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CO_2 emissions embodied in China's exports from 2002 to 2008: A structural decomposition analysis

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ABSTRACT

This study examines the annual CO_2 emissions embodied in China's exports from 2002 to 2008 using environmental input–output analysis. Four driving forces, including emission intensity, economic production structure, export composition, and total export volume, are compared for their contributions to the increase of embodied CO_2 emissions using a structural decomposition analysis (SDA) technique. Although offset by the decrease in emission intensity, the increase of embodied CO_2 emissions was driven by changes of the other three factors. In particular, the change of the export composition was the largest driver, primarily due to the increasing fraction of metal products in China's total export. Relevant policy implications and future research directions are discussed at the end of the paper.

1. Introduction

Development economists believe that international trade enables each country to specialize in the product it is more suited to produce. The global economy subsequently benefits from the specialization and international trade (Heckscher and Ohlin, 1991). Hence, developed countries usually specialize in capital-intensive products, whereas developing countries specialize in labor-intensive goods. The shift of manufacturing to developing countries, such as China, is caused by this specialization and fueled by international trade. Given that developing countries usually have less advanced technologies and lower level of environmental standards, the shift of manufacturing makes China the world factory and is often regarded as a shift of environmental impacts from developed countries (Muradian et al., 2002). From the policy point of view, international trade makes the "pollution haven" effect possible in the way that the consumption in countries with strict environmental regulations is met by increased production in countries with loose regulations (Levinson and Taylor, 2008). The magnitude of environmental impacts embodied in trade and its associated importance to policy have been highlighted by numerous studies reported at the global (Peters and Hertwich, 2008; Hertwich and Peters, 2009), bilateral (Shui and Harriss, 2006; Li and Hewitt, 2008; Xu et al., 2009), and national (Lenzen, 1998; Kondo et al., 1998; Weber and Matthews, 2007; Li et al., 2007) scales.

Increasingly, the research on environmental impacts embodied in trade has been instigated by global concern for climate change (Wiedmann et al., 2007). By shifting carbon-intensive industries to developing countries from developed countries, the global carbon emissions could be actually increased due to the implementation of strict climate policy in developed countries (Felder and Rutherford, 1993; Babiker, 2005). This so-called carbon leakage phenomenon has instigated studies to quantify emissions embodied in trade. As the world's largest fossil carbon dioxide (CO_2) emitter (IEA, 2010) and largest merchandise exporter (UNSD, 2011), China's CO_2 emissions embodied in exports have been extensively studied in recent years (Ahmad and Wyckoff, 2003; Peters et al., 2007; Peters and Hertwich, 2008; Pan et al., 2008; Wang and Watson, 2008; Weber et al., 2008; IEA, 2009; Xu et al., 2010a; Liu et al., 2010; Chen and Zhang, 2010; Lin and Sun, 2010). An environmental input–output (EIO) technique (Turner et al., 2007) is commonly used in these studies. According to these studies, the fraction of China's embodied CO_2 emissions in its total domestic CO_2 emissions was estimated to steadily increase from about 15% in 1997 to about 40% in 2007, as shown in Fig. 1.

In international climate negotiations, greenhouse gas (GHG) emissions embodied in trade are often discussed in allocating mitigation responsibilities between developed countries and developing countries to avoid carbon leakage (Ferng, 2003; Whalley and Walsw, 2009). As early as in the 1990s, allocating GHG emission responsibility among countries was discussed

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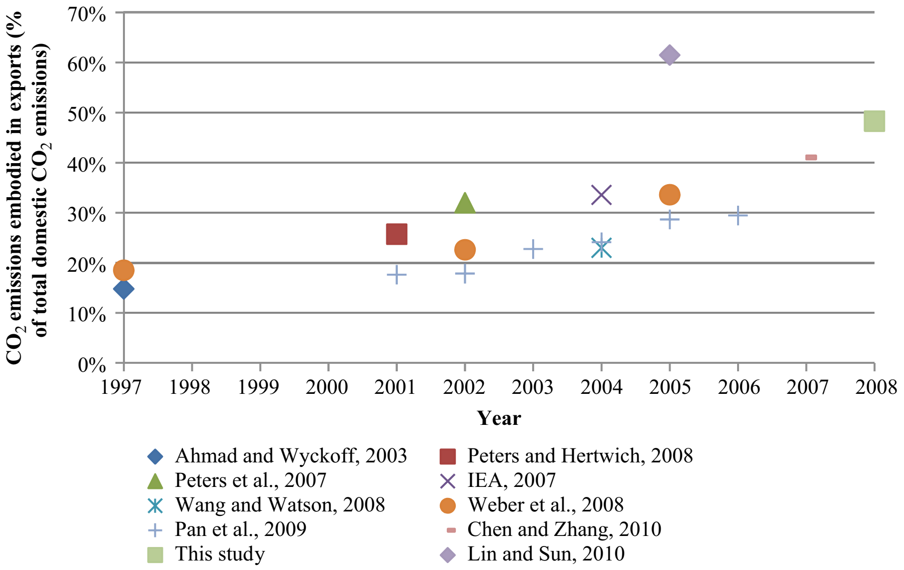

Fig. 1. Estimation of CO_2 emissions embodied in China's exports as percentages of total domestic CO_2 emissions in literature.

