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Research on Embodied Carbon Emission in Sino-Korea Trade based on MRIO Model

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Abstract

Purpose – This paper research on the embodied carbon emission in Sino-Korea trade. It calculates and analyzes the carbon emission coefficient and specific carbon emissions in Sino-Korea trade from 2005 to 2014.

Design/methodology – This paper conducted an empirical analysis for embodied carbon emission in Sino-Korea trade during the years 2005–2014, using a multi-region input-output model. First, direct and complete CO2 emission coefficient of the two countries were calculated and compared. On this basis, combined with the world input-output table, the annual import and export volume and sector volume of embodied carbon emission are determined. Then through the comparative analysis of the empirical results, the reasons for the carbon imbalance in Sino-Korea trade are clarified, and the corresponding suggestions are put forward according to the environmental protection policies being implemented by the two countries.

Findings – The results show that South Korea is in the state of net trade export and net embodied carbon import. The carbon emission coefficient of most sectors in South Korea is lower than that of China. However, the reduction of carbon emission coefficient in China is significantly faster than that in South Korea in this decade. The change of Korea's complete CO2 emission coefficient shows that policy factors have a great impact on environmental protection. The proportion of intra industry trade between China and South Korea is relatively large and concentrated in mechanical and electrical products, chemical products, etc. These sectors generally have large carbon emissions, which need to be noticed by both countries.

Originality/value – To the best knowledge of the authors, this study is the first attempt to research the embodied carbon emission of ten consecutive years in Sino-Korea Trade. In addition, In this paper, some mathematical methods are used to overcome the error problem caused by different statistical caliber in different databases. Finally, the accurate measurement of carbon level in bilateral trade will provide some reference for trade development and environmental protection.

Keywords: Embodied Carbon Emission, Environmental Protection, MRIO Model, Sino-Korea Trade
JEL Classifications: F18, R15

1. Introduction

China and South Korea are geographically close. Since the establishment of diplomatic relations in 1992, political relations have been stable and the economy has developed rapidly. While international trade improves the welfare of the two countries, the consumption of natural resources, energy and environmental capacity cannot be avoided.

Significant progress was made in the bilateral trade between South Korea and China in 2005. The scale of bilateral trade broke through the $100 billion mark for the first time, reaching $100.56 billion. After 15 years of development, the total volume of Sino-Korea trade

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has increased greatly, reaching $243.43 billion in 2019, with an overall growth rate of 142%. Although China's economy has grown several times, South Korea has always been a stable trade partner of China. Since 2008, China has become the largest trading partner, export destination and import source of South Korea. Apart from the sharp decline in trade between China and South Korea, which resulted from political factors such as the THAAD event in 2015 and 2016, China has always been Korea's largest trading partner. The detailed data are shown in Table A of appendix.

Different from China's overall foreign trade surplus, China has been in a deficit position in bilateral trade between China and South Korea for many years. But the study found that the embodied carbon emission is a surplus for China in Sino-Korea trade. This problem is worthy of further study. As a developed country, South Korea had also faced the problems of energy shortage and environmental pollution in the process of rapid economic development, so it has accumulated a lot of advanced technology about energy-saving, emission reduction, pollution control. South Korea is the first country in East Asia to establish a national carbon market. As early as 2009, the South Korean parliament passed the *RAMEWORK ACT ON LOW CARBON, GREEN GROWTH* and formally implemented in the following year. As a developing country, in the 13th Five Year Plan of 2015, China also explicitly proposed to take a low-carbon development path. Therefore, it is of great significance for the future economic development of the two countries to accurately calculate the carbon level of bilateral trade and reasonably adjust the trade structure of the two countries.

However, there is little research about embodied carbon emission in Sino-Korea trade. And Due to the complex calculation of MRIO model, the different statistical caliber of several world input-output databases, to the best knowledge of the authors, this study is the first attempt to research the embodied carbon emission of ten consecutive years in Sino-Korea Trade based on MRIO Model. The accurate measurement of carbon level in bilateral trade will provide some reference for Sino-Korea trade development and environmental protection.

The rest of this paper is organized as follows. Section 2 reviews extant literature on the technical means of Embodied Carbon estimation, the measurement of Embodied Carbon based on MRIO model, and the study of Embodied Carbon emissions in bilateral trade. Section 3 explains the methodologies and the dataset employed in this paper. Section 4 presents the direct and complete CO_2 emission intensity in the two countries, the annual import and export volume and sector volume of Embodied Carbon and discusses possible explanations. Finally, Section 5 presents the conclusions and suggestions of this research.

2. Literature Review

2.1. Technical Means of Embodied Carbon Estimation

In 1974, the concept of "embodied" first appeared at the Energy Group Meeting of the International Federation of Institutes for Advanced Study. After that, the names of resources such as water and land could be added to measure the resources consumed by products or services during the entire production process. Later, it was thought, "embodied" can be followed by not only the name of resources, but also the name of pollutants such as CO_2, SO_2, which could be used to represent the emission of pollution gases such as CO_2 during the whole production process (Brown and Herendean, 1996). Then the word ""embodied carbon" was produced.

At present, the calculation of embodied carbon emissions can be summarized into three types: IPCC accounting method, Life Cycle Assessment (LCA) and Input-Output Analysis (IOA). Each of the three methods has its own advantages and disadvantages. The Input-Output Analysis has more advantages in the comprehensiveness of statistics and the stability of calculation. Therefore, now it is the most basic and common method for the Embodied Carbon in international trade.

The Input-Output Analysis was first proposed by Wassily W. leontiel. Originally, this method was used to analyze the relationship between inputs and outputs in economic field (Leontief, 1936/1941). By the 1960s, some research began to use this method to energy and environmental field (Daly, 1968; Isard et al., 1968; Ayres and Kneese, 1969; Leontief, 1970). The input-output table reflects the balance between supply and demand of products among different departments. The outstanding advantage of this method is that it can use the input-output table to reflect the relationship between carbon emissions of various industries, and calculate the direct and indirect energy consumption of inputs in each stage of production by using the direct consumption coefficient and the complete demand coefficient in the input-output table, and then obtain the complete embodied carbon behind the product trade. This is a macro analysis method, which has been proved to be an important analysis method in the field of energy and environment research in the 20th century (Wright, 1974; Bullard and Herendeen, 1975; Hannon et al., 1983).

