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CO_2 embodied in China's foreign trade 2007 with global policy implications

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Abstract: This article estimated the carbon emissions embodied in China's foreign trade in 2007 with an input-output method. The results showed that China was a net exporter of at least 484.18MT carbon emissions in 2007, which accounted for 8.59% of total on a production basis. In total emissions, imported carbon accounted for 21.97% while exported carbon occupied 30.56%. In terms of sectors, Manufacture of Textile was the biggest net exporter, which was followed by Smelting and Pressing of Ferrous Metals, Manufacture of Metal Products, and so on. In terms of trading partners, Hong Kong was the biggest recipient of exported emissions of mainland China, which was followed by the US, Netherlands, UK, Singapore, and so on. Considering that a large amount of goods exported from mainland China to Hong Kong would be re-exported to the US, the emissions ultimately embodied in China-US trade would be greater than the estimation. Given that current production-based mechanism for allocating carbon abatement burden in international climate regime fails to reflect the complexities of international trade, the sacrifices that net carbon exporters are making and the actual environmental impact of consumption activities, BEET must be paid more attention if future policies would to be equitable and able to encourage active participations. Actually, so far, the seeking of a global solution for combating climate change because of its global impact seems to be prone to problems such as international conflict, carbon leakage, and free riding, etc., and current progress in slowing GHG emissions is actually arriving via fragmented and multispeed efforts, we may not just waiting for a global solution for the problem. Instead, a polycentric approach, which means actions at various levels with active oversight of local, regional, and national stakeholders, may be a choice.

***Keywords**: Embodied carbon; China; climate policy*

1. INTRODUCTION

Controlling greenhouse gas (GHG) emissions is now one of the greatest issues in the globalization context, which is not only related to environmental protection, but also international trade and politics. The global effect of climate change determines that this problem must be addressed by all the countries that generate GHG emissions. However, carbon leakage has been being one of the most depressing problems that undermine the effectiveness of global endeavor. For better understanding the extent of carbon leakage, accounting balance of emissions embodied in trade (BEET) of countries should be attached much importance. In addition, to a large extent, current production-based emission inventories for allocating carbon abatement responsibilities unavoidably lead to carbon leakage, for countries can easily cut emissions by importing carbon intensive products instead of producing themselves. Under production-based mechanism, carbon emissions generated within the scope of a country will be simply attributed to that country no matter where produced goods will be consumed. Obviously, such mechanism neglects the environmental impact of consumption. For countries whose exports occupy a large share in national economy, such as China, it could put a considerable unfair burden on them. In this sense, BEET also helps accounting consumption-based emissions, which give a more complete and balanced picture of the responsibilities of various countries for carbon emissions.

Recent years, more and more researches concerning BEET of various countries and regions have emerged to analyze the relationship between carbon emissions, international trade, and international responsibilities for controlling GHG emissions. Wyckoff and Roop [1994] evaluated the carbon embodied in the imports of manufactured goods in the six largest OECD countries between 1984 and 1986 and warned that many national policies for reducing domestic GHG emissions might not be effective if imports contribute significantly to domestic consumption. Schaeffer and de Sá [1996] examined the carbon embodied in Brazilian imports and exports between 1970 and 1992, and expressed concerns that developed countries were transferring CO_2 emissions to developing countries through offshore manufacturing and production of goods. Jiun-Jiun Ferng [2003] suggested using a benefit principle to assign responsibility for pollutant emissions related to the consumption of goods. Sanchez-Choliz, J. and R. Duarte [2004] evaluated embodied carbon in Spainish foreign trade and found a slightly exporting behavior in the Spanish economy which, nevertheless, hides important pollution interchanges. Maenpaa, M. and H. Siikavirta [2007] evaluated the trend of BEET of Finland from 1990 to 2003 and showed the GHG emissions embodied in the exports have exceeded the GHG emissions embodied in the imports from early 1990s. Shui, B. and R. C. Harriss [2006] examined carbon emissions embodied in China-US trade and suggested the export of US technologies and expertise related to clean production and energy efficiency to China could be a double dividend for both countries for reducing trade imbalance and mitigating global CO_2 emissions. Peters, G. P. and E. G. Hertwich [2008] evaluated the BEET among 87 countries for the year 2001 and found globally there were over 5.3GT of CO_2 embodied in trade and that Annex B countries are net importers of CO_2 emissions. Also, the authors proposed policy recommendations for cutting global emissions, such as encouraging formation of collation and adjusting emission inventories of international trade.