(e.g., Swisher and Masters, 1992; Chichilnisky and Heal, 1994). Based on the principles of the Climate Convention, Sagar (2000) proposed an allocating framework, which can be favorable to the least-developed countries. Bastianoni et al. (2004) compared different methods to allocate responsibility for GHG emissions. Without taking into account exports and imports, it is difficult to determine the CO_2 responsibility for an open economy (Munksgaard and Pedersen, 2001). The EIO method has been widely used to quantify emissions embodied in trade in allocating emission responsibilities (e.g., Tunç et al. 2007; Andrew and Forgie, 2008; Muñoz and Steininger, 2010). For China in particular, it is argued that the CO_2 abatement responsibility should be reevaluated by taking emissions embodied in trade into account (Pan et al., 2008).

To better understand these issues and provide useful decision-making support for China's climate and energy policy, a detailed study on China's annual CO_2 emissions embodied in exports is required. Existing studies for China's CO_2 emissions embodied in exports are shown in Fig. 1 and mostly focus on a given year but not provide a year-by-year estimation. To better support decision making in climate and energy policy in China, in this study, we quantify the CO_2 emissions embodied in China's exports from 2002 to 2008 on a yearly basis utilizing the newly released 2007 economic input–output (I–O) data for China (NBSC, 2010). In addition to this estimation, we examine the underlying driving forces for the change of CO_2 emissions embodied in China's exports over the course of 2002 to 2008. Finally, we discuss the implications of our findings to China's climate and energy policy.

2. Method and data

2.1. Environmental input–output (EIO) analysis

Environmental impacts embodied in trade are usually quantified using the EIO analysis (Turner et al., 2007), a well-established method dating back to Leontief's groundbreaking work in the 1930s (Leontief, 1951,1986). While technical details of this method can be referred to in reputable literature (e.g., Miller and Blair, 2009), here we provide a brief introduction on applying it to quantify environmental impacts embodied in exports. In an economy, sectors are connected with each other by the supply–demand relationship. For example, a machinery sector needs direct input from the steel manufacturing sector in order to produce a machine. The manufacturing of steel needs input from the electricity sector. Essentially, input from the electricity sector can be regarded as the indirect input to the machinery sector. Thus, the quantification of energy use and CO_2 emissions embodied in exports needs to take into account not only direct inputs but also those indirect inputs from a life-cycle perspective. Assume an economy consists of n sectors. The value of each sector's products exporting to other countries is denoted as $\boldsymbol{t}_i$ ($i=1, 2, \ldots, n$). The total (direct and indirect) input from each sector in the life cycle of producing an economy's exports can be quantified as

$$\boldsymbol{F}=(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{T}=\boldsymbol{LT} \qquad (1)$$

where $\boldsymbol{F}$ is an $n\times n$ matrix whose element $\boldsymbol{f}_{ij}$ indicates the total input required from sector i in order to produce the export goods, in the value of $\boldsymbol{t}_j$, in sector j ($j=1, 2, \ldots, n$); $\boldsymbol{I}$ is the identity matrix; $\boldsymbol{A}$ is the economy's $n\times n$ direct requirements matrix (Miller and Blair, 2009); $\boldsymbol{L}=(\boldsymbol{I}-\boldsymbol{A})^{-1}$ is called the Leontief inverse; and $\boldsymbol{T}$ is an $n\times n$ diagonal matrix whose diagonal element $\boldsymbol{t}_{ii}$ equals to the value of exporting goods in each sector, $\boldsymbol{t}_i$. CO_2 emissions embodied in export $\boldsymbol{T}$ can be computed by coupling with a carbon intensity matrix $\boldsymbol{F}$, as in the following:

$$\boldsymbol{E}=\boldsymbol{RF}=\boldsymbol{RLT} \qquad (2)$$

where $\boldsymbol{E}$ is a $1\times n$ vector whose element $\boldsymbol{e}_j$ denotes environmental impacts, CO_2 emissions in this study, embodied in the exports of sector j; and $\boldsymbol{R}$ is a $1\times n$ vector whose element $\boldsymbol{r}_j$ stands for the amount of environmental impacts generated per unit economic output in sector j. With the matrix $\boldsymbol{E}$ computed using the above two equations, one can quantify the environmental impacts embodied in the life cycle of the manufacturing of exported goods in each sector in the given year.