The Input-Output Analysis can be divided into single-region input-output(SRIO) model(Shui and Harriss, 2006; Dietzenbacher and Mukhopadhyay, 2007; Li and Hewitt, 2008) and multi-region input-output (MRIO) model (Kanemoto et al., 2012, 2013; Kanemoto, Moran and Lenzen, 2013; Feng et al., 2013; Liu et al., 2015;Young Yoon et al., 2020). The MRIO model is based on the technology of origin, and the calculation results are more accurate(Lenzen and Pade, 2004). SRIO model is usually used to study the carbon emissions of one country's export trade to another or more countries. However, the homogeneity technology assumption of the model is not necessarily valid, which may cause large deviation in the calculation. If there is a big difference in the production technology level between countries, the error of complete carbon emission coefficient will be relatively large (Chen Hongmin, 2011).

2.2. Measurement of Embodied Carbon Based on MRIO Model

Due to the complexity of the model, the difficulty of data acquisition and processing, the development and application of MRIO model is slow. Until recent years, with the development of big data technology, MRIO model has been widely used.

The carbon emissions of international trade of 24 countries, which accounted for 80% of global emissions and GDP in 1995, were measured by MRIO model. It is found that there are embodied carbon imports in most of OECD countries, and China is the largest exporter of implied carbon in OECD countries (Ahmad and Wyckoff, 2003). United States, Japan and other developed countries are the net importers of carbon---similar results were obtained by calculating the embodied carbon in the world's major trading powers by using the MRIO model (Zhou Xin, 2010). According to the calculation of MRIO model, China's carbon emission caused by production increased from 2.92 billion tons to 7.08 billion tons from 2005 to 2009, while the carbon emission caused by consumption increased from 2.47 billion tons to 6.18 billion tons, which provided evidence for the separation of consumption and production in the current international carbon emission accounting system (Yan Yunxiu and Zhao Zhongxiu 2013).

2.3. Embodied Carbon Emissions in Bilateral Trade.

At present, there are three scales to measure trade carbon: single country scale, bilateral scale and multilateral scale.

On the scale of bilateral trade, there are the following studies in recent years. Through the research on embodied carbon transfer between two developed countries in Japan and Canada, it is found that the carbon emission of manufacturing products exported from Japan to Canada is low due to its high technological advantages, while the carbon emission of manufacturing products exported to Japan from Canada is also relatively low due to its high production efficiency (Hayami and Nakamura, 2002). During 1997-2004, the United States reduced its carbon emissions by 3% - 6% through imports from China, while China increased its carbon emissions by 7% - 14%. And the overall carbon emissions of the two countries increased due to bilateral trade (Hyun-Jae Rhee, 2016). Through the research of the transmission effect of CO_2 emissions resulting from bilateral international trade between China, Japan and South Korea, proved that South Korea has successfully reduced its pollution emissions through international trade with China and Japa(Shui and Harriss, 2006).n. By measuring the embodied carbon in the bilateral trade between China and Japan, it is found that Japan mainly imports products with high carbon emission intensity from China, making China a “pollution haven” (Jin Jihong and Ju Yiyi, 2018).

3. Methodology and Data Description

3.1. Methodology

MRIO model can be extended from the Input-Output Model of a country.

Table 1. Basic Input-output Table

Input-output		**Intermediate Output**				**Final Output**	**Total Output**
		Sector 1	**Sector 2**	**...**	**Sector n**		
Intermediate Input	Sector 1	X_{11}	X_{12}	...	X_{1n}	Y_1	X_1
	Sector 2	X_{21}	X_{22}	...	X_{2n}	Y_2	X_2
	...	...	...	...	...	...	...
	Sector n	X_{n1}	X_{n2}	...	X_{nn}	Y_n	X_n
Value Added		Z_1	Z_2	...	Z_n		
Total Input		X_1	X_2	...	X_n		

For a country, all industry sectors that comprise the national economy carry out production activities while finely linked with another, and supply necessary goods and services for final demand. It is reflected from intermediate output and intermediate input. Each point in the input-output table contains both vertical and horizontal economic meanings. Therefore, we can get two relations: horizontal output balance and vertical input balance:

$$\text{Total output} = \text{intermediate output} + \text{final output} \tag{1}$$

$$\text{Total input} = \text{intermediate input} + \text{value added} \tag{2}$$

Suppose there are n sectors in the national economy, “i” stands for horizontal sector, “j” stands for vertical sector. According to the horizontal balance of the input-output table, we can get

$$\begin{cases} x_{11} + x_{12} + \cdots + x_{1n} + y_1 = x_1 \\ x_{21} + x_{22} + \cdots + x_{2n} + y_2 = x_2 \\ \cdots \\ x_{n1} + x_{n2} + \cdots + x_{nn} + y_n = x_n \end{cases} \tag{3}$$

It is expressed by matrix

$$AX+Y=X \tag{4}$$

The above formula is the most basic input-output model. After adjustment, we can get

$$X=(1-A)^{-1}Y \tag{5}$$

Among them, X is the total output vector of each department, and its element Xi is the total output of the ith department; Y is the final product column vector of each sector, and Y_i is the final product of the ith sector, including domestic final consumption, capital formation and export;

I is n×n-dimensional matrix, $A=\{a_{ij}=x_{ij}/x_j\}$, a_{ij} represents the input of i sector directly consumed by unit output of j sector. x_{ij} represents the direct consumption of the products of department i in the production process of department j. x_j is the total output of sector. If one of the total output vector X or the final product vector y is known, according to the input-output table, the direct consumption coefficient matrix A can be found, and another unknown term can be calculated.

