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Abstract

Most climate scientists around the world are concerned about global warming. These concerns have resulted in calls for reductions in CO_2 emissions over time. If these calls are to be heeded, an appropriate emissions accounting method must first be agreed upon by CO_2 emitting countries, none of which are more important than China. This paper estimates China's CO_2 emissions in 2002 and in 2007 using firstly a production-based, and then a consumption-based, accounting method, both in aggregate and at the sectoral industry level. Our objectives are firstly to investigate the recent trends in Chinese emissions of CO_2, and secondly to reveal the extent of the differences in the estimates produced by these two methods. Our estimates confirm what others have found, namely that Chinese emissions of CO_2 increased substantially over this relatively short time period. Furthermore, the consumption-based method results in China being responsible for 38% fewer emissions in 2007 than would be the case with the production-based method. Problems caused by global warming will only be ameliorated if an acceptable worldwide distribution of responsibilities for emissions reduction efforts can be found. We believe that the consumption based method is more appropriate because it allocates responsibilities according to final consumption.

Keywords: CO_2 emissions, China, Accounting methods.

JEL Codes: Q01, Q53 and Q58

I. Introduction

Over the last 50 years, the accelerating rate of globalisation has resulted in perhaps the greatest geographical and chronological separation between production and final consumption in documented history. Combined with the recent threat of climate change, this phenomenon has resulted in an increasingly sharp focus being directed to the quantum of greenhouse gas emissions embodied in exported and imported goods and services. This focus is especially concerning for countries heavily involved in world trade, and few are more heavily involved than China.

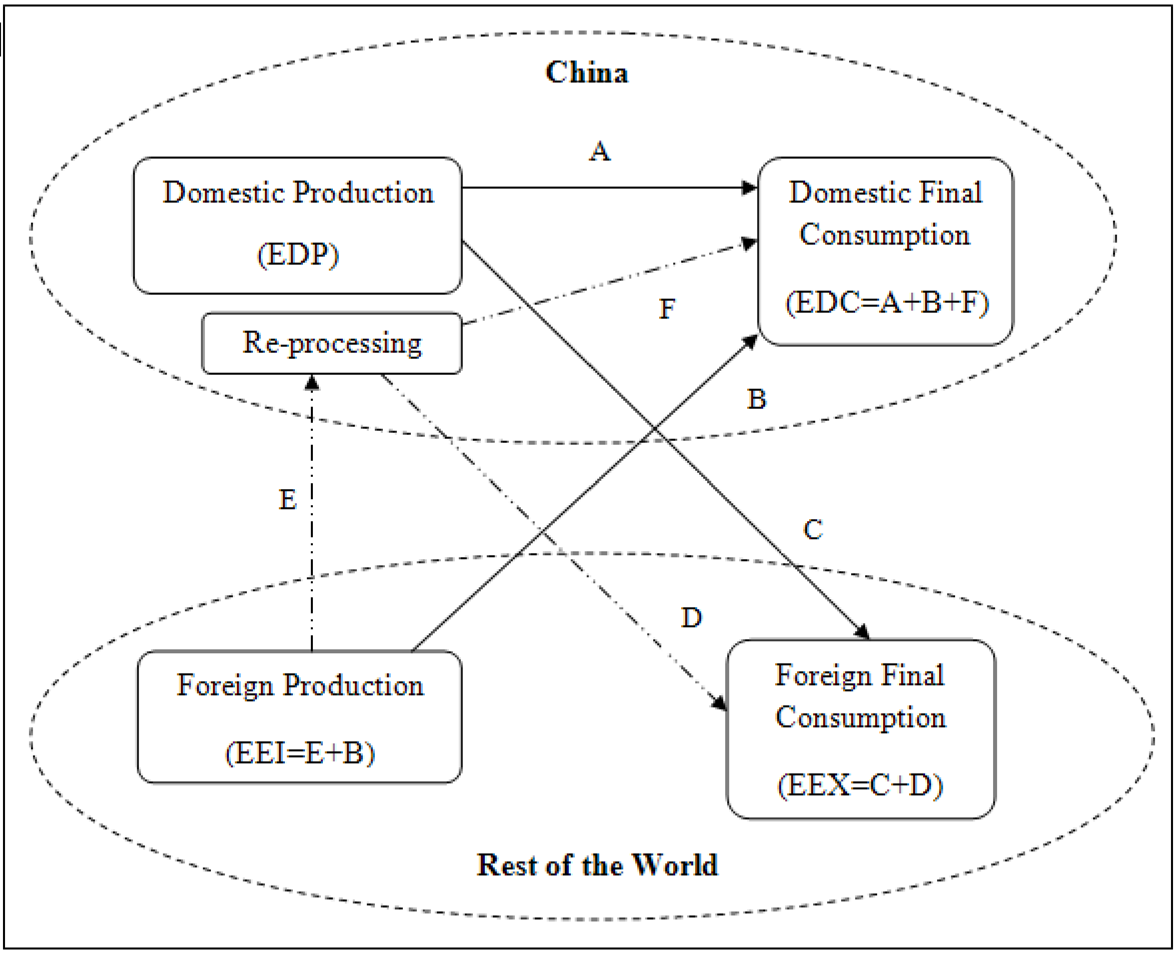
Over the last two decades China has become the dominant supplier of manufactured exports to many of the world's economies. Whilst this remarkable economic achievement continues to transform the Chinese urban and rural landscape, most of China's burgeoning electricity needs are met via the burning of coal. Hence considerable worldwide attention is now focused on China's enormous and growing output of emissions, especially of the greenhouse gas Carbon Dioxide (CO_2). The United Nations Framework Convention on Climate Change (UNFCCC) requires that all parties to the convention develop and submit national greenhouse gas inventories on the basis of a production-based accounting approach where countries are held responsible for the CO_2 emissions that emanate from all productive activities within their national geographic borders.