China is now the largest CO_2 emitter, largest exporter and the third largest economy in the world. With the latest 2007 input-output table of China, this paper estimated China's BEET and emissions flows with trading partners and proposed recommendations for future global climate policy, which is expected to help addressing problems such as allocation of carbon reduction responsibility and competitiveness issue more effectively.

2 METHODOLOGY

Considering the economy of n sectors, the output of each sector can be either used as the intermediate input for other sectors or final use. So, the economic activity of a country can be represented by $O=AO+F$, where O is gross output vector over sector i, $A=O_{ij}/O_j$ is the matrix of production technology or direct use coefficient, and F is vector of final use including consumption, investment, and exports (X) in our input-output tables. Rewriting the formula, we can get $O=(I-A)^{-1}F$, where $(I-A)^{-1}$ is Leontief inverse matrix and I is identity matrix. The elements of Leontief inverse matrix represent the direct and indirect input requirements by unit of final demand.

If we let $D_j=E_j/O_j$ be direct emission intensity of production processes within a sector, where E_j is the direct carbon emissions generated by sector j, then $D'=D\cdot(I-A)^{-1}$ will represent the direct and indirect carbon emissions generated within the country in order to obtain a unit of final demand of sector j, which we define as total emission intensity. On a production basis, carbon emissions are measured as $E_p=D'\cdot F$, that is to say, China generates E_p of carbon emissions no matter what the origin of the production inputs or the final use of the production.

In foreign trade, China imports inputs for intermediate use and for final use from trading partners. In this process, a part of imports will then be re-exported through processing trade. So, for accounting exported emissions from domestic production, this part of imported goods should be excluded. This can be achieved as $E_{re\text{-}ex}= D'A_{im}(I-A)^{-1}X$, where A_{im} is matrix of technical coefficients which measure the imported inputs. However, as a result that there is only data of aggregate import of each sector in our input-output table, we use gross measure $E_{ex}= D'X$. Though this would result in overestimation of emissions embodied in exports, the magnitude of the error is limited due to the concentration of exports in sectors such as textiles that only partially depend on the processing trade. The bias is also counteracted by the re-import of some goods to China, which may be wrongly incorporated at foreign rather than Chinese emissions intensity [Pan, Phillips et al. 2008].

Since imports come from various trading partners, emissions embodied in imports should be evaluated in terms of emission intensities of productions in countries from which China imports. Unfortunately, emission intensity of each sectors of each trading partner is unavailable. So we adopt a compromise method that assumes sectoral emission intensities of trading partners are equal to that of China. Then emissions embodied in imports can be estimated as $E_{im}=D'M$, where M denotes imports volume of each sector. Considering that emission intensity of China is relatively high compared to its trading partners, imported carbon emission calculated in our model should be the upper limit of actual value.

Finally, the carbon emissions on a consumption basis should be given as $E_c=E_p+E_{im}-E_{ex}$. Balance of emissions embodied in international trade is $B=E_p-E_c=E_{ex}-E_{im}$. If B is positive, i.e. an emissions surplus, it indicates that a country exports more pollution than imported from other countries, the opposite being true if the balance is negative.

Further, in order to identify the sources and recipients of China's carbon emissions, we assign total emissions embodied in imports and exports to each trading partners according to their total trade volume with China and average carbon emission intensity in production. Specifically, because all exported goods are produced in China, for emission recipients, the carbon emissions China exports to them are proportionate to trade volume that China exports to them. On the contrary, due to the difference of emission intensity of each partner, the emissions China imports from them should be proportionate to trade volume China imports from them multiplying their emission intensities.