The direct consumption coefficient plus the total indirect consumption coefficient is the complete consumption coefficient, which represents the sum of direct consumption and indirect consumption of unit product produced by department j and the input of department i, which is recorded as b_{ij}. The complete consumption coefficient matrix is represented by B.

The relationship between the direct consumption coefficient matrix A and the complete consumption coefficient matrix B can be expressed as

$$B=(I-A)^{-1}-I. \tag{6}$$

$(I-A)^{-1}$ is the complete demand coefficient matrix, that is, the Leontief inverse matrix.

In the calculation of embodied carbon emission in Sino-Korea trade, the bilateral input-output table of China and South Korea is constructed in Table 2.

When calculating the carbon emission coefficient of each sector, the direct CO_2 emission coefficient is $E=\{ E_j/E \}$. Complete CO_2 emission coefficient of China is $E_c(I-A_c)-1$, complete CO_2 emission coefficient of South Korea is $E_k(I-A_k)-I$.

Table 2. Sino-Korea Input-output Table

Input-output			Intermediate Demand: CHN Sector 1,2…n	Intermediate Demand: KOR Sector 1,2…n	Row	Final Demand: CHN	Final Demand: KOR	Final Demand: W	Total output
Intermediate Input	CHN	Secto1,2…n	Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	X_i^c
	KOR	Secto1,2…n	Q_7	Q_8	Q_9	Q_{10}	Q_{11}	Q_{12}	X_i^k
	W								
Value Added									
Total Input			X_j^c	X_j^k					

Note: W Refers to Other Countries.

In the calculation of embodied carbon in Sino-Korea trade, the embodied carbon of South

Korea's export to China is:

$$E_{kc}=E_k(I-A_k)^{-1}Q_7+E_k(I-A_k)^{-1}Q_{10} \quad (7)$$

The embodied carbon of China's export to South Korea is:

$$E_{ck}=E_c(I-A_c)^{-1}Q_2+E_c(I-A_c)^{-1}Q_5 \quad (8)$$

3.2. Data Description

The data used in this paper is mainly from the WIOD database and the EORA database. There are several Mario database, such as EXIOBASE, EORA, WIOD, FIGARO, OECD, etc. Observing trends in carbon emissions requires time continuity and data stability. Because of the great difference of statistical methods and statistical caliber, the data from different sources will lead to serious deviation. Therefore, this paper selects two databases which are compiled continuously according to the year. The WIOT(World Input-Output Table) in the WIOD database is recognized to be more systematic, accurate, standardized and easy to use. Based on WIOT, this paper compiles the non competitive input-output table of China and South Korea from 2005 to 2014, and according to the needs of this paper, the original 56 sectors are integrated into 18 sectors as Table 3.

Table 3. Classification of Sectors

No.	Sector	No.	Sector
1	Agriculture, Hunting, Forestry and Fishing	10	Other Non-Metallic Mineral
2	Mining and Quarrying	11	Basic Metals and Fabricated Metal
3	Food, Beverages and Tobacco	12	Machinery, Nec.
4	Textiles and Leather	13	Electrical and Optical Equipment
5	Wood and Products of Wood	14	Transport Equipment
6	Pulp, Paper, Paper, Printing and Publishing	15	Manufacturing, Nec.; Recycling
7	Coke, Refined Petroleum and Nuclear Fuel	16	Electricity, Gas and Water Supply
8	Chemicals and Chemical Products	17	Construction
9	Rubber and Plastics	18	Service

The CO_2 emissions from 2005 to 2009 come from the environment account of WIOD. Because this account is only counted until 2009, so the 2010-2014 CO_2 data were extracted from the EORA database. Unlike WIOD databases by sector, EORA databases directly statistics products. Therefore, according to the WIOD database sectors integration standard,123 products of China and 78 products of Korea in EORA database are classified and merged into 18 sectors. Because of the statistical differences, the unit carbon emissions of EORA are obviously different from the statistics in the WIOD when measuring individual products. Therefore, it is not scientific to directly compare the implied carbon emissions of the two databases. For the direct coefficient and complete coefficient of carbon emissions in ten years, the annual growth rate is compared to replace the specific coefficient, which is more scientific for the embodied carbon change trend of the two countries. For the total amount of carbon emissions in Sino-Korea trade, this paper divides the ten years into two periods of 2005-2009, 2009-2104 for comparative study. This division also perfectly fits the division of environmental protection stage of the South Korean government. For the sector carbon embodied in Sino-Korea trade, this paper selects 2005, 2008, 2010,2014 as the samples to analyze and grasp the change trend of each department as a whole. The above methods make up for the imperfection of the data to the greatest extent, and can objectively and truly reflect the actual situation

4. Empirical Results

4.1. Direct CO_2 Emission Intensity

Direct CO_2 emission coefficient indicates the amount of CO_2 directly emitted by a unit of product produced by a sector. It represents the level of environmental protection in the production technology of a sector. Through the model calculation, we get the following direct CO_2 emission coefficient as Table 4.