In this study, we quantify yearly embodied carbon emissions for China's exports (vector $\boldsymbol{E}$) from 2002 to 2008. For each year, a set of variables ($\boldsymbol{A}$, $\boldsymbol{T}$, and $\boldsymbol{R}$) are compiled using government statistics or other publicly available data.

The requirements matrix $\boldsymbol{A}$ is provided by the standard Chinese economic I–O tables for 2002 and 2007, which consist of 122 and 135 sectors, respectively (NBSC, 2006, 2010). Imports are reported in the Chinese economic I–O tables as a single column from which the origins of imports are inexplicit. To obtain a better understanding on domestic production as the driving force in China's embodied CO_2 emissions, we reconstruct the $\boldsymbol{A}$ matrix by removing imports from the standard economic I–O tables, following the assumption that imports are used in the same proportions in each sector and final demand category (Weber et al., 2008). In this research, we use the two reconstructed $\boldsymbol{A}$ matrix for 2002 and 2007 to approximate $\boldsymbol{A}$ matrix for other years. In particular, the 2002 $\boldsymbol{A}$ matrix is used to approximate $\boldsymbol{A}$ matrix for 2003 and 2004, while the 2005, 2006, and 2008 $\boldsymbol{A}$ matrix are approximated by the 2007 $\boldsymbol{A}$ matrix.

Given that the standard economic I–O tables only contain export values for 2002 and 2007, export data for other years are obtained from the United Nations Commodity Trade Statistics Databases (UN Comtrade), which provides China's export statistics classified under the Harmonized Commodity Description and Coding System (HS) (UNSD, 2011). To reduce the uncertainty from data sources, we also use the UN Comtrade database for export data in 2002 and 2007. In particular, the $\boldsymbol{T}$ matrix for each year is constructed by integrating the export data from the UN Comtrade database according to the 122- and 135-sector systems used by the 2002 and 2007 economic I–O tables. Given that the customs records export values based on the exchange rate between Chinese currency and US dollars, we use annual exchange rates reported by the International Monetary Fund (IMF, 2010) to convert between the two currencies rather than purchasing power parity (PPP) when calculating embodied emissions, as suggested by previous studies (e.g., Ahmad and Wyckoff, 2003). However, when presenting the results, we first convert Chinese Yuan into international dollars using PPP, and then convert all monetary values into constant international dollars based on the 2008 price (IMF, 2010).

Vector $\boldsymbol{R}$ contains CO_2 emissions per unit of economic output in each sector in each year. The construction of the $\boldsymbol{R}$ vector requires the value of the economic output and the amount of energy use for each sector in each year. Sectoral economic output and energy use data from 2002 to 2008 are obtained from Chinese government statistics (NBSC, 2003–2009; NBSC and NDRC, 2005–2010). CO_2 emissions from fuel combustion and industrial processes are estimated based on the Intergovernmental Panel on Climate Change reference approach (IPCC, 2006) using the energy mix consumed by each sector (NBSC and NDRC, 2005–2010). Elements in the vector $\boldsymbol{R}$ are then derived by dividing CO_2 emissions in each sector by economic output in the same sector. Note that a conversion of sectors is required as the sectoral energy consumption data are reported according to a 45-sector classification.

The inherent uncertainties of the EIO method come from data aggregation, time-lag, the assumption of a linear relationship between sectors, and the assumption of homogeneous products in each sector. Theoretical discussion on those uncertainties has been extensively discussed (Lenzen, 2000). In this research particular, other uncertainties primarily come from the data from various sources. In particular, the export value data from the UN Comtrade database contain data reported by both the country of origin and the country of destination. Due to re-exports through intermediate third destinations (e.g., Hong Kong), the data reported by the two parties are often inconsistent with each other. Extensive resources are needed to adjust the discrepancies in bilateral trade data (Xu et al., 2009). Thus this study only chooses to quantify CO_2 emissions embodied in the total Chinese exports rather than allocating it according to the destinations of exports, which represents an interesting avenue for future research.

2.2. Structural decomposition analysis (SDA)

SDA is a technique to describe economic change as the changes of a set of key parameters in an I–O table (Rose and Casler, 1996). This technique can be modified to examine the underlying driving forces for the change of embodied CO_2. To do so, the total CO_2 emissions embodied in exports, $\boldsymbol{e}$, is expressed as the following:

$$\boldsymbol{e} = \boldsymbol{RLT}_C\boldsymbol{v} \tag{3}$$

where $\boldsymbol{T}_C$ is an $n \times 1$ vector, the elements of which are each sector's export value as a fraction of the total export; and $\boldsymbol{v}$ is the total export value. In this study, embodied CO_2 emissions are decomposed into four driving forces: emission intensity ($\boldsymbol{R}$), economic production structure ($\boldsymbol{L}$), composition of export ($\boldsymbol{T}_C$), and total export volume ($\boldsymbol{v}$). In particular, the change of emission intensity ($\boldsymbol{R}$) could be the result of changes in energy efficiency and/or energy input mix. In addition, the change of economic production structure ($\boldsymbol{L}$) reflects the change of production efficiency in the entire economy due to production structure adjustment (Peters et al., 2007). The SDA can be expressed as follows by examining the change in each variable over time