3 DATA

The domestic input-output data is from Input-Output Tables of China 2007 with 135 sectors [National Bureau of Statistics 2007]. Energy consumption data sources from China Energy Statistical Yearbook 2008 [National Bureau of Statistics and National Energy Administration 2008]. In order to match these two data sources, we classify Chinese economy into 41 trade sectors through integration of corresponding sectors in input-output tables. Data on trade volume between China and partners is from China Statistical Yearbook 2008 [National Bureau of Statistics 2008]. Carbon emission intensities of trading partners are from Climate Analysis Indicators Tool (CAIT) of the World Resources Institute [CAIT Version 7.0 2010]. In 2007, emission intensity of China was 1046.5 Ton of CO_2 Equivalent/Million Dollars (tCO_2e/Mil.), which was the 12th biggest in the world. As is shown in table 1, compared to its main trading partners, China is much more carbon intensive.

Table 1 Emission intensities of top 20 trading partners of China

Partners	Intensity (tCO_2e/Mil.)	Partners	Intensity (tCO_2e/Mil.)
US	453.3	Australia	599.6
Japan	314.6	UK	273.2
Hong Kong	233.2	India	496.4
South Korea	436.5	Thailand	530.9
Chinese Taipei	410.6	France	203.5
Germany	316.2	Italy	281.1
Russia	885.3	Philippines	276.3
Singapore	213.3	Canada	472.2
Malaysia	522.1	Brazil	216.0
Netherlands	307.3	Saudi Arabia	698.8

4 RESULTS

In 2007, China was a net exporter of 484.18MT CO_2 emissions, which accounted for 8.59% of the total. This make China's carbon emissions in 2007 decreased from 5635.60MT on a production basis to 5151.42MT on a consumption basis.

4.1 Sectoral BEET

Out of 41 sectors, 28 sectors were net exporters with 844.64MT of total carbon emissions. Other 13 sectors were net importers with 360.46MT of total carbon emissions.
Top 10 of 28 net exporting sectors were in turn Manufacture of Textile (MTT), Smelting and Pressing of Ferrous Metals (SPF), Manufacture of Metal Products (MMP), Transport, Storage, Postal and Telecommunications Services (TPS), Manufacture of Electrical Machinery and Equipment (MEM), Manufacture of Textile Wearing Apparel, Footwear, and Caps (MWC), Manufacture of Communication Equipment, Computers and Other Electronic Equipment (MCE), Manufacture of Non-metallic Mineral Products (MNM), Wholesale, Retail Trade and Catering Service (WRC), and Manufacture of Articles For Culture, Education and Sport Activity (MAS), whose exports volume and exported carbon emissions respectively accounted for 80.75% and 82.41% of the total.

Table 1 Top 10 net exporting sectors

	Share in total exports volume (%)	E_{ex} (MT)	E_{im} (MT)	BEET (MT)	Share in total exported carbon (%)
MTT	17.39	172.11	17.14	154.97	18.35
SPF	4.74	184.04	83.30	100.73	11.93
MMP	6.99	101.66	16.70	84.96	10.06
TPS	6.88	99.79	27.32	72.46	8.58
MEM	7.97	124.83	62.82	62.00	7.34
MWC	8.49	61.03	2.15	58.88	6.97
MCE	11.94	191.72	146.17	45.55	5.39
MNM	2.60	59.15	15.04	44.11	5.22
WRC	9.92	47.78	5.27	42.51	5.03
MAS	3.81	32.36	2.44	29.92	3.54

As is shown in table 1, MTT contributes most exported carbon emissions and also most exports volume. Carbon intensive sectors such as SPF, MMP and MNM, occupy a relatively small proportion in exports volume but contribute a much larger share in exported carbon emissions. On the contrary, cleaner sectors, such as MCE and WRC, generate more exports volume with less exported carbon emissions. In addition, though the BEET of MCE is ranked seventh, both of its imported and exported carbon emissions are ranked first, which indicate the importance of processing trade in the sector.