Table 4. Annual Direct CO_2 Emission Coefficient

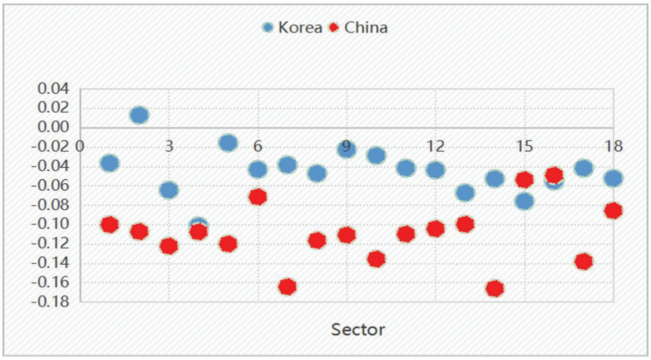
Sector	2005 WIOT	2006 WIOT	2007 WIOT	2008 WIOT	2009 WIOT	2009 EORA	2010 EORA	2011 EORA	2012 EORA	2013 EORA	2014 EORA
Panel A: China											
1	0.29	0.27	0.21	0.14	0.13	0.14	0.13	0.12	0.11	0.11	0.11
2	0.53	0.44	0.42	0.34	0.36	0.38	0.33	0.26	0.25	0.22	0.19
3	0.18	0.15	0.12	0.10	0.09	0.09	0.08	0.07	0.06	0.06	0.06
4	0.15	0.12	0.10	0.09	0.08	0.26	0.25	0.23	0.21	0.19	0.18
5	0.12	0.10	0.07	0.08	0.06	0.14	0.16	0.13	0.11	0.10	0.09
6	0.35	0.31	0.27	0.30	0.25	0.64	0.66	0.60	0.53	0.48	0.45
7	0.62	0.51	0.35	0.29	0.30	0.47	0.32	0.26	0.24	0.23	0.22
8	0.58	0.55	0.45	0.39	0.36	0.50	0.46	0.37	0.32	0.28	0.26
9	0.15	0.12	0.10	0.10	0.08	0.46	0.44	0.39	0.35	0.31	0.29
10	3.62	2.81	2.14	2.08	1.61	0.29	0.30	0.24	0.21	0.18	0.17
11	0.90	0.72	0.59	0.45	0.51	0.33	0.31	0.26	0.23	0.20	0.19
12	0.02	0.02	0.02	0.02	0.02	0.22	0.16	0.14	0.13	0.11	0.11
13	0.10	0.08	0.07	0.06	0.05	0.65	0.67	0.58	0.56	0.50	0.47
14	0.09	0.07	0.05	0.05	0.04	0.31	0.24	0.22	0.20	0.17	0.16
15	0.07	0.05	0.04	0.05	0.05	0.65	0.83	0.74	0.59	0.51	0.48
16	6.69	6.10	5.16	5.75	5.79	5.61	5.54	5.27	4.98	4.55	4.01
17	0.12	0.10	0.08	0.05	0.05	0.38	0.34	0.28	0.26	0.24	0.22
18	0.18	0.17	0.14	0.12	0.12	0.07	0.07	0.06	0.06	0.05	0.05
Panel B: Korea											
1	0.26	0.23	0.21	0.20	0.23	0.12	0.11	0.10	0.10	0.10	0.10
2	2.54	2.21	1.91	2.17	2.98	0.19	0.20	0.19	0.19	0.17	0.17
3	0.05	0.05	0.04	0.04	0.04	0.11	0.10	0.09	0.09	0.08	0.08
4	0.12	0.10	0.08	0.07	0.07	0.13	0.11	0.09	0.08	0.08	0.08
5	0.07	0.06	0.06	0.06	0.08	0.09	0.08	0.07	0.07	0.07	0.07
6	0.22	0.19	0.17	0.15	0.18	0.13	0.11	0.10	0.10	0.10	0.10

Table 4. (Continued)

Sector	2005 WIOT	2006 WIOT	2007 WIOT	2008 WIOT	2009 WIOT	2009 EORA	2010 EORA	2011 EORA	2012 EORA	2013 EORA	2014 EORA
Panel B: Korea											
7	0.32	0.27	0.25	0.21	0.31	0.17	0.14	0.10	0.09	0.09	0.10
8	0.12	0.11	0.11	0.10	0.11	0.10	0.08	0.07	0.07	0.06	0.06
9	0.16	0.14	0.15	0.14	0.15	0.29	0.29	0.29	0.28	0.27	0.25
10	3.54	3.39	3.28	3.39	3.13	0.28	0.27	0.27	0.26	0.25	0.24
11	0.48	0.44	0.39	0.39	0.42	0.10	0.09	0.07	0.07	0.08	0.08
12	0.01	0.01	0.01	0.01	0.01	0.11	0.10	0.09	0.09	0.09	0.09
13	0.03	0.02	0.02	0.02	0.02	0.13	0.11	0.10	0.09	0.09	0.09
14	0.03	0.03	0.02	0.02	0.02	0.09	0.08	0.07	0.07	0.07	0.06
15	0.08	0.06	0.06	0.06	0.06	0.21	0.14	0.13	0.13	0.12	0.12
16	3.39	3.04	2.83	2.95	3.87	4.40	3.70	3.40	3.11	2.76	2.09
17	0.05	0.05	0.04	0.05	0.05	0.41	0.40	0.37	0.37	0.34	0.29
18	0.15	0.12	0.11	0.12	0.14	0.20	0.18	0.16	0.16	0.15	0.13

Comparison of direct CO_2 emission coefficient between China and South Korea, obviously, the direct carbon emission coefficient of South Korea was lower than that of China in most sectors. This shows that South Korea's production was more environmentally friendly, and the direct emissions of CO_2 from various sectors were relatively small. But compared to the data in 2009, there are some differences between a few sectors of the WIOT and EORA databases. This paper uses the 2005-2009 coefficient calculated by WIOT database to calculate the growth rate from 2005 to 2008, and uses the 2009-2014 coefficient calculated by EORA database to calculate the growth rate from 2009 to 2013. This method ensures that under the condition of consistent statistical methods, the annual coefficient increase range can be accurately calculated, and the time series comparison can be carried out. We use DCI to express direct CO_2 emission intensity, annual DGI growth rate=DCI_n-DCI_{n-1}/DCI_{n-1}(n means the year). According to the Chinese and Korean annual DGI growth rate Table B in the appendix, we can get the the Fig.1. By comparison, the direct CO_2 emission coefficient of China decreased faster than that of South Korea in this decade. This shows that during this period, China has made great progress in technology and significantly improved energy efficiency.

Fig. 1. Ten Years' Average Change Rate of Direct CO_2 Emission Coefficient (2005-2013)



4.2. Complete CO_2 Emission Intensity

Complete CO_2 emission coefficient indicates the amount of CO_2 completely emitted by a unit of product produced by a sector. It includes direct emission and indirect emission. This coefficient shows the total pollution level of a sector's products to the environment.

