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Analyses of CO_2 Emissions Embodied in Japan-China Trade

Xianbing Liu [a,*], Masanobu Ishikawa [b], Can Wang [c], Yanli Dong [b], Wenling Liu [c]

[a] *Kansai Research Centre, Institute for Global Environmental Strategies, Kobe, Japan*
[b] *Graduate School of Economics, Kobe University, Kobe, Japan*
[c] *Department of Environmental Science and Engineering, Tsinghua University, Beijing, China*

[*] **Corresponding Author:** Xianbing Liu
Postal Address: Kansai Research Centre, Institute for Global Environmental Strategies (IGES),
IHD Centre 3F, 1-5-1, Wakinohama Kaigan Dori,
Chuo-ku, Hyogo, 651-0073, JAPAN
Tel: +81-78-262-6634; Fax: +81-78-262-6635
E-mail Address: liu@iges.or.jp

[Abstract] This paper examines CO_2 emissions embodied in Japan-China trade. Besides directly quantifying the flow of CO_2 emissions between the two countries by using a traditional input-output (IO) model, this study also estimates the effect of bilateral trade to CO_2 emissions by scenario analysis. The time series of quantifications indicate that CO_2 emissions embodied in exported goods from Japan to China increased overall from 1990 to 2000. The exported CO_2 emissions from China to Japan greatly increased in the first half of the 1990's. However, by 2000, the amount of emissions had reduced from 1995 levels. Regardless, there was a net export of CO_2 emissions from China to Japan during 1990-2000. The scenario comparison shows that the bilateral trade has helped the reduction of CO_2 emissions. On average, the Chinese economy was confirmed to be much more carbon-intensive than Japan. The regression analysis shows a significant but not perfect correlation between the carbon intensities at the sector level of the two countries. In terms of CO_2 emission reduction opportunities, most sectors of Chinese industry could benefit from learning Japanese technologies that produce lower carbon intensities.

Key words: CO_2 embodiment, Japan-China trade, quantitative estimation

1. Introduction

As it is well known, the currently adopted principle for accounting CO_2 emissions is production based *(IPCC, 2008)*. The Intergovernmental Panel on Climate Change (IPCC) authorized methodology presenting that a country solely takes the responsibility for CO_2 emissions derived from the domestic combustion of fossil fuels. It has been recently argued whether the production based measurement of CO_2 emissions could effectively encourage emissions reduction efforts *(Peters and Hertwich, 2008a)*. As an example, Helm et al. *(2008)* found that the UK's CO_2 emissions have fallen by 15% since 1990 based on IPCC measurement, whereas they have risen by 19% in the same period if using consumption based measurement. Theoretically, the consumption based measurements have more attractive features than the production based quantifications *(Peters and Hertwich, 2008b)*. It is said that the consumption based measurements are important for allocating the reduction of CO_2 emissions from the viewpoint of equity. They have the advantages of avoiding carbon leakage, increasing the options for mitigation, encouraging environmental comparative advantage, addressing competitiveness concerns, and inevitably speeding up technology diffusion *(Peters and Hertwich, 2008a)*. The consumption based measurement calculates CO_2 emissions generated for producing the goods consumed inside a region, regardless of the place of production. Naturally, international trade is taken into account as the most important factor for this approach. However, there is still a lack of detailed and systematic global analyses of CO_2 emissions that use the consumption based principle. This alternative principle has particular implications for developing countries like China, which is experiencing significant economic growth driven by the dramatic increases of exports and energy use. There are large economic costs associated with the participation in global climate regime for those countries with a large share of exports in carbon intensive production *(Peters and Hertwich, 2008a)*. If the climate regime has inadequate participation, there is a risk that production will be increasingly shifted to nonparticipating countries *(Peters et al., 2007)*. Additionally, a lot of low cost CO_2 mitigation options may exist outside of the country of consumption. Very few proposals have been assessed on whether trade could underlie some of the concerns within the post-Kyoto regime.

In general, there are three topics to be discussed about the research of carbon embodiment in international trade. The first is a directly quantitative estimation of the embodiment amount for better understanding the environmental effects of the trade. The second is the analysis of carbon leakage revealing the extent of the shifted pollution rather than the abated amount. The last question is whether the trade adjusted CO_2 emission inventories could really help eliminate carbon leakage and mitigate global CO_2 emissions. The literature with aims to quantitatively estimate CO_2 embodiment in international trade and discuss its policy implications, has been growing fast in the past few years. The applied analytical methodologies share a common principle of using IO modeling with consideration of the study's feasibility. Due to the shortcoming of quantification approaches themselves and great insufficiency of necessary data, these studies revealed high diversity in boundary and estimation accuracy. Nevertheless, several meaningful messages may be observed from these emerging quantitative estimations.