$$\begin{aligned}\Delta\boldsymbol{e} &= \boldsymbol{e}_{(t+1)} - \boldsymbol{e}_{(t)} = \boldsymbol{R}_{(t+1)}\boldsymbol{L}_{(t+1)}\boldsymbol{T}_{C(t+1)}\boldsymbol{v}_{(t+1)} - \boldsymbol{R}_{(t)}\boldsymbol{L}_{(t)}\boldsymbol{T}_{C(t)}\boldsymbol{v}_{(t)} \\ &= \Delta\boldsymbol{RL}_{(t+1)}\boldsymbol{T}_{C(t+1)}\boldsymbol{v}_{(t+1)} + \boldsymbol{R}_{(t)}\Delta\boldsymbol{LT}_{C(t+1)}v_{(t+1)} + \boldsymbol{R}_{(t)}\boldsymbol{L}_{(t)}\Delta\boldsymbol{T}_C v_{(t+1)} \\ &\quad + \boldsymbol{R}_{(t)}\boldsymbol{L}_{(t)}\boldsymbol{T}_{C(t)}\Delta\boldsymbol{v}\end{aligned} \tag{4}$$

Each term in the SDA equation stands for the contribution of each driving force to the change in embodied CO_2 emissions, when keeping other variables constant. For example, the first term represents the change in embodied CO_2 emissions due to changes in emission intensity ($\boldsymbol{R}$) with all other variables remaining constant. While one can compare terms relative to either the start or end of each time period in SDA, we use the average of all possible first order decompositions (Dietzenbacker and Los, 1998; Hoekstra and van der Bergh, 2002). More details about SDA can be found in reputable literature (e.g., Rose and Casler, 1996; Miller and Blair, 2009). Given that only two I–O tables are available for China between 2002 and 2008, we only perform the SDA for the change between the two I–O tables, but not on a yearly basis.

3. Results

We find that CO_2 emissions embodied in China's exports increased from 1.7 billion tons (Gt) in 2002 to 3.1 Gt in 2008. Fig. 2 compares the relative changes of China's GDP, exports, total CO_2 emissions, and CO_2 emissions embodied in exports since 2002. In particular, the GDP and export data are converted into 2008 constant international dollars using PPP (IMF, 2010), same hereinafter for other monetary data. China's domestic CO_2 emissions have generally been increasing along with the growth of the GDP. The growth of total export is significantly faster than that of the GDP. As a result, CO_2 emissions embodied in exports grows at an average rate of 11% per annum. Note that CO_2 emissions embodied in exports decreased in 2004. Given the continuous growth of total export in the same period, this contradiction could be the result of underlying changes in export composition and/or efficiency.

Fig. 3 compares CO_2 emissions embodied in China's exports with its total domestic emissions aggregating results for each product category using Eq. (2). Overall, emissions embodied in exports were around 48% of China's total domestic emissions, meaning almost half of China's CO_2 emissions were generated because of producing goods for foreign consumption. This result is relatively large as compared to previous studies (Peters et al., 2007; Peters and Hertwich, 2008; Pan et al., 2008; Wang and Watson, 2008; Weber et al., 2008), which use only the 2002 economic I–O table, but comparable with recent studies (Chen and Zhang, 2010; Lin and Sun, 2010) using the latest 2007 table as shown in Fig. 1. Clearly, there are significant uncertainties in the economic I–O tables, which will be discussed later.

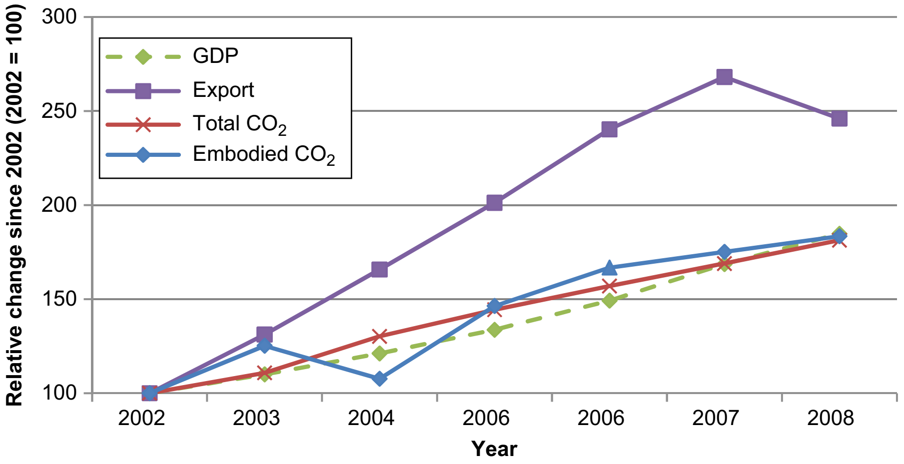

Fig. 2. Relative changes of China's GDP, exports, total CO_2 emissions, and CO_2 emissions embodied in exports from 2002 to 2008 (2002 = 100%).