It can be seen from the comparison of the complete CO_2 emission coefficient in Table 5, the real technology gap between China and South Korea was relatively large. As of 2014, only one sector in South Korea had a relatively high coefficient. It was Electricity, Gas and Water Supply sector, which was also the sector with the largest coefficient for China. And China's figures is more than double that of Korea.

Considering the use of two databases, we observe the trend of numerical change in the two time periods from 2005 to 2009, 2009 to 2014. During these two five-year periods, the coefficient of each sector in China had been declining. For South Korea, the coefficient of each sector generally increased slightly in 2009. This indicates that Korea was greatly affected by the 2008 financial crisis.

Table 5. Annual Complete CO_2 Emission Coefficient

Sector	2005 WIOT	2006 WIOT	2007 WIOT	2008 WIOT	2009 WIOT	2009 EORA	2010 EORA	2011 EORA	2012 EORA	2013 EORA	2014 EORA
Panel A: China											
1	1.02	0.89	0.72	0.65	0.66	0.93	0.87	0.75	0.73	0.67	0.63
2	3.86	3.30	2.56	3.11	2.90	2.95	2.80	2.73	2.41	2.26	2.12
3	0.61	0.54	0.46	0.48	0.52	0.62	0.58	0.53	0.56	0.53	0.50
4	0.51	0.45	0.39	0.41	0.47	0.95	0.84	0.73	0.71	0.66	0.62
5	0.45	0.38	0.31	0.30	0.31	0.64	0.61	0.54	0.48	0.46	0.42
6	0.97	0.81	0.66	0.68	0.64	1.25	1.21	1.07	0.95	0.85	0.79
7	1.56	1.38	1.20	1.11	1.16	1.40	1.45	1.34	1.23	1.07	0.96
8	2.11	1.81	1.53	1.51	1.46	2.03	1.84	1.68	1.59	1.46	1.34
9	0.60	0.49	0.39	0.41	0.42	1.04	0.94	0.82	0.75	0.68	0.63
10	4.44	3.48	2.68	2.60	2.13	0.68	0.61	0.53	0.48	0.45	0.41
11	3.05	2.50	2.09	1.91	1.90	2.14	1.86	1.67	1.59	1.47	1.32
12	1.29	1.15	0.98	1.05	1.10	1.53	1.68	1.56	1.50	1.41	1.24
13	0.89	0.79	0.67	0.65	0.69	1.51	1.38	1.22	1.10	1.02	0.94
14	0.52	0.46	0.44	0.38	0.40	0.87	0.77	0.63	0.53	0.51	0.47
15	0.20	0.20	0.13	0.11	0.12	0.74	0.89	0.79	0.63	0.56	0.52
16	12.40	11.63	10.09	9.69	9.86	9.68	9.26	8.53	8.03	7.37	6.63
17	0.18	0.14	0.12	0.11	0.13	0.48	0.45	0.40	0.38	0.36	0.33
18	4.97	4.10	3.31	3.18	3.45	3.93	3.52	3.10	3.08	2.94	2.85
Panel B: Korea											
1	0.37	0.33	0.31	0.30	0.37	0.27	0.22	0.19	0.20	0.20	0.19
2	2.69	2.31	2.00	2.24	3.10	0.28	0.25	0.22	0.22	0.20	0.20
3	0.17	0.16	0.16	0.17	0.22	0.25	0.21	0.18	0.19	0.19	0.18
4	0.20	0.19	0.17	0.18	0.22	0.28	0.23	0.20	0.19	0.20	0.19
5	0.12	0.10	0.10	0.10	0.12	0.14	0.12	0.11	0.11	0.11	0.10
6	0.48	0.41	0.37	0.34	0.41	0.27	0.22	0.19	0.19	0.19	0.18
7	0.92	0.85	0.79	0.77	0.88	0.47	0.41	0.39	0.38	0.36	0.32
8	1.05	1.00	1.01	0.95	1.09	0.75	0.67	0.63	0.61	0.56	0.52
9	0.20	0.19	0.20	0.19	0.21	0.34	0.33	0.32	0.31	0.29	0.28

Table 5. (Continued)

Sector	2005 WIOT	2006 WIOT	2007 WIOT	2008 WIOT	2009 WIOT	2009 EORA	2010 EORA	2011 EORA	2012 EORA	2013 EORA	2014 EORA
Panel B: Korea											
10	3.79	3.63	3.51	3.60	3.36	0.33	0.32	0.31	0.30	0.29	0.27
11	1.06	1.02	1.02	1.02	1.12	0.60	0.58	0.56	0.52	0.47	0.41
12	0.21	0.26	0.29	0.27	0.41	0.48	0.41	0.33	0.33	0.31	0.30
13	0.19	0.20	0.22	0.21	0.25	0.32	0.31	0.29	0.26	0.23	0.21
14	0.24	0.26	0.27	0.22	0.25	0.23	0.22	0.21	0.20	0.18	0.17
15	0.09	0.09	0.09	0.10	0.11	0.25	0.19	0.17	0.16	0.16	0.15
16	4.26	3.83	3.59	3.69	4.83	5.16	4.39	4.06	3.77	3.42	2.77
17	0.11	0.11	0.10	0.10	0.11	0.45	0.43	0.40	0.39	0.37	0.31
18	3.29	2.99	2.89	2.99	3.56	1.99	1.74	1.57	1.50	1.37	1.18

Considering the use of two databases, we observe the trend of numerical change in the two time periods from 2005 to 2009, 2009 to 2014. During these two five-year periods, the coefficient of each sector in China had been declining. For South Korea, the coefficient of each sector generally increased slightly in 2009. This indicates that Korea was greatly affected by the 2008 financial crisis.

By comparing the growth rate of the complete coefficient between China and South Korea in the two periods, Table 6 can be obtained.