The literature analyzing CO_2 embodiment in trade has provided clear evidence that the major developed countries are net CO_2 importers, while developing countries as a whole and a number of developed countries with rich resources are net exporters of carbon. Wyckoff and Roop *(1994)* showed that 13% of total carbon emissions caused by the consumption of the six largest OECD countries were due to carbon embodied in imports. Chung and Rhee *(2001)* found that Korean exports to Japan were more carbon intensive than Japanese exports to Korea. Another analysis, focused solely on Japanese trade, showed that Japan was a net exporter of embodied CO_2 emissions in 1975, yet switched to be a net importer of CO_2 before 1990 *(Kondo et al., 1998)*. An OECD study estimated that net carbon exports from China and Russia in 1995 were roughly equal to net carbon imports of the OECD in total, which was about 5% of OECD domestic emissions *(Ahmad and Wyckoff, 2003)*. Although OECD as a whole is a net carbon importer, individual countries vary widely. Ahmad and Wyckoff *(2003)* found net carbon exports from Australia, Canada, the Czech Republic, Denmark, Finland, Netherlands, Norway, and Poland, balanced carbon trade in Hungary, and net carbon imports from other countries including the U.S., Japan, Korea, and all the large European economies. Other studies, which analyzed individual country cases, reached similar results indicating significant net carbon exports from Australia *(Lenzen, 1998)*, Norway *(Peters and Hertwich, 2006)*, and Sweden *(Kander and Lindmark, 2006)*, and approximately balanced carbon trade in Denmark *(Munksgaard et al., 2005)*.

In theory, environmental effects of trade can be decomposed into three kinds: composition, scale, and technique effects. The multi-layer effects of trade may cause positive or negative impacts on the environment *(Anderson and Strutt, 2000; Beghin et al., 2002)*. Some estimation studies provide evidence that international trade could reduce global CO_2 emissions in certain conditions. Hayami and Nakamura *(2002)* obtained encouraging results that the bilateral trade of Japan and Canada reduced emissions in both countries. Japan exported many manufactured goods which it produced very efficiently with low carbon emissions, while Canada exported energy and resource intensive products like paper products and coal. Canada can produce these products with relatively low emissions due to its abundant natural resources which create a comparative advantage and allow more efficient production. The comparative advantage theory suggests that each country would specialize in the production of goods for which its production costs are relatively low. Since there were few economic incentives for minimizing the carbon emissions in the past, the ability to emit CO_2 freely might increase the comparative advantage of manufacturing. This could account for the positive correlation between comparative advantage and emissions, as occurs in U.S.-China trade *(Shui and Harriss, 2006)*.

By indicating the noticeable change of carbon emissions embodied in international trade, most of the literature underlines the importance of energy and climate policies which have been recently debated *(Dimaranan, 2006; Peters and Hertwich, 2008b)*. From the perspective of public policy, carbon taxes and other possible limitations on CO_2

emissions should be employed. National and regional policies to raise the costs of carbon emissions are required to make a lower carbon emission path worldwide. Several countries in Europe have adopted carbon taxes as part of their strategies to meet Kyoto Protocol commitments, such as Denmark, Sweden, Norway, Finland, Italy, Netherlands, and the UK *(Hoerner and Bosquet, 2001)*. Since their adoption, carbon taxes have proven to be largely effective. As an example, Denmark's carbon tax policy, which includes using revenue from the tax to finance energy efficiency investment, resulted in the reduction of carbon dioxide emissions by 4% between 1992 and 2000. Finland's carbon tax, enacted in 1990, was credited with reducing CO_2 emissions by 7% in 1998 *(Brown, 2003)*.

In order to assist in a better understanding of the current development of quantitative analysis on carbon embodiment in trade, the first aspect of necessary research mentioned earlier, this paper quantitatively examines a case within this topic: the carbon content of Japan-China trade. The analysis was conducted by using two available approaches. One is to directly estimate CO_2 emissions embodied in the goods traded between the two countries. This method can identify whether one country is a net importer of CO_2 emissions from another country. Another approach is to assume a 'no-trade' scenario and compare total CO_2 emissions of each country under those circumstances with that of the actual case. The second approach aims to monitor whether the bilateral trade could reduce or increase CO_2 emissions overall. Regression analysis is also practiced to find whether the comparative advantage in Japan-China trade is more or less associated with carbon-intensive productions. This paper has a time series of observations in which the period of 1990-2000 is covered by analyzing three individual cases (the years 1990, 1995 and 2000) due to data availability of cross-country IO tables.

2. Methodologies used in this study

A number of tools and methodologies have been developed to calculate the embodied CO_2 emissions in international trade, among which IO modeling has been often applied *(Ackerman et al., 2007; Costanza, 1980; Ferng, 2003; Machado et al., 2001; Shui and Harriss, 2006; Wyckoff and Roop, 1994;)*. IO analysis was originated by Leontief *(1941)*, and then was extended to interregional and international trade applications in early contributions by Chenery *(1953)*, Isard *(1951)* and Moses *(1955)*. Although this approach can analyze the embodied CO_2 emissions in the imports and exports of a country as a whole, it has some difficulties quantifying details at the sector level *(Treloar et al., 2001)*. Since the sector CO_2 emission coefficients are usually averaged by the ratios of all the products in each sector, this quantitative estimation inevitably generates particular uncertainties. The available IO tables greatly determine the level of detail and accuracy of these studies. The estimation methodologies used in this study also follow the principle of using IO modeling based on a careful identification of available data sources. The approaches of this study are described in detail as follows.

2.1 Direct quantification of CO_2 embodiments in bilateral trade

CO_2 embodiments in bilateral trade can be estimated by directly quantifying the induced domestic CO_2 emissions in one country for the production of goods exported to another country. This can be done in two steps. The first step is to prepare the vectors of embodied CO_2 emission intensities at the sector level for both countries. The second step is to multiply CO_2 emission intensities by the corresponding volume of exports and sum them up to achieve the total CO_2 embodiments in trade.