Table 2 Top 10 net importing sectors

	Share in total imports volume (%)	E_{ex} (MT)	E_{im} (MT)	BEET (MT)	Share in total imported carbon (%)
MRC	19.32	112.94	244.23	-131.29	36.42
EPG	26.63	2.08	69.00	-66.92	18.57
MFM	13.26	0.01	37.39	-37.38	10.37
SNM	5.63	39.11	70.54	-31.43	8.72
SPM	5.56	42.68	64.15	-21.47	5.96
PCN	3.25	19.74	37.28	-17.54	4.87
MNF	5.76	1.16	18.34	-17.19	4.77
FFF	7.91	6.70	23.42	-16.72	4.64
MPP	1.47	7.21	14.28	-7.07	1.96
MMW	3.30	26.17	31.77	-5.60	1.55

Top 10 of 13 net importing sectors were in turn Manufacture of Raw Chemical Materials and Chemical Products (MRC), Extraction of Petroleum and Natural Gas (EPG), Mining and Processing of Ferrous Metal Ores (MFM), Smelting and Pressing of Non-ferrous Metals (SNM), Manufacture of Special Purpose Machinery (SPM), Processing of Petroleum, Coking, Processing of Nuclear Fuel (PCN), Mining and Processing of Non-Ferrous Metal Ores (MNF), Farming, Forestry, Animal Husbandry, Fishery & Water Conservancy (FFF), Manufacture of Paper and Paper Products (MPP), Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work (MMW), whose imports volume and imported emissions respectively accounted for 92.07% and 97.82% of the total. As is shown in table 2, unlike exported carbon emissions, which are distributed relatively evenly among sectors, most imported carbon emissions are distributed in MRC, EPG and MFM. Especially, imported emissions of MRC occupy 36.42% of the total, which indicates great dependency of this sector on foreign input. Also, MFM is similar, whose imported carbon emission is ranked third but exported carbon emission is considerably little.

As a whole, manufacturing industry was responsible for the great majority of China's BEET in 2007, which reflected the comparative advantage of these sectors. Sectors that ran large carbon surplus or deficit, such as MTT, SPF, MRC and EPG, would be easier to be subject to change of international trade and climate policy.

4.2 BEET with trading partners

In this article, we estimated BEET between China and 183 trading partners in 2007, whose trade volume with China accounted for more than 99% of total.

In terms of carbon embodied in exports, the results show that Hong Kong was the biggest recipient of exported emissions of mainland China, which was followed by the US, Netherlands, UK, Singapore, and so on. Top 10 recipients of China's exported emissions and detailed information are listed in table 3, which receive 75.87% of China's exported carbon emissions. Evidently, all the recipients are developed economies, which supports that the majority of China's exported emissions are generated for consumption of developed world. In addition, considering that a number of goods exported from mainland China to Hong Kong would be re-exported to the US, the emissions ultimately exported from China to the US may be even greater than the estimation. According to Hong Kong Statistics, in 2007, 61.97% of re-exported goods and services of Hong Kong came from mainland China and 13.35% of them went to the US.

Table 3 Top 10 recipients of China's exported emissions

Countries and Regions	E_{ex} (MT)	E_{im} (MT)	BEET (MT)	Share (%)
Hong Kong	262.06	10.20	251.86	27.55
US	330.60	107.45	223.15	24.41
Netherlands	58.85	5.17	53.68	5.87
UK	44.98	7.26	37.72	4.13
Singapore	42.09	12.77	29.32	3.21
Italy	30.08	9.80	20.27	2.22
Germany	69.22	49.02	20.20	2.21
France	28.88	9.27	19.61	2.14
Spain	23.48	4.35	19.13	2.09
United Arab Emirates	24.19	5.49	18.70	2.05

In terms of carbon embodied in imports, the results show mainland China imported the most emissions from Chinese Taipei, which was followed by South Korea, Saudi Arabia, Australia, Malaysia, Thailand, and so on. Top 10 countries and regions, from which China imported 84.43% emissions of total, are listed in table 4.