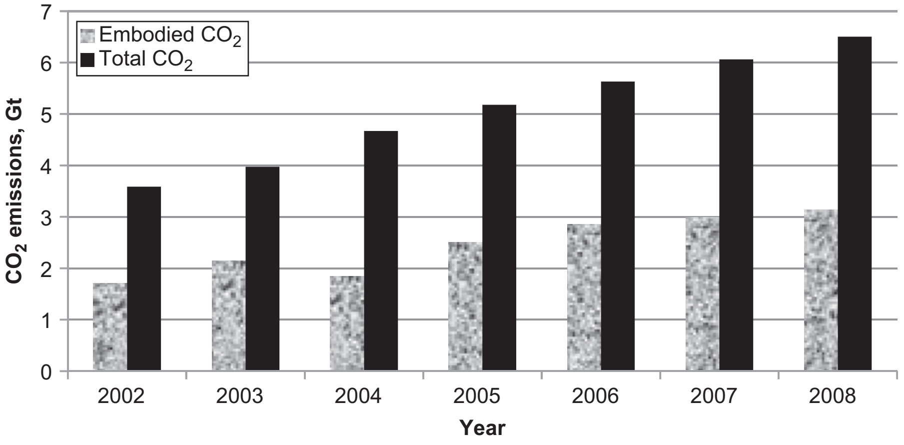

Fig. 3. Comparison of China's total domestic CO_2 emissions and CO_2 emissions embodied in exports.

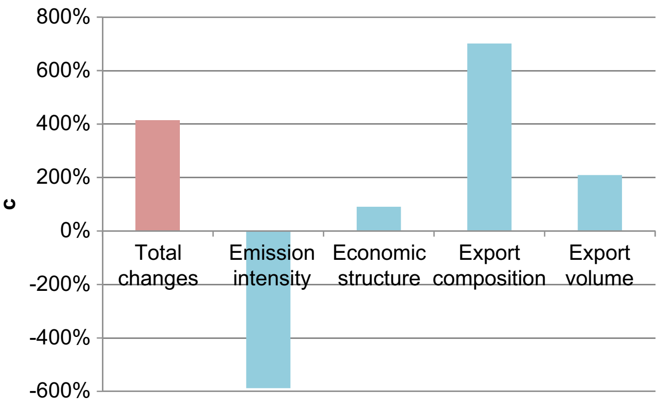

Fig. 4. Contribution of driving forces to the increase of CO_2 emissions embodied in China's exports from 2002 to 2007.

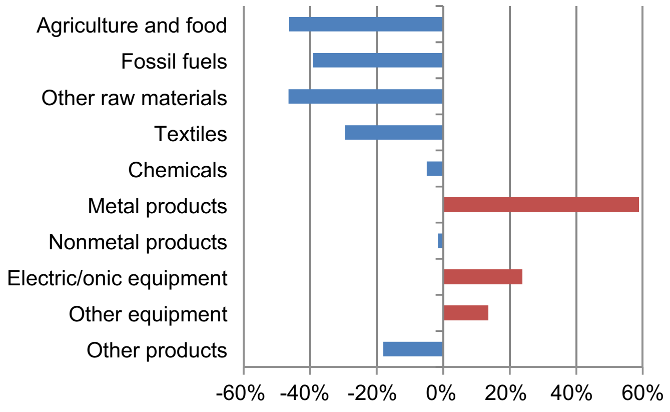

Fig. 5. Change in proportion of export value by major product categories from 2002 to 2007.

Fig. 4 illustrates the result of SDA by comparing the contribution of the driving forces to the increase of CO_2 emissions embodied in China's exports from 2002 to 2007 using Eq. (4). Overall, CO_2 emissions embodied in exports increased by over 414%. The change of export composition, the third term in Eq. (4), is the largest contributor, which could cause a 701% increase of embodied CO_2 emissions, if keeping other factors constant. Changes of economic production structure and export volume, the second and fourth terms in Eq. (4), could increase embodied CO_2 emissions by about 91% and 209%, respectively. However, the reduction of emission intensity, the first term in Eq. (4), due to both efficiency gain and energy input structure change, in China's manufacturing offset the contribution on increasing embodied CO_2 emissions from the other three driving forces by 588%. Obviously, the change of export composition is responsible for most of CO_2 emissions embodied in China's exports. Fig. 5 compares the change in the proportion of the export value by major product categories. China exported, relatively, more metal products and equipment, particularly electric and electronic equipment, in 2007 than in 2002, while other products were exported relatively less in 2007. The fraction of metal products in the total export increased by almost 60% from 2002 to 2007, which significantly increased energy use and thus CO_2 emissions, especially from the smelting and pressing of metals. This is interesting because the export of metal products is only about 6.1% of China's total export in 2002 and 9.7% in 2007.