In the two five-year period, different from the continuous and stable decline in China, the pollution index of most sectors in South Korea even increased during 2005-2009. In addition to the impact of the 2008 financial crisis, the policy of the South Korean government during this period was also an important reason for this rise. Although from the late 1990s, South Korea had entered the peak of environmental protection legislation. However, from 1988 to 2006, South Korea's investment in new and renewable energy R & D was only 4% of that of the United States and 7% of that of Japan. The neglect at the national level led to little improvement in the complete CO_2 emission coefficient of various sectors in South Korea during this period. In 2008, then President Lee Myung Bak put forward the idea of "green growth", increasing investment in new energy and renewable energy research, so as to develop renewable energy industry and improve employment rate. South Korea's energy structure began to gradually transform into a "low energy consumption" structure. In 2009, the South Korean parliament passed the RAMEWORK ACT ON LOW CARBON, GREEN GROWTH and formally implemented in the following year. Then, from 2009 to 2014, the complete CO_2 emission coefficient of South Korea decreased significantly. Although the initial coefficient is far lower than that of China, it has reached the same decline rate as China. This group of comparison shows that in addition to technological factors, policy factors also have a great impact on environmental protection.

Table 6. Growth Rate of Complete CO_2 Emission Coefficient

Sector	CHN 2005-2009	CHN 2009-2014	KOR 2005-2009	KOR 2009-2014
1	-0.35	-0.32	0.01	-0.29
2	-0.25	-0.28	0.15	-0.30
3	-0.15	-0.19	0.30	-0.30
4	-0.09	-0.34	0.08	-0.31

Table 6. (Continued)

Sector	CHN 2005-2009	CHN 2009-2014	KOR 2005-2009	KOR 2009-2014
5	-0.31	-0.35	0.07	-0.26
6	-0.34	-0.36	-0.13	-0.33
7	-0.26	-0.31	-0.04	-0.32
8	-0.31	-0.34	0.03	-0.30
9	-0.29	-0.39	0.04	-0.19
10	-0.52	-0.40	-0.11	-0.18
11	-0.38	-0.38	0.05	-0.31
12	-0.15	-0.19	0.95	-0.38
13	-0.22	-0.38	0.31	-0.32
14	-0.23	-0.45	0.04	-0.24
15	-0.41	-0.30	0.28	-0.38
16	-0.21	-0.32	0.13	-0.46
17	-0.26	-0.30	0.01	-0.33
18	-0.31	-0.27	0.08	-0.41

4.3. Total Carbon Embodied in Sino-Korea Trade

Through the MRIO model, this paper calculates the embodied carbon emission in the Sino-Korea trade from 2005 to 2014, and the results are shown in Table 7.

From 2005 to 2014, South Korea had been in the state of net trade export and net embodied carbon import. Due to the decrease of the complete CO_2 emission coefficient, although the bilateral trade volume in 2014 increased to 2.3 times of 2005, the growth of implied carbon was relatively small. From the perspective of South Korea, the embodied carbon export increased by 1.61 times, and the embodied carbon import increased by 1.67 times. On the premise of increasing trade volume and improving people's welfare of the two countries, slowing down the growth of CO_2 emissions is of positive significance to world environmental protection.

The same five-year interval is used to analyze. Excluding the abnormal data affected by the financial crisis in 2009, the embodied carbon trading volume of the two countries shows the same trend as the complete CO_2 emission coefficient. From 2005 to 2008, the import trade volume of South Korea from China increased by 1.99 times, while the import embodied carbon net value only increased by 1.44 times, indicating that China had significantly improved its internal technology in environmental protection. Over the same period, South Korea's export trade increased by 1.48 times, while its net embodied carbon export increased by 1.56 times. This is consistent with the fact that the carbon emission coefficient of South Korea did not decrease during this period. From 2010 to 2014, the growth ratio of trade volume and embodied carbon between China and South Korea was similar. The growth rate of trade volume is greater than that of carbon emissions.

Table 7. Embodied Carbon Emission in Sino-Korea Trade (South Korea)

Unit: Million Tons, Billion Dollars

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CO_2 Imp	68.9	71.5	75.9	99.1	83.5	106.9	132.3	121.6	123.2	115.0
Trade Imp	386.5	485.6	630.3	769.3	542.5	715.7	864.3	807.8	830.5	900.7

Table 7. (Continued)

Unit: Million Tons, Billion Dollars

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CO_2 Exp	41.2	44.6	55.4	64.1	54.0	60.3	65.6	67.2	67.6	66.2
Trade EXP	619.2	695.5	819.9	913.9	867	1168.4	1342	1343.3	1458.7	1453.3
CO_2 Net	-27.7	-26.9	-20.5	-35.0	-29.5	-46.6	-66.7	-54.4	-55.6	-48.8
Trade Net	232.7	209.9	189.6	144.6	324.6	452.6	477.8	535.5	628.2	552.6

4.4. Sector Carbon Embodied in Sino-Korea Trade

Through the MRIO model, this paper calculates the sector embodied carbon emission in the Sino-Korea trade from 2005 to 2014 and Select 2005, 2008, 2010, 2014 to form the Table 8.

Table 8. Sector Embodied Carbon Emission

Unit: Million Tons

Sector	CHN 2005	CHN 2008	CHN 2010	CHN 2014	KOR 2005	KOR 2008	KOR 2010	KOR 2014
1	1256	533	625	485	13	8	12	12
2	7227	5705	2122	1035	11	61	23	10
3	1877	2548	3101	3286	96	188	177	298
4	3705	3949	5629	6545	1753	1359	1246	1527
5	233	328	515	676	7	9	7	13
6	364	320	640	987	591	611	327	241
7	941	1657	2273	2664	7620	14246	7140	4733
8	4758	7675	10610	11379	11101	15952	10974	10181
9	664	873	1325	1679	594	646	633	663
10	935	1472	2552	4140	225	205	154	237
11	12855	23523	15114	15788	3788	4533	3555	2271
12	10980	17479	34625	42473	19154	28557	25591	30542
13	1521	4014	5666	6282	2267	4442	4072	2821
14	1284	2599	4349	3432	3755	3368	2481	2955
15	1594	2105	2564	3820	629	421	339	923
16	247	186	150	155	1	23	22	23
17	0	0	0	0	0	0	0	0
18	5504	7993	9304	9064	3902	5613	3562	6525

For South Korea, 1,2,3,5,6,10,16 were types of sectors which were resource-intensive or labor-intensive ones, due to less exports, lead to less embodied carbon exports. Mechanical and electrical products (12,13), chemical products (8) have always been the top two exports of South Korea to China. Although the CO_2 emission coefficient of these sectors decreased, the amount of embodied carbon continued to increase significantly due to the sharp increase of trade volume.