2.1.1 Preparation of vectors of embodied CO_2 emission coefficients by sector

The treatment of imports in IO tables has a significant effect on the basic IO model. Assuming that CO_2 emissions related to the production of imported products are identical to those of the same domestic products, the familiar equation (1) can be given as below.

$$e = d(I - A)^{-1} \quad (1)$$

Where e is the embodied CO_2 emission coefficient vector; d is the direct CO_2 emission coefficient vector; A is the intermediate input coefficient matrix; and I is a unit matrix with the same dimension as matrix A.

The matrix $(I - A)^{-1}$, called "Leontief's Inverse Matrix", is a fundamental matrix which identifies the ripple effects among different economic sectors. It has been widely used since making accurate estimations of CO_2 emissions for imported products is very difficult. However, the method using equation (1) may provide quite different values for this study since primary products such as petroleum, coal, iron ore, aluminum, etc., are only produced in small quantities in Japan. An alternative approach, involving the calculation of embodied CO_2 emissions for only domestic production activities, is applied in this study. By defining an import coefficient, m_i which represents the ratio of imports to the total intermediate demand and domestic final demand of sector i as expressed in equation (2), the equation for calculating embodied CO_2 emission intensity vector e can be deduced as equation (3).

$$m_i = \frac{M_i}{\sum_{j=1}^{n} a_{i,j} X_j + F_i} \qquad (2)$$

Where M_i is the import of sector i; n is the number of sectors in IO table; and F_i is domestic final demand of sector i.

$$e = d[I - (I - M)A]^{-1} \qquad (3)$$

Where M is a diagonal matrix of import coefficient (m_i).

2.1.2 Calculation of embodied CO_2 emissions in bilateral trade

The explicit modeling of embodied CO_2 emissions requires a decomposition of standard IO framework into domestic and traded components *(Peters and Hertwich, 2008b)*. The total production based CO_2 emissions in country *r* can be expressed as equation (4). The linearity assumption of IO analysis allows equation (4) to be decomposed into emission components for domestic demand on domestic production and embodied emissions from country *r* to country *s*, as expressed by equation (5). Another useful quantity is the balance of emissions embodied in bilateral trade (BEET), which represents one country's trade balance of CO_2 emissions with another. BEET can be calculated by equation (6). This method is transparent and can sum up CO_2 emissions embodied in the imports and exports of a specific bilateral trade. This study is conducted by using the trade volume data in cross-country IO tables and the embodied CO_2 emission coefficients prepared at a medium level of sector classifications.

$$Em_r = d_{rr}[I-(I-M)A_{rr}]^{-1}\left(y_{rr}+\sum_s e_{rs}\right) \quad (4)$$

Where d_{rr} is a row vector with each element representing direct CO_2 emissions per unit of industry output; A_{rr} is the matrix of intermediate input coefficients of domestically produced products demanded by domestic industrial sectors; y_{rr} is the products produced and consumed domestically; e_{rs} is the exports from country *r* to country *s*; and I is the unit matrix.

$$Em_{rs} = d_{rr}[I-(I-M)A_{rr}]^{-1}e_{rs} \quad (5)$$

$$Em_r^{BEET} = Em_{rs} - Em_{sr} \quad (6)$$

2.2 Effect analysis of bilateral trade to CO_2 emissions

Scenario analysis has been used to estimate the CO_2 emissions effects from trade between a selected pair of countries *(Ackerman et al., 2007)*. Considering two countries 1 and 2, with *X* as the vector of total output, *A* as the intermediate input coefficient matrix, *F* as the final demand vector, and *L* as exports to the other countries, the familiar one-region IO model can be extended to a cross-country format, as expressed by equation (7). The solution is given by equation (8). The total output vector calculated by the model can be multiplied by the carbon coefficients to obtain CO_2 emissions of each sector. This provides a 'base case' for scenario comparison, indicating actual conditions in a defined year.

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \cdot \begin{pmatrix} X_1 \\ X_2 \end{pmatrix} + \begin{pmatrix} F_{11} \\ F_{21} \end{pmatrix} + \begin{pmatrix} F_{12} \\ F_{22} \end{pmatrix} + \begin{pmatrix} L_1 \\ L_2 \end{pmatrix} \quad (7)$$

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} I-A_{11} & -A_{12} \\ -A_{21} & I-A_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} F_{11}+F_{12}+L_1 \\ F_{21}+F_{22}+L_2 \end{pmatrix} \quad (8)$$

A way to measure the effects of bilateral trade is to set matrix blocks A_{12} and A_{21} to zero, and then recalculate the total output which would be required to satisfy the same final demand under this assumption. Accordingly, two scenarios can be defined to measure the CO_2 emission effects from the bilateral trade in this study. Scenario 0 (S0) is the actual base case expressed by equation (8). Scenario 1 (S1) is a 'no trade' scenario, in which each country is assumed to domestically produce the goods that are currently being imported from another country, leaving trade flows with all the other countries unchanged. Extended from equation (8), S1 can be expressed by equation (9). The difference of CO_2 emissions between S0 and S1 represents the emissions attributable to the bilateral trade. If the CO_2 emissions are smaller in S1 than S0, then the bilateral trade would have increased overall carbon emissions. Otherwise, the bilateral trade helps to reduce the emissions.