Fig. 6(a) shows the breakdown of CO_2 emissions embodied in China's exports in ten categories. In 2002, embodied CO_2 emissions were substantially contributed by electronic/electric equipment (25%), textiles (18%), other equipment (17%), and fossil fuels and chemicals (13%). The increasing embodied CO_2 emissions since 2002 was primarily due to advanced products, given that the composition in 2008 was significantly different: electronic/electric equipment (23%), other equipment (19%), fossil fuels and chemicals (14%), and textiles (12%).

Fig. 6(b) shows the composition of export value in international dollars in the ten categories. Notably, the value of exports in each category has been continuously increasing from 2002 to 2007 and decreased in 2008, as opposed to the dynamics shown in Fig. 6(a). Thus, the primary driving force of the dynamics of CO_2 emissions embodied in China's exports is the change of energy efficiencies in each sector. Measured by emissions embodied in each dollar of exports, the CO_2 intensity of manufacturing in each category is illustrated in Fig. 6(c). The lower carbon intensity in most categories in 2004 caused the decrease of embodied CO_2 emissions, while the export was increased. In 2008, the higher carbon intensity is the reason for the increasing embodied CO_2 when the export was declining. More detailed discussion about the change of emission intensity in each category can be found in reference (Xu et al., 2009).

The electronic/electric equipment category contributes about one fourth of CO_2 emissions embodied in China's exports. Fig. 7(a) breaks it down into four sub-categories including electric equipment, computers, communication equipment, and other electronics. In particular, more than 40–50% of the embodied CO_2 emissions were contributed by the export of electronics, such as home entertainment equipment, excluding computers and communication equipment. Computer exports contributed about 15–30% of the embodied CO_2 emissions, while electric equipment was responsible for 20–30%, and 5–15% for communication equipment. The export value of each of the above product

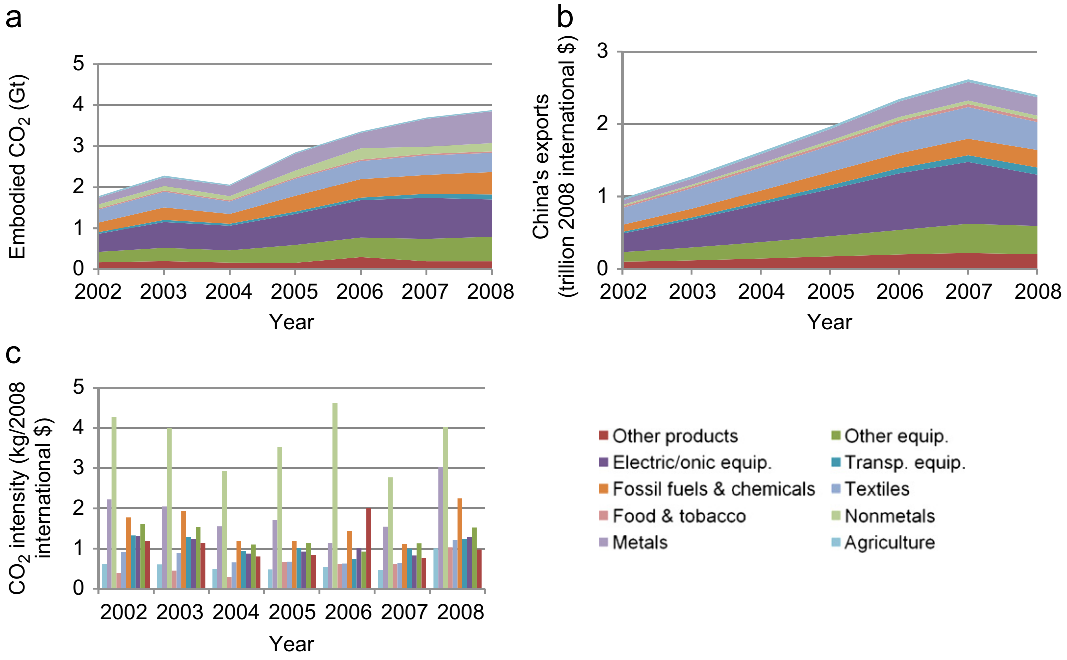

Fig. 6. Composition of (a) CO_2 emissions embodied in exports, (b) China's export in international dollars, and (c) CO_2 intensities in manufacturing by major product categories.