For China, carbon emissions from exports of natural resource intensive industries such as agriculture (1) and mining (2) decreased significantly. There are two reasons for this: one is the reduction of CO_2 emission coefficient caused by technological progress; the other is the sharp decrease of export volume caused by China's adjustment of industrial structure. Mechanical and electrical products (12,13), chemical products (8) and base metals (11) had been the top three exports of China to South Korea in the past decade. Although the complete CO_2 emission coefficient of these sectors had been greatly reduced, it was still the highest in China until 2014, which was about three times that of South Korea.

From the perspective of implied carbon transfer, there is a lot of intra industry trade between China and South Korea. These sectors should continue to improve technology to help curb total carbon emissions.

5. Conclusions and Suggestions

5.1. Conclusions

In this paper, we have calculated the embodied carbon emissions in Sino-Korea trade based on the ARIO Model. Through quantitative calculation and analysis, the direct CO_2 emission coefficient, complete CO_2 emission coefficient, total carbon emissions and sector emissions in bilateral trade from 2005 to 2014 are determined.

In the trade between China and South Korea, South Korea had been in trade surplus and embodied carbon deficit. From 2005 to 2014, the Embodied Carbon coefficient of various sectors in China continued to decrease significantly, which made a certain contribution to the world environmental protection. During the period of 2005-2009, South Korea had little effect in improving the carbon emission coefficient. However, with the implementation of many environmental protection laws and policies of the government after 2008, the complete CO_2 emission coefficient of all sectors in South Korea had decreased significantly. In 2014, the CO_2 emission coefficient of most sectors in South Korea was still significantly lower than that in China, indicating that the CO_2 emissions of various sectors in South Korea were smaller.

Although the carbon emission coefficient was significantly reduced due to technical factors, the total amount of embodied carbon in Sino-Korea trade still showed an upward trend from 2005 to 2014. This is mainly due to the closer trade cooperation between the two countries and the substantial increased in trade volume. From the perspective of sectors, there was obvious intra industry trade between China and South Korea. The import and export of embodied carbon are also concentrated in several sectors such as Mechanical and electrical sector, chemical sector. How to develop these departments scientifically needs the attention of the two governments.

In order to test the above conclusions, the authors uses SDA model to analyze the influencing factors of embodied carbon emission in Sino-Korea trade. The results show that technology has a significant inhibitory effect on embodied carbon emission, trade scale has a significant role in promoting the growth of embodied carbon emission, and trade structure has a inhibitory effect on embodied carbon emission, but the effect is not significant.

5.2. Suggestions

5.2.1. Strengthen Technical Cooperation and Encourage the R&D and Use of Low-carbon Technologies

From the empirical data of this paper, the government behavior has a significant positive impact on the production side to reduce carbon emissions. In 2012, the report of the 18th

National Congress of the Communist Party of China put forward “promoting green development, circular development and low-carbon development” for the first time. In recent years, China’s various industries strive to explore a low-carbon green development path. This is a good opportunity for enterprises of the two countries to strengthen technical cooperation and develop environmental protection industry. Low carbon economy is mainly reflected in energy conservation, emission reduction and environmental protection. In terms of improving the level of energy conservation and emission reduction, as a member of developed countries, South Korea has accumulated a lot of experience in improving the legal framework, establishing clear objectives, implementing preferential policies, utilizing market mechanism, developing circular economy and relying on scientific and technological innovation, which has certain reference significance for China to realize energy conservation and emission reduction through environmental protection and governance. South Korea has technological advantages in air pollution prevention, waste treatment, water treatment and contaminated soil remediation. The South Korean government supports South Korea’s environmental protection industry to develop China’s environmental protection market, constructs a series of mechanisms and platforms for the exchange and cooperation of China’s and South Korea’s environmental protection industries, and issues the “China’s market development strategy”. China’s enterprises can cooperate with South Korea’s excellent environmental protection enterprises to improve the technical level, build China South Korea environmental protection industrial park, and solve the problems of enterprises in environmental protection technology while improving the quality of China’s foreign investment. There is a huge space for China and South Korea to cooperate in environmental protection industry and energy conservation and emission reduction.

5.2.2. Developing Regional Economy and Leading Global Emission Reduction

On June 1, 2015, China and South Korea officially signed the FTA agreement. This is a free trade agreement signed by China involving the largest amount of trade and the widest range of trade. Geographical advantages and similar cultural traditions give China and South Korea a natural advantage in regional cooperation. In addition to strengthening cooperation and competition between China and South Korea in specific export commodities and sectors, carbon tariff system can also become an area for the two countries to strengthen consultation and cooperation. Under the general trend of carbon tariffs imposed by the EU and the United States, China and South Korea can strengthen exchanges and cooperation in carbon tariff policy research, adopt a consistent attitude towards such unfair carbon tariff policies implemented in disguise by the European Union, the United States and other western countries, and formulate win-win bilateral trade agreements.

On September 22, 2020, China’s president Xi Jinping proposed at the seventy-fifth UN General Assembly China will strive to achieve carbon neutralization by 2060. In October 28th, South Korean President moon Jae in the statement said South Korea will realize carbon neutralization by 2050. For both China and South Korea, energy supply will shift from coal to renewable energy. In the process of transformation, on the one hand, it is necessary to continue to play the inhibiting role of technological factors in the embodied carbon emission, and on the other hand, it is necessary to adjust the trade structure and strive for its significant inhibiting effect on the embodied carbon emission.