A production based accounting approach makes for a relatively straightforward measurement task. However, it ignores the phenomenon, which is especially relevant for China and its major trading partners, known as carbon leakage (Lin and Sun, 2010). Carbon leakage occurs when a country is able to reduce its greenhouse gas inventories by importing goods from another country. In the case of trade between Australia and China, for example, the production-based approach means that China is held responsible for all of her emissions of CO_2 despite the fact that some of her output, especially of manufactures such as whitegoods, is produced for consumption in Australia. In this way the production-based approach can result in an accounting discontinuity whereby the final consumers of output are not held responsible for the entirety of the greenhouse gas emissions that result from their consumption activities.

In response to this potentially inequitable outcome, a more sophisticated but more complicated consumption-based greenhouse gas accounting approach has been advocated, which is summarised diagrammatically by Figure 1. With this approach a country such as China would be held responsible for CO_2 emissions from domestic production of goods and services for local consumption (flow A), CO_2 emissions embodied in imported final consumption goods (flow B) and CO_2 emissions embodied in imported intermediate goods requiring re-processing for domestic consumption (flow F). Additionally, China would be held responsible for only the domestic CO_2 emissions added whilst re-processing intermediate goods for eventual re-export (flow D), but would not be held responsible at all for CO_2 emissions from the production of goods for export (flow C).

In this way the consumption-based approach allows emissions to be assigned to individual countries in a consistent manner based on final consumption (Wiedmann, 2009). Compared to the production-based accounting approach, especially given the volume and asymmetric nature of much world trade, the consumption-based approach would in some cases significantly alter the way in which responsibility for CO_2 emissions are assigned and, as a corollary, the distribution of responsibilities that would fall on individual member countries for any agreed upon overall greenhouse gas emissions reduction target in a post-Kyoto framework.

Figure 1. A Consumption-based Approach to Accounting for CO_2 Emissions



Note: EDP= emission embodied in domestic production; EDC=emission embodied in domestic consumption, from both domestic and foreign production; EEX= emissions embodied in export, exports of domestic production and re-export; EEI=emission embodied in import, including foreign imports as domestic final consumption and imports as intermediate inputs for re-processing and export.

Source: Constructed by authors.

Early empirical studies on this issue tended to focus on developed countries. For example, Wyckoff and Roop (1994) first investigated CO_2 emissions embodied in exports and imports for six OECD countries from 1984 to 1986 and found that imports indeed reduce the necessity for domestic emission reduction measures. Subsequent studies on the relationship between trade and CO_2 emissions include Munskgaard and Pedersen (2001) for Denmark, Mongelli *et al*. (2006) for Italy, Ghertner and Fripp (2007) for the USA, and McGregor *et al*. (2008) for the UK. These studies adopt extended environmental input-output

(I-O) analyses which allow emissions and resource use to be assigned to final demand in a consistent manner.

China has received more attention recently. For example, Pan *et al*. (2008) use 2002 input-output data to analyse the greenhouse gas emissions embodied in Chinese trade from 2001 to 2006 and conclude that the consumption based approach lowers the 2006 CO_2 emissions attributable to China from 5500 Mt to 3840 Mt and reduces the annual average growth rate of Chinese CO_2 emissions over the period 2001-2006 from 12.5% to 8.7%. Weber *et al*. (2008) examine the CO_2 emissions embodied in Chinese exports from 1987 to 2005 and find that these nearly tripled over their study period, from 12% in 1987 to around 33% by 2005.