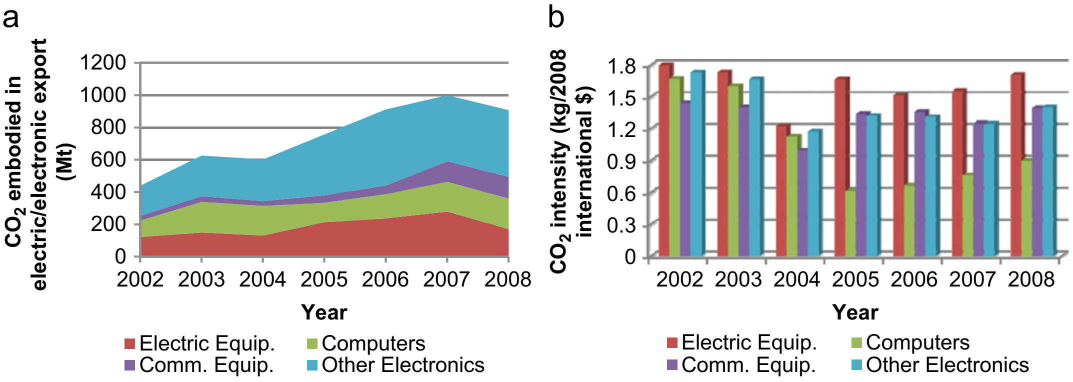

Fig. 7. Breakdown of CO_2 emissions embodied in electronic/electric export from 2002 to 2008 (a); CO_2 intensity of China's electronic/electric export from 2002 to 2008 (b).

categories in electronic/electric equipment has been continuously increasing since 2002. Thus, the dynamics of CO_2 emissions embodied in electronic/electric equipment exports were primarily caused by the change of emission intensity in each category, as shown by CO_2 intensities in Fig. 7(b).

4. Policy implications

China is now responsible for about 22% of the world's 29 Gt CO_2 emissions as of 2008 (IEA, 2010). Remarkably, about 48% of China's CO_2 emissions, or 10% of the world's total emissions, were caused by the manufacturing of export products. Without a doubt, reducing CO_2 emissions embodied in China's exports is critical for solving the "gigaton" problem of carbon emissions worldwide (Xu et al., 2010b). In general, exporting raw materials or less advanced products requires more energy consumption and generates more CO_2 emissions than exporting advanced products on a unitary value basis. In China, policies have been implemented by the government to discourage the export of carbon-intensive products, such as decreasing the export tax rebate rate on selected products or even abolishing selected rebate programs. The result of this study can provide insights in making such decisions. In particular, when quantifying CO_2 emissions embodied in China's exports, we find that most emissions are contributed by a minority of sectors. Fig. 8 shows the fraction of sectors whose export values or CO_2 emissions embodied in exports in 2008 were greater than or equal to certain thresholds. If sectors are ranked according to their export values or CO_2 emissions embodied in exports from high to low, the probability of a sector ranking top decreases along with the increase of its export value or the amount of embodied CO_2 emissions. In other words, only a small proportion of sectors account for the most export values or embodied CO_2 emissions, while most of sectors contribute a little. Similar probability distribution can be found for other years. This type of probability distribution, an approximate straight line on a log–log scale, represents a phenomenon known as the Pareto distribution, power law, or Zipf's law, which has been observed in various disciplines such as physics, biology, economics, computer science, or demography (Newman, 2005).

Among all sectors, the top ten in export values account for 51.7% of China's total export value in 2008, while the top ten in embodied CO_2 emissions contribute 53.1% of the total embodied emissions, as shown in Table 1. Overall, only about 20% of the commodities contribute approximately 80% of China's total export value and embodied CO_2 emissions. This phenomenon holds true for other years as well. In general, the dominating commodities are textiles, electronic/electric equipment, and steel. Other commodities ranking top from 2002 to 2008 in both export value and embodied CO_2 emissions include basic chemical materials, cultural and office equipment, toy, sports and entertainment goods, measuring instruments and meters, and household audio–video equipment. In addition, although metal products are only about 6–10% of the total export, the increase of their share contributes significantly to the CO_2 emissions embodied in China's exports.

In a globally integrated market, it is difficult for one country alone to alter the global supply–demand relationship. Thus, apart from designing and implementing appropriate domestic policies, the other effective way for China to reduce energy use and GHG emissions while keeping the economy growing is to reduce emission intensity by introducing advanced technologies and