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = \begin{pmatrix} I - A_{11} - A_{21} & 0 \\ 0 & I - A_{12} - A_{22} \end{pmatrix}^{-1} \cdot \begin{pmatrix} F_{11} + F_{21} + L_1 \\ F_{12} + F_{22} + L_2 \end{pmatrix} \qquad (9)$$

This measurement excludes the emissions actually created by other countries' exports to the two countries in discussion. A principal drawback of this method is having to develop a necessary and detailed dataset of cross-country transactions which are irregular and always dynamic. Fortunately, the Institute of Developing Economies, Japan External Trade Organization (IDE/JETRO) has constructed Japan-China IO tables for 1985 and 1990. In spite of an obvious time lag, Asian international IO tables, including nine Asian countries and the U.S., were developed for 1985, 1990, 1995, and 2000 *(IDE, 2001, 2006; Tamamura, 1994)*. This study used the Japan-China 1990 IO table directly. For

1995 and 2000, we prepared the cross-country IO table by compiling the data from the Asian IO tables of the same year.

3. Data sources and dataset construction

3.1 Cross-country IO tables

Domestic IO tables are popularly compiled and used for various purposes of analyses. In China, the benchmark IO tables are constructed every five years with the 1987 table being the first national account. In Japan, tables have been compiled every five years since 1955, with the latest being in 2005. The national IO tables are different in structure from country to country and it is difficult to construct uniform cross-country IO tables. Nevertheless, the 1990 Japan-China IO table, compiled by IDE/JETRO, provides comprehensive information for comparing the economic structures of the two countries in 1990 *(IDE, 1997)*. For an easier understanding, the format of the 1990 Japan-China IO table is depicted in Figure 1. Reading in row-wise direction, the table shows the distribution structure of goods in each sector. Column-wise, the table lists the inputs for the production of commodities in the sector. Eighty-nine sectors are classified in detail. In the first column of Figure 1, A^{CC} depicts the domestic intermediate inputs of goods and services within China. A^{JC} represents the flow of goods from Japanese industries to industries in China. A^{WC} is the import matrix of China from the rest of the world (R.O.W.) excluding Japan. V^{C} is the value added in Chinese industries and X^{C} is the sum of this column, representing the total input of industries in China. In a similar way, the second column represents the input structure of industries in Japan. Regarding the final demand column of the two countries, F^{CC} depicts the domestic final demand within China, and F^{JC} represents China's final demand for goods produced in Japan. The final demands of China for goods from the R.O.W. are listed in F^{WC}. The exports of China and Japan to the R.O.W. are listed in the blocks of L^C and L^J.

			INT. DEMAND			FINAL DEMAND			GC900	GJ900	EX. TO R.O.W.	QX001	XX600
			China	Japan	ET900	China	Japan	FX900					
INT. INPUTS	China		A^{CC}	A^{CJ}		F^{CC}	F^{CJ}				L^C		X^C
	Japan		A^{JC}	A^{JJ}		F^{JC}	F^{JJ}				L^J		X^J
	BF001												
	R.O.W.		A^{WC}	A^{WJ}		F^{WC}	F^{WJ}						
	Tariff	DT001											
	Total	ET900											
Value added			V^C	V^J									
Total Input		XX600	X^C	X^J									

Figure 1: The format of Japan-China 1990 IO table.

A project on "Industrial Interdependencies in the Asia-Pacific Region" was launched by IDE/JETRO in 1998 to integrate the IO tables of ten countries in the region. The Asian IO tables of 1995 and 2000 are designated to describe the industrial network of ten countries and regions, namely China, Indonesia, Korea, Malaysia, Taiwan, the Philippines, Singapore, Thailand, Japan and the U.S., and give a picture of intermediate IO distribution of each domestic industry as well as foreign countries' industries *(IDE, 2001,* *2006)*. The Japan-China IO dataset of 1995 and 2000 used in this study is compiled from Asian IO tables of the same year. The intermediate input matrices and vectors of final demand for Japan and China are directly picked up from the Asian IO table. The imports from the other countries to the two countries in discussion are achieved by summing up the intermediate inputs and final demands from the other eight countries/regions, HongKong (HK), the European Union (EU) and the R.O.W. listed in the table. In a similar way, the exports to the other countries are achieved by aggregating the intermediate inputs and final demands to the other eight countries, and the exports to HK, the EU, and the R.O.W. in the table. The Asian 1995 and 2000 tables respectively classified 78 and 76 sectors respectively in detail.