Table 4 Top 10 contributors of China's imported emissions

Countries and Regions	Share in total imports volume (%)	E_{ex} (MT)	E_{im} (MT)	BEET (MT)	Share (%)
Chinese Taipei*	22.50%	33.33	141.70	-108.36	25.26
South Korea	23.10%	79.71	154.70	-74.99	17.48
Saudi Arabia	3.91%	11.09	41.92	-30.82	7.18
Australia	5.75%	25.56	52.93	-27.36	6.38
Malaysia	6.39%	25.13	51.18	-26.05	6.07
Thailand	5.05%	17.01	41.10	-24.09	5.61
Iran	2.96%	10.35	31.50	-21.15	4.93
Russia	4.38%	40.45	59.54	-19.09	4.45
Kazakhstan	1.43%	10.58	27.72	-17.14	4.00
Oman	1.50%	0.78	13.96	-13.18	3.07

* Non-parties to the UNFCCC

Among these partners, although South Korea was ranked second in BEET, both of its imported and exported carbon emissions with China were the largest, which indicated a mutual trade and carbon dependency. A more typical example was Japan. China exported 144.94MT of carbon emissions to Japan and imported 143.94MT from Japan in 2007. In addition, countries such as South Korea and Australia, whose production and goods are cleaner or less carbon intensive, had a bigger share in China's imports volume but contributed less in imported carbon of China. On the contrary, countries such as Kazakhstan and Russia, contributed more imported carbon with less imports volume of China. Further, due to our assumption in the calculation model that imported goods have same emission intensity with domestic goods, actual carbon deficit between China and partners that is less carbon intensive would be larger than our estimation. On the contrary, for dirtier countries, real carbon deficit would be smaller than estimation.

In sum, in 2007, With 145 out of 183 partners, China ran a surplus of 914.21MT CO_2 emission, while with other 38 partners China ran a deficit of 429.04MT CO_2 emission. The distribution of China's 781.60MT of BEET over the world is shown in Figure 2, which focuses on North America, west Europe and south-east Asia.

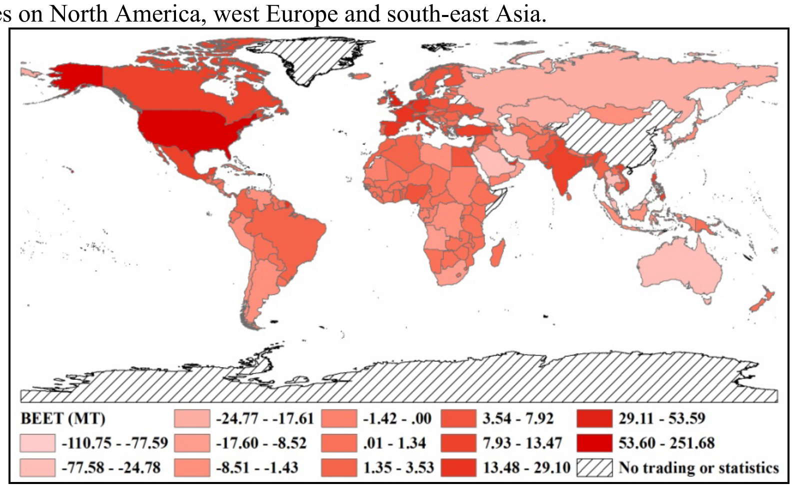

Figure 2 The distribution of China's BEET over the world

5 CONCLUSION AND DISCUSSION

In 2007, China was a net exporter of 484.18MT of CO_2, accounting for 8.59% of total emissions, most of which supported the consumption of developed countries.

The Heckscher-Ohlin trade theory suggests that, under free trade, countries would specialize in the production that is intensive in the factors that they are endowed within relative abundance. So as long as there is trade, a part of countries will specialize in carbon intensive production. The challenge for global carbon reduction is to ensure countries engage cleaner technologies in carbon intensive production, rather than moving it elsewhere. However, current production-based mechanism for allocating carbon reduction burden provides incentive for pollution shift. It is arguably already an issue that the ratified Annex B countries only account for one-third of global GHG emissions [Peters and Hertwich 2008]. China is planning to reduce carbon intensity by 40-45% on 2005 level by 2020. In this process, China's exports may decrease. Then consumption demand of developed countries will shift to other countries and increase their production. If carbon intensity of these countries is lower than that of China, then global emissions will decrease, on the contrary, China's carbon reduction will even increase global emissions. Similarly, if China also shifts emission intensive industries to other countries, on a production basis, its carbon emissions will decrease but global emissions will not and may even increase. Moreover, production-based inventories have placed disproportionate responsibilities on developing and developed countries. For example, carbon emission of China would have been 8.95% lower in 2007 if calculated according to final consumption while emission of carbon recipients of China would have been larger. By allocating the entire BEET to countries that productions take place, the Kyoto Protocol fails to reflect the complexities of international trade, the sacrifices that net carbon exporting countries are making and the actual environmental impact of consumption activities. In this sense, a more systematic consumption-based approach, which can eliminate carbon leakage and encourage reduction to occur where the costs are lowest, will be better. Moreover, carbon border tax adjustment has been proposed as a method for addressing competitiveness concerns in global carbon reduction. The methodology used to construct consumption-based inventories is a consistent method to determine the value of border taxes for aggregated sectors. By allocating exports to other countries and including the foreign emissions to meet domestic consumption, a consumption methodology provides a more rational basis for countries to impose tax adjustments [Victor, House et al. 2005; Pan, Phillips et al. 2008].

