carbon emissions in international trade can have an impact on environment due to the consumption abroad. While previous researches have different conclusion, our results imply that trade diversion between China and South Korea can help to reduce global carbon emissions, and it can be explained by environmental emissions coefficients in South Korea. To be specific, China has a trade deficit with South Korea, which implies China imported more goods from South Korea, especially in carbon-intensive goods (see Table 3). Because of the environmental emissions coefficients, South Korea emits less carbon than China, and the global emissions will reduce if South Korea produce these goods rather than production domestically in China. In this regards, we should pay more attention to the potential development of the bilateral trade under the background of FTA.

Secondly, the pollution haven hypothesis points that the carbon-intensive industries would relocate from the developed countries to developing countries because of the different environment standard. However, our findings cannot support the hypothesis. Actually, South Korea has large output in carbon-intensive goods, and due to the small domestic market, it has to export these goods to China. Therefore, when it comes to the impact of international trade on emissions, we have to analyze in accordance with specific conditions, because environment standard is not the only factor for trade diversion.

Given that the Sino-South Korea free trade zone will be established in the near future, we shouldn't overlook the potential development of trade between two countries. As it mentioned in FTA, the tariff will be eliminated, and it enables Chinese products to be more comparative to South Korea, for this reason, further researches could pay attention to the balance of trade, which might change and have a different impacts on global carbon emissions. With the development of bilateral trade, there must be an increase of production, and it should also be taken into consideration, which could cause more emissions.

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