3.2 Vectors of CO_2 emission coefficients

3.2.1 Preparation of CO_2 emission coefficient vector of Japan

Stored at the National Institute for Environmental Studies (NIES) in Japan, are data obtained during studies of structural CO_2 emissions by life cycle inventory analyses. The results for the period of 1975-1990 were compiled as "Carbon Dioxide Emission Intensity Based on IO Analysis" *(Kondo and Moriguchi., 1997)*, and published in 1997 by the Center for Global Environmental Research (CGER) at NIES. Since then, NIES added data of air pollutant emissions to the intensity database. After the release of "1995 IO Table" of Japan *(MCAG, 1995)*, the energy and CO_2 emission intensities for 1995 were compiled and entitled "Energy Consumption and Carbon Dioxide Emission Intensities Based on IO Analysis: 95 (β Edition)". Major improvements of the 2002 data book, entitled "Embodied Energy and Emission Intensity Data for Japan Using IO Tables (3EID)," over the β Edition are more accurate estimations for fuel consumption, changes in calorific value, and CO_2 emission factors for individual fuel types *(Nansai et al., 2002).*

The direct CO_2 emission coefficients, compiled in 3EID for 1990, 1995, and 2000, are used to construct CO_2 emission intensity vectors for Japan according to the sectors in the cross-country IO tables prepared for this study. There have been clear sector converters between the cross-country IO tables and the corresponding domestic tables of Japan. Generally, a sector in the international IO table covers one or several sectors in the Japanese domestic table. By repeating equation (10), the direct CO_2 emission coefficient by sector in the international IO table is calculated out for Japan.

$$I^i = \frac{\sum_{j=1}^{n}(X_J^j \times I_J^j)}{\sum_{j=1}^{n} X_J^j} \qquad (10)$$

Where I^i is the direct CO_2 emission coefficient of sector *i* in the international IO table; I_J^j is the direct CO_2 emission coefficient of sector *j* in Japan's IO table which is covered by sector *i* of the international IO table; and X_J^j is the total output of sector *j* in Japan's IO table.

3.2.2 Preparation of CO_2 emission coefficient vector of China

The cross-country IO tables and energy consumption matrix of China were used for calculating CO_2 emission coefficients in 1990, 1995 and 2000 for China by similar procedures. The data from the Chinese Energy Statistical Yearbook and the China Energy Data Book compiled by Lawrence Berkeley National Laboratory were used to develop an energy consumption matrix consisting of 37 rows and 16 columns, which indicates the use of 16 types of energy in 37 sectors under Chinese classification. As there are more sectors in the international IO table than in the Chinese data, the 37 sectors in the energy matrix were decomposed into sub-sectors by coordinating the sector definitions from both classifications. After the sector decomposition, energy consumptions by the sectors in the international IO tables were estimated by using the gross intermediate inputs as decomposition factors. This is because total intermediate input of each sector may reflect the volume of resources and energy consumed by the sector. The energy uses in the Chinese sector classifications were therefore split into corresponding sectors of the international IO table. As an example, sector 24, nonmetal mineral products from the Chinese energy matrix of 2000, was divided into sectors AC0038 (cement and cement products), AC0039 (glass and glass products) and AC004（other non-metallic mineral products）in the 2000 international IO table. Energy use of these three sectors was estimated by multiplying the ratio of the gross intermediate input value of each sector with each type of energy use included in sector 24 of the Chinese energy matrix.

Regarding the 16 types of energy, the CO_2 emission factor of each was calculated by multiplying its average calorific value by carbon content with an assumption of a 100% oxidation rate. CO_2 emissions were quantified by multiplying the use of each fuel with the corresponding emission factor. CO_2 emissions by fuel type were aggregated to get the total emissions of each sector. Lastly, CO_2 emission coefficients were obtained by dividing the total emission amount by the gross output of the sector. The number of sectors in the cross-country IO tables and domestic classifications of both countries is listed in Tab 1.

Tab 1: Sector number of international IO tables and domestic classifications

Year	Sector number in international IO table	Sector number of Japanese 3EID database	Sector number of Chinese energy matrix
1990	89	407	37
1995	78	399	37
2000	76	401	37

4. Results and discussions

4.1 CO_2 emissions embodied in Japan-China trade

CO_2 emissions embodied in Japan-China trade are directly quantified by using the method in section 2.1. The aggregated results are listed in Tab 2.

Tab 2: Traded amount of CO_2 emissions in Japan-China trade during 1990-2000

Year	Traded amount of carbon emission (in Mt of CO_2)		
	From China to Japan	From Japan to China	Balance of China with Japan
1990	43.52 (1.9%)	4.49 (0.43%)	39.03
1995	58.81 (2.03%)	10.8 (0.9%)	48.01
2000	44.01 (1.48%)	16.3 (1.35%)	27.71

Note: Ratio of embodied emissions in country's total is listed in the parenthesis. The total emissions are from IEA data referring to CO_2 emissions from the consumption of fossil fuels.

The emissions embodied in the exports from China to Japan were 43.52 Mt of CO_2 in 1990. This amount increased to 58.81 Mt in 1995 and then decreased to 44.01 Mt of CO_2 in 2000. The ratio of the exported CO_2 emissions from China to Japan in China's total emissions fluctuated between 1.5% and 2.0%. Conversely, CO_2 emissions embodied in the exports from Japan to China increased from 4.49 Mt in 1990 to 10.8 Mt in 1995 and reached 16.3 Mt of CO_2 in 2000. This amount accounted for 0.43-1.35% of Japanese total emissions. CO_2 emissions embodied in the exports from China to Japan were much larger than the reverse flow of emissions. There was a net export of CO_2 emissions from China to Japan in the 1990s. This result is consistent with other previous studies which documented that China is a giant carbon exporting country to major OECD countries including Japan and the U.S. *(Ahmad and Wyckoff, 2003; Kondo and Moriguchi, 1998; Shui and Harriss, 2006)*. It should be noticed that there is certain bias in this quantitative estimation. During the study period, Japan had a heavier reliance than China on imported raw materials and intermediate products with higher carbon intensities through a comparison of the import vectors in cross-country IO tables. The application of equation (3) by only considering the embodied emissions for domestic production activities may result in a little bit larger balance of embodied emissions from China to Japan.