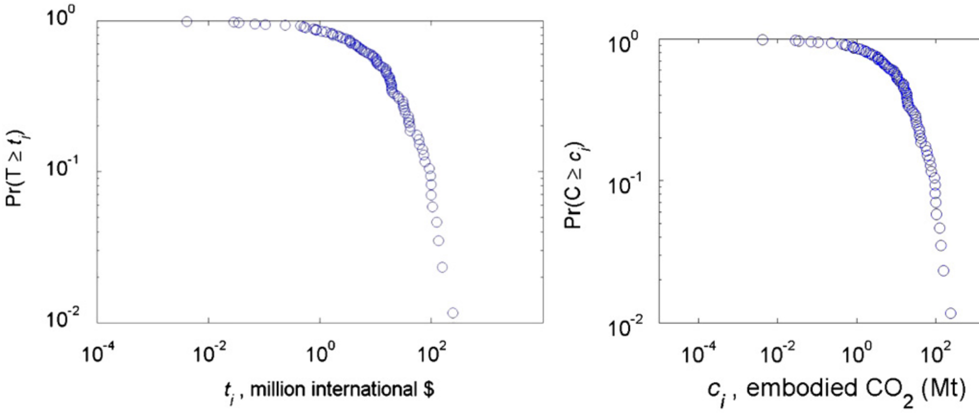

Fig. 8. The fraction (P_r) of sectors whose export values (left) or CO_2 emissions embodied in exports (right) in 2008 were greater than or equal to certain thresholds. Similar distribution can be observed for other years.

Table 1
Top ten China's export commodities in economic values and embodied CO_2 emissions in 2008.

Rank	Export value		Embodied CO_2 emissions	
	Commodity	%	Commodity	%
1	Garments, footwear, and headgear	10.88	Steel	9.15
2	Other electronic and telecommunications equipment	6.94	Garments, footwear, and headgear	6.50
3	Computers	5.58	Metal products	5.67
4	Other electric equipment and machinery	4.56	Other electronic and telecommunications equipment	5.32
5	Other ordinary machinery	4.48	Other ordinary machinery	4.89
6	Metal products	4.03	Raw chemical materials	4.45
7	Electronic devices	3.99	Computers	4.37
8	Telecommunication equipment	3.91	Other electric equipment and machinery	4.29
9	Other equipment for special purposes	3.68	Other equipment for special purposes	4.26
10	Other computer equipment	3.63	Electronic devices	4.17

management systems from developed countries. By helping developing countries to reduce their emission intensity, developed countries can also meet their emission reduction responsibility or commitment via the clean development mechanism as part of the Kyoto Protocol (Olsen, 2007).

5. Future research

Mitigating global carbon emissions requires extensive international collaborations, especially between developing and developed countries. One of the facts preventing countries from effective collaboration is that developing countries and developed countries hardly agree with each other in equally allocating the responsibility of reducing GHG emissions. Developed countries blame major developing countries, such as China, for their increasing current emissions, whereas developing countries claim fair opportunities to develop and criticize developed countries' historical emissions (Botzen et al., 2008). In addition, different perspectives exist in allocating carbon responsibilities based on production or consumption (Bastianoni et al., 2004).

Thus, a successful international collaboration on reducing global GHG emissions must be associated with a reasonably equal attribution of the reduction responsibility agreed upon by both parties, especially those major players such as the US, China, and the European Union. This study lays the technical background for future research on equally allocating carbon responsibilities between China and its major trading partners.

In addition, given the increasing global diffusion of renewable energy technology, international trade may finally contribute to the reduction of global GHG emissions. In particular, the manufacturing of renewable energy products (e.g., PV panel, clean vehicles, biofuels, wind turbines, etc) requires energy input and generates carbon emissions. Thus producing renewable energy products in the developing countries should generally use more energy and produce less carbon emissions. However, because of lower costs of resources, producing renewable energy products in developing countries may be able to drive prices down significantly. Thus from a system perspective, developing and developed countries may actually both benefit from international trade by utilizing lower costs of resources in developing countries to scale up production and eventually promote the global diffusion of renewable energy. At the global scale, GHG emissions may be reduced because of the diffusion of renewable energy technology. The analytical framework presented in this paper could be integrated with multi-regional IO models and relevant economic models to evaluate the tradeoff between emissions embodied in trade and emission reduction due to the deployment of renewable energy products.

6. Conclusion

This study adopted an environmental input–output analysis to examine the CO_2 emissions embodied in China's exports from 2002 to 2008. Extensive data were collected and harmonized according to the two available Chinese economic I–O tables for 2002 and 2007. In addition to estimate the annual CO_2 emissions embodied in exports, we used a structural decomposition analysis technique to compare the contribution of four driving forces to the increase of embodied emissions from 2002 to 2007 including emission intensity, economic production structure, export composition, and total export volume. The result shows that, while the reduction of emission intensity drove the embodied emissions down, changes in the other three factors, especially the change in export composition, led to the increase of embodied emissions. In particular, the most significant change in export composition from 2002 to 2007 was the increasing fraction of metal products. Policy implications were discussed based on the findings. Finally we highlighted areas for future research based on the technical ground laid by this study, including equally allocating GHG emission responsibility between China and its major trading partners and evaluating the tradeoff between increasing embodied emissions and emission reduction from the global diffusion of renewable energy technology due to international trade. These findings provide helpful decision support for China's climate and energy policy.

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