Similarly, Lin and Sun (2010) demonstrate that 3357 Mt of CO_2 emissions were embodied in Chinese exports, whilst 2333 Mt of CO_2 were avoided by Chinese imports, in 2005. Lin and Sun (2010) take into account the re-exported emissions due to the importance of processing trade in China's international trade. Shui and Harris (2006) focus on bilateral trade between China and the USA rather than Chinese multilateral trade and conclude that between 7% and 14% of China's CO_2 emissions are directly attributable to the production of manufactured exports for consumption in the USA. Applying a similar methodology, Li and Hewitt (2008) find that about 4% of China's emissions of CO_2 were due to the production of manufactured exports for consumption in the UK.

Although these and other studies have made significant contributions to our understandings in this area, two challenges remain. Firstly, most studies assume that the emissions embodied in, and therefore the emissions avoided by, intermediate manufactured goods imported from developed countries are the same as would be the case had those intermediate manufactures been produced within China (the EAI assumption). Considering that the emission intensity of Chinese manufacturing industries is still relatively high compared with those of its major trading partners, due to technological and other lags from the relevant worldwide frontier, this assumption is problematic. Secondly, processing trade is an important part of China's international trade. If the re-exported emissions component is excluded, as it is in many earlier studies, the emissions embodied within total Chinese exports will over-estimate China's true output of CO_2 emissions.

This paper estimates China's emissions of CO_2 in 2002 and in 2007 using both the production-based and the consumption-based approaches, firstly to demonstrate the rapid increase in emissions emanating from China over this relatively short time period and secondly to demonstrate the magnitude of the differences between the two measurement approaches. Secondly, using the consumption-based approach, we provide more detailed microeconomic snapshots of sectoral CO_2 emissions by adopting a sectoral environmental input-output analysis. Finally, unlike many prior studies which adopt the EAI assumption, our estimates are based on a weighted average emissions intensity for intermediate imports, the weights being the shares of each major trading partners imports into China. This is a potentially important adjustment to the measurement approach because the emission intensity of Chinese producers is generally regarded as being much higher than that of similar producers in developed countries and so our adjustment means that the emissions avoided by China via importation of intermediate goods is much lower than would have been the case with the earlier simplifying assumption.

The remainder of this paper is structured as follows. In the next section we discuss the measurement methodology used in this paper. In section III we discuss our data, present and interpret our results. Finally section IV concludes.

II. Estimating CO_2 emissions: methodology

CO_2 emissions for China can be estimated at the sectoral level by using the following International Panel on Climate Change (IPCC) formula:

$$CO_{2i} = \sum_{g=1}^{3} CO_{2g} = \sum_{g} E_{ig} \times CEF_g \times COF_g \times \left(44/12 \right) \tag{1}$$

where are total carbon dioxide emissions of the i[th] sector and CO_{2g} are carbon dioxide emissions from energy source g (the three major energy sources being coal, oil and gas). Emissions of carbon dioxide from the i[th] sector will thus depend on the consumption of the g[th] energy in the i[th] sector (E_{ig}) (with these being typically measured in tons of coal equivalent (tce))[1] as well as the carbon emissions factors for each energy source (CEF_g). These are assumed to be 0.7266 for coal, 0.5588 for oil and 0.4224 for natural gas (see appendix 1 for details). COF_g represents the carbon oxidisation factors. We use the default values obtained from Houghton *et al*. (1996) which are 0.98 for coal, 0.99 for oil and 0.995 for natural gas. Finally, the ratio 44/12 is the molecular weight ratio of carbon dioxide to carbon. Therefore, the calculated CO_2 emission coefficient ($CEF_g \times COF_g \times 44/12$) for coal, oil and natural gas are, respectively, 2.611, 2.028 and 1.541 tons of CO_2 per ton coal equivalent.

Emission embodied in domestic production (EDP)

Assuming that an economy includes n industries, the input-output model indicates that the output of each industry can be used as the intermediate input for other industries or for

[1] The data for different types of energy usually are converted into standard coal equivalent (tce, ton of coal equivalent) or standard oil equivalent (toe, ton of oil equivalent). As coal is the major energy source in China, we use tce. In the China Energy Statistical Yearbook consumptions of coal and oil are measured in tons whilst natural gas is measured in cubic meters. The assumed transformation rates are as follows: coal: 1 ton = 0.7143 tce; oil: 1 ton = 1.4286 tce; natural gas: 1 cubic meter = 0.00133 tce.

final consumption. So total output can be represented by $X = AX + Y$, where X and Y are column vectors representing the total output (output vector X_i) of the entire economy and final use that incorporates consumption, investment and export (final use vector Y_i) respectively.

Sectoral output can be defined as,

$$X_i = \sum_{j=1}^{n} (a_{ij} \times X_i) + Y_i \qquad (2)$$

where $a_{ij} = \frac{X_{