CO_2 emissions embodied in the exports from Japan to China increased overall from 1990 to 2000. This is probably due to the increase of export volume as listed in Tab 3. Although exports from China to Japan increased dramatically during the same period, the exported CO_2 emissions increased in the first half of the 1990s, but decreased in the second half of the decade. This pattern of change indicates the complexity of the relationship between trade and its effects on emissions. CO_2 embodiments are jointly determined by three aspects of trade: total trade volume, trade composition and carbon intensities of the traded goods *(Grossman and Krueger, 1991)*. The composition of traded goods between the two countries was relatively stable. As expressed in Tab 3, CO_2 emission intensities of Japanese goods exported to China also remained stable during the study period. Therefore, CO_2 embodiments in Japanese exports were more affected by the trade volume. However, the carbon intensity of Chinese goods exported to Japan greatly decreased during 1990-2000. The total amount of CO_2 embodiments from China to Japan was affected by the export volume and its carbon intensities. This is why some researchers have found that trade expansion can cause negative environmental impacts *(Beghin et al., 2002)*, whereas others have concluded differently through case studies *(Anderson and Strutt, 2000)*.

Tab 3: Volume and carbon intensity of traded goods of Japan and China during 1990-2000

Year	Export volume (in Mill. USD)		Carbon intensity of traded goods (in t CO_2/1,000 USD)	
	China to Japan	Japan to China	China to Japan	Japan to China
1990	11323.07	7183.69	3.84	0.63
1995	31704.78 (2.8)	27611.58 (3.84)	1.85	0.39
2000	44903.98 (3.96)	34467.21 (4.80)	0.98	0.47

Note: Data in the parenthesis is the times of export volume to that of 1990.

4.2 Results of scenario analysis

Using the compiled Japan-China IO tables and the corresponding CO_2 emission coefficient vectors, the total CO_2 emissions of Japan and China were estimated for the defined years. The aggregated results of the two scenarios, S0 with trade and S1 with no bilateral trade, are listed in Tab 4. The base case estimation in 1990 amounted to 1617.96 Mt of CO_2 for China and 908.42 Mt for Japan. The sectors included in our calculations accounted for most but not all, of the emissions in both countries. China's total emissions in 1990 were 2293.39 Mt of CO_2 equivalents, and Japan's total was 1053.77 Mt. Therefore, the base case in 1990 accounted for 70.5% of China's total emissions and 86.2% of Japan's overall emissions. The ratio was 68% and 94.9% in 1995 and 57% and 90.5% in 2000 for China and Japan respectively. The lower ratio of China in 2000 may be due to the lower statistical coverage and accuracy of the Asian IO table used.

Tab 4: Total CO_2 emissions in base case and assumed no trade scenario

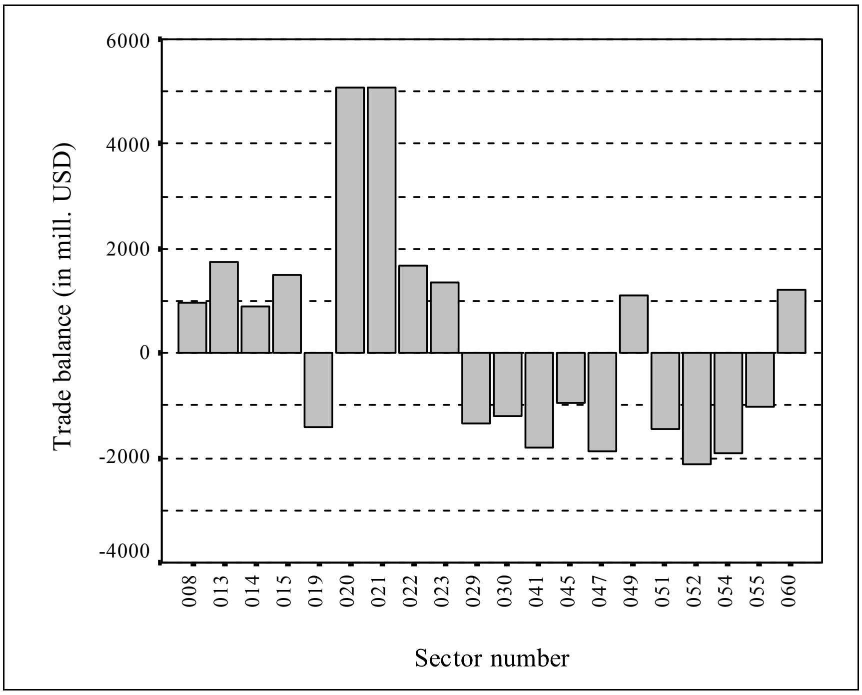
Year	China (in Mt of CO_2)		Japan (in Mt of CO_2)	
	Base case	Change of S1 from base case	Base case	Change of S1 from base case
1990	1617.96	6.9 (0.43%)	908.42	-0.07 (-0.01%)
1995	1973.71	24.58 (1.25%)	1063.11	-0.7 (-0.07%)
2000	1690.22	32.9 (1.99%)	1089.65	-3.51 (-0.32%)

Note: Data in the parenthesis is the ratio of the change amount to the total emissions in base case.