In sum, carbon emissions embodied in trade must be paid more attention to bridge the gap between the concerns of developed and developing countries, encourage active participations and reduce carbon leakage.

However, as if carbon emissions embodied in trade are fully understood and international responsibilities are reallocated on a consumption basis, it is far from enough to promote global cooperation to combat climate change though it would be a great progress, not to mention that net carbon importers may not accept consumption-based method. So far, the seeking of a global solution for climate problem is continually prone to problems such as carbon leakage, free riding and international conflict, etc. To a large extent, global schemes are too weak to monitor and enforce, and are also vulnerable to exit when commitments become inconvenient. As a matter of fact, current progress in slowing GHG emissions is arriving via fragmented, multispeed and multilevel efforts. The most important efforts have involved carbon trading. So far, six trading systems have emerged- each a laboratory with its own procedures, stringency, and prices [Victor, House et al. 2005]. In addition, for example, in October 2008, a merger with the Clinton Climate Initiative was arranged to create the C40 Cities Climate Leadership group, whose members have jointly pledged to reduce emissions in each of their cities to meet or even improve on Kyoto standards. The C40 Large Cities Climate Summit was held in May 2007 to exchange information about many policies adopted to reduce emissions and to announce a $5 billion global Energy Efficiency Building Retrofit Program by the Clinton Climate Initiative[1]. Other local-level efforts to increase alternative energy production and reduce fossil fuel consumption of automobile have been reported for many cities around the world- including Sorsogon, Philippines; Esmeraldas, Ecuador; Maputo, Mozambique; and Kampala, Uganda, where efforts are supported by the Cities in Climate Change Initiative, funded by the government of Norway and the UN Development Account [UN-HABITAT 2008; Ostrom 2009b]. In a word, besides national governments, many regions, local governments, community organizations and individual firms over the world at multiple levels have recognized the importance to tackle climate change and have made great achievement. Then, must we wait for a global solution for addressing this global problem? Given the decades-long failure at international level to reach an efficient, fair, and enforceable agreement, continuing to wait may defeat the possibilities of significant adaptations and mitigations in time to prevent tragic disasters [Ostrom 2009b]. The reason why the world has been trying to seek a global agreement to regulate the behaviors of each country originates from the classic theory of collective action, which predicts the benefits that might be achieved through collective action are impossible to obtain without externally imposed regulations. However, contrary to such argument, a large number of empirical studies at a small to medium scale find many groups in the field have self-organized to develop solutions to common-pool resource problems [Ostrom, Gardner et al. 1994; Sandell and Stern 1998; Ostrom 2009a]. As a foundation for the conventional theory of collective action, rational choice theory is well supported when applied to the analysis of the provision and production of private goods in a highly competitive environment, while it is not convincing when applied to situations involving social dilemmas where participants trust one another to be effective reciprocators [Ostrom 1998]. Thus, simply trying to seek a single global solution that is implemented by national governmental unit because of global impacts is far from enough. The important role of smaller-scale effects must be recognized. In this sense, a polycentric approach might be a choice for the problem, which means actions at various levels with active oversight of local, regional, and national stakeholders[Ostrom 2009b]. Given the slowness and conflict

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[1] http://www.c40cities.org/ (Accessed March 5, 2010)

involved in achieving a global solution, recognizing the potential of building more effective ways of reducing GHG emissions at multiple levels is an important step forward.

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