Appendices

Table A. Volume and Proportion of Sino-Korea Trade (2005-2019)

Unit: Hundred Million US Dollars

Date	Bilateral Trade	Total Foreign Trade (CHN)	RATIO	Total Foreign Trade (KOR)	RATIO	NET (KOR)
2005	1005.6	14219.06	7.07%	5456.6	18.43%	232.7
2006	1180.2	17604.38	6.70%	6348.5	18.59%	209.9
2007	1450.2	21761.75	6.66%	7277.8	19.93%	189.6
2008	1683.2	25632.55	6.57%	8572.8	19.63%	144.6
2009	1409.5	22075.35	6.38%	6866.2	20.53%	324.6
2010	1884.1	29740.01	6.34%	8916.0	21.13%	452.6
2011	2206.3	36418.64	6.06%	10808.9	20.41%	477.8
2012	2151.1	38671.19	5.56%	10676.6	20.15%	535.5
2013	2289.2	41589.93	5.50%	10752.2	21.29%	628.2
2014	2354.0	43015.27	5.47%	10986.5	21.43%	552.6
2015	2273.8	39530.33	5.75%	9634.5	23.60%	469.0
2016	2113.9	36855.57	5.74%	9015.3	23.45%	374.7
2017	2399.7	41071.38	5.84%	10521.3	22.81%	442.6
2018	2686.4	46224.44	5.81%	11403.4	23.56%	556.8
2019	2434.3	45761.26	5.32%	10455.8	23.28%	289.7

Source: China Statistical Yearbook, Statistical Korea.

Table B. Annual Direct CO_2 Emission Coefficient Growth Rate

Sector	2005	2006	2007	2008	2009	2010	2011	2012	2013
Panel A: China									
1	-0.06	-0.22	-0.33	-0.05	-0.06	-0.11	-0.03	-0.03	-0.03
2	-0.16	-0.04	-0.20	0.08	-0.16	-0.21	-0.02	-0.12	-0.12
3	-0.19	-0.23	-0.10	-0.10	-0.12	-0.17	-0.09	-0.07	-0.02
4	-0.19	-0.21	-0.07	-0.15	-0.02	-0.09	-0.11	-0.09	-0.05
5	-0.23	-0.23	0.05	-0.28	0.10	-0.16	-0.15	-0.14	-0.05
6	-0.13	-0.13	0.12	-0.16	0.03	-0.10	-0.12	-0.10	-0.06
7	-0.19	-0.30	-0.16	0.01	-0.46	-0.19	-0.08	-0.03	-0.06
8	-0.05	-0.19	-0.12	-0.08	-0.10	-0.19	-0.14	-0.12	-0.06
9	-0.19	-0.20	0.00	-0.17	-0.05	-0.12	-0.09	-0.12	-0.06
10	-0.22	-0.24	-0.03	-0.23	0.01	-0.18	-0.13	-0.15	-0.06
11	-0.20	-0.17	-0.24	0.13	-0.05	-0.15	-0.15	-0.09	-0.06
12	-0.06	-0.17	-0.05	0.10	-0.38	-0.12	-0.11	-0.10	-0.06
13	-0.18	-0.21	-0.09	-0.10	0.03	-0.13	-0.04	-0.11	-0.06
14	-0.19	-0.30	-0.06	-0.25	-0.31	-0.10	-0.09	-0.13	-0.06
15	-0.24	-0.21	0.33	-0.07	0.22	-0.11	-0.20	-0.13	-0.06
16	-0.09	-0.16	0.12	-0.01	-0.01	-0.05	-0.06	-0.09	-0.12
17	-0.16	-0.20	-0.34	-0.01	-0.14	-0.16	-0.08	-0.07	-0.08
18	-0.09	-0.16	-0.13	0.01	-0.08	-0.12	-0.05	-0.06	-0.08

Table B. Annual Direct CO_2 Emission Coefficient Growth Rate

Sector	2005	2006	2007	2008	2009	2010	2011	2012	2013
Panel A: Korea									
1	-0.12	-0.07	-0.06	0.15	-0.11	-0.09	0.01	0.01	-0.05
2	-0.13	-0.13	0.13	0.37	0.03	-0.03	0.01	-0.14	0.00
3	-0.12	-0.09	-0.11	0.06	-0.10	-0.13	0.01	-0.07	-0.03
4	-0.19	-0.16	-0.10	-0.04	-0.19	-0.18	-0.07	0.05	-0.04
5	-0.14	0.00	0.00	0.23	-0.16	-0.10	0.06	-0.02	0.00
6	-0.14	-0.12	-0.06	0.17	-0.16	-0.10	0.06	-0.02	0.00
7	-0.16	-0.08	-0.14	0.46	-0.19	-0.29	-0.10	0.02	-0.13
8	-0.12	-0.03	-0.02	0.10	-0.13	-0.15	-0.05	-0.03	0.00
9	-0.08	0.06	-0.05	0.02	-0.02	0.01	-0.04	-0.05	-0.05
10	-0.04	-0.03	0.03	-0.08	-0.02	0.01	-0.04	-0.05	-0.05
11	-0.08	-0.11	-0.01	0.07	-0.13	-0.15	-0.02	0.05	0.00
12	-0.12	-0.15	0.06	0.01	-0.06	-0.11	0.00	-0.03	0.02
13	-0.16	-0.22	0.01	0.09	-0.18	-0.11	-0.04	-0.02	0.01
14	-0.02	-0.24	0.05	0.06	-0.13	-0.13	-0.05	0.00	-0.01
15	-0.16	-0.13	0.04	0.06	-0.33	-0.10	-0.01	-0.04	-0.02
16	-0.10	-0.07	0.04	0.31	-0.16	-0.08	-0.09	-0.11	-0.24
17	0.02	-0.15	0.04	0.06	-0.03	-0.07	0.00	-0.08	-0.16
18	-0.18	-0.07	0.04	0.17	-0.12	-0.11	-0.02	-0.04	-0.12

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