Comparing the results of S0 and S1, bilateral trade allowed China to reduce CO_2 emissions, while it slightly increased Japanese emissions. Bilateral trade helped China reduce 6.9 Mt of CO_2 in 1990, which accounts for 0.43% of the amount in the base case. Conversely, it led to an increase of 0.07 Mt of CO_2 for Japan or 0.01% of Japan's total in the base case. Therefore, a net reduction of 6.83 Mt of CO_2 could be attributable to the bilateral trade in 1990. Similarly, in 1995, an avoidance of 23.88 Mt of CO_2 might be attributed to the bilateral trade. The amount for 2000 was 29.39 Mt of CO_2.

The difference between S1 and S0 is a purely domestic and single country measurement.

It is equal to the domestic emissions generated if the imports were domestically manufactured, minus the domestic emissions created by producing the exports. The foreign emissions created by other countries' exports to Japan and China are excluded. This result may be further observed from the composition of traded goods between the two countries. As an example, Figure 2 summarizes the top ten sectors of China with trade surpluses and trade deficits to Japan in 2000.



Top 10 sectors with trade surplus		Top 10 sectors with trade deficit	
No.	Description	No.	Description
008	Crude petroleum and natural gas	019	Weaving and dyeing
013	Fish products	029	Synthetic resins and fiber
014	Slaughtering, meat products and dairy products	030	Basic industrial chemicals
015	Other food products	041	Iron and steel
020	Knitting	045	General machinery
021	Wearing apparel	047	Specialized machinery
022	Other made-up textile products	051	Semiconductors and integrated circuits
023	Leather and leather products	052	Other electronics and electronic products
049	Television sets, radios, audios and communication equipment	054	Lighting fixtures, batteries, wiring and others
060	Other manufacturing products	055	Motor vehicles

Figure 2: Major sectors with trade surpluses/deficits of China to Japan in 2000.

We found that the trade composition between the two countries was relatively stable in the study period. China was exporting more primary products to Japan such as agricultural and food products, textile goods and clothing, etc. On the contrary, Japan was exporting chemical products, machinery equipment and electronic products to China. Each country was exporting the goods in which they had environmentally comparative advantages, which might explain CO_2 emission reductions in a scenario comparison of this study.

4.3 National overall difference in CO_2 emission intensity

As indicated in Tab 5, China had a much more carbon-intensive economy than Japan during the study period. China's average was 1833.3 kg CO_2 per 1000 USD of outputs in 1990, while that of Japan was 159.7 kg. This implies that the carbon intensity of the Chinese economy as a whole was about 11.5 times that of Japan's in 1990. This situation did not change greatly in the first half of the 1990s. The Chinese economy's carbon intensity was about 9.5 times that of Japan's in 1995. However, in the second half of the 1990s, the carbon intensity of China was reduced dramatically to 532.9 kg CO_2 per 1000 USD of shipments in average in 2000, which became about 4.2 times the level of Japan's economy. During 1990-2000, almost all of the induced CO_2 emission intensities at the sector level in Japan were much smaller than in China.

In this study, CO_2 emission intensities of China were found to drop precipitously in 2000. Some researchers suggested that this obvious decrease of energy use was realistic and resulted from energy efficiency improvement and structural change *(Sinton and Fridley,* *2000; Fisher-Vanden et al., 2004)*. Some others questioned the accuracy of the official Chinese energy statistics data since coal produced by small coalmines which had been supposedly shutdown and illegal smuggling of diesel were not included in the import statistics. Recent research argues that there was significant under-reporting of coal use in China from 1996 to 2003 by using satellite observational data *(Akimoto et al., 2006)*. Despite these arguments, government statistics are still viewed as relatively reliable data sources. We used the energy consumption data of the China National Statistics Bureau for preparing the CO_2 emission intensity vectors in this study. This may generate an underestimation of the CO_2 emissions embodied in the exports from China to Japan in 2000.

Tab 5: Overall CO_2 emission intensity in the two countries during 1990-2000

Year	Overall carbon intensity (in kg CO_2/1,000 USD)		China/Japan
	China	Japan	
1990	1833.3	159.7	11.48
1995	1053.1	110.6	9.52
2000	532.9	126.6	4.21

4.4 CO_2 emission intensity by sector

To quantify the total CO_2 emissions embodied in the bilateral trade, the variances of CO_2 emission intensities by sector were examined. By defining I_C^i as the CO_2 emission intensity of sector *i* in China (induced CO_2 emissions of sector *i*/total shipments value of sector *i*), and I_J^i as the corresponding CO_2 emission intensity of sector *i* in Japan, linear regressions were conducted for the sectors having emission coefficients in both countries. The results are listed in Tab 6. Logarithms were used in order to reduce the influence of outliers. The regression coefficients of 0.414, 0.314 and 0.437 are significantly less than 1 indicating that the variance of induced CO_2 emission intensity by sector is larger in Japan than that of China.

Tab 6: Regression results of CO_2 emission intensity by sector in the two countries

Year	Regression results of CO_2 emission intensity by sector in two countries *(with t statistics in parentheses below the coefficients)*
1990	$\ln(I_C^i) = 1.75 + 0.414\ln(I_J^i)$, (19.5) (6.0), or equivalently, $I_C^i = 5.75 I_J^{i\,0.414}$, with adjusted r^2=0.34, N=68
1995	$\ln(I_C^i) = 1.17 + 0.314\ln(I_J^i)$, (7.7) (3.6), or equivalently, $I_C^i = 3.22 I_J^{i\,0.314}$, with adjusted r^2=0.14, N=71
2000	$\ln(I_C^i) = 0.64 + 0.437\ln(I_J^i)$, (5.1) (5.7), or equivalently, $I_C^i = 1.9 I_J^{i\,0.437}$, with adjusted r^2=0.30, N=75

4.5 CO_2 emission intensity and trade balance by sector

The theory of comparative advantage suggests that a country will specialize in the production of goods for which its cost is relatively lower, and that such a specialization maximizes the overall welfare. If each country specialized in the production of goods for which its CO_2 emission intensity is lower, aggregate emissions would be minimized. However, the actual case is far from idealistic. There were no economic incentives for the minimization of CO_2 emissions during the study period since the emissions were unregulated and costless in both countries. The improvement of energy efficiency may reduce the cost of fuel use, lower CO_2 emissions, and reduce production costs simultaneously, which suggests that economic comparative advantage in trade might be negatively associated with CO_2 emission intensity, like the case of Japan-Canada trade *(Ahmad and Wyckoff, 2003)*. In another viewpoint, the ability to emit CO_2 without cost might be a free resource which could be substituted for other costly resources. This could explain a positive correlation between comparative advantage and CO_2 emission intensities, such as the case of U.S.-China trade *(Shui and Harriss, 2006)*.

In order to identify whether CO_2 emission intensities are positively or negatively correlated with the comparative advantages of Japan-China trade, an explanatory variable was added to define the trade balance of the two countries. As expressed in equation (11), B^i may be recognized as China's trade surplus or deficit coefficient with Japan in the i^{th} sector. As a fraction of the total trade volume of the sector, it ranges from 1, if the bilateral trade only consists of China's exports, to -1, if the bilateral trade is only China's imports.

$$B^i = (Ex_C^i - Ex_J^i)/(Ex_C^i + Ex_J^i) \qquad (11)$$

Where Ex_C^i is China's export to Japan in sector *i*, and conversely for Ex_J^i .

The regression results of CO_2 emission intensities and trade coefficients defined by equation (11) are listed in Tab 7. The logarithm of B^i can not be used since it takes negative values for some sectors. The result indicates that when controlling for Japanese emission intensity in the same sector, China's CO_2 emissions intensity has a slightly significant and negative relationship with its trade surplus to Japan in 1990. This implies that emitting less CO_2 was associated with China's trade comparative advantage. The result could be a reflection of the nature of the two economies and the long-standing absence of any limitation for CO_2 emissions. The regression results are not significant for 1995 and 2000.

Tab 7: Regression results of CO_2 emission intensity and trade balance by sector

Year	Regression results of CO_2 emission intensity by sector with the trade balance (with t statistics in parentheses below coefficients)
1990	$\ln(I_C^i) = 1.85 + 0.475\ln(I_J^i) - 0.142B^i$ (20.7) (6.9) (−2.1), with adjusted r^2=0.44, N=65
1995	$\ln(I_C^i) = 1.44 + 0.531\ln(I_J^i) - 0.072B^i$ (11.8) (6.9) (−0.8), with adjusted r^2=0.46, N=62
2000	$\ln(I_C^i) = 0.84 + 0.582\ln(I_J^i) - 0.05B^i$ (6.9) (6.7) (−0.6), with adjusted r^2=0.5, N=63

5. Summary and policy implications

This study was started by asking whether Japan-China trade increases or decreases CO_2 emissions, and whether one country displaces part of its emissions onto another. Despite certain bias attributable to the treatment of imports, the quantification result indicates that Japan-China trade shifted part of the CO_2 emissions associated with Japan's consumption into China. The comparison of the actual case and a hypothetical scenario assuming 'no trade' suggests that the bilateral trade was beneficial for the decrease of CO_2 emissions. The regressions at the sector level found a significant but not perfect correlation between emissions intensities in the two countries. Chinese industries were much more carbon-intensive than their Japanese counterparts. There was a slightly significant and negative correlation between the comparative advantage of China's trade to Japan and its carbon emission intensity for 1990. An important policy message, in terms of opportunities for CO_2 emissions reduction, is that many sectors of Chinese industry could benefit from learning Japanese production technologies that have lower carbon intensities. It is necessary to give limitations on CO_2 emissions which may encourage the lower CO_2 emission choice of the industries in China.

This study inevitably has several limitations which shall be addressed by future works. First of all, this analysis only focuses on the trade of a specific pair of countries. A comprehensive evaluation of the impacts of trade on global CO_2 emissions requires the application of an integrated multi-regional IO model. The inadequate treatment of the imports from other regions to the two countries in discussion is a second limitation of this study. The time lag of cross-country IO tables limits the period of this analysis. Further quantitative estimations will be able to observe the latest changes in embodied CO_2 emissions once usable international IO tables are available. The sector converters between the different data sources are not exactly in line with reality, which may generate bias of CO_2 emission coefficients at the sector level. More detailed analysis for specific sectors will be useful for identifying the opportunities of CO_2 emissions reduction by using the environmental comparative advantage existing in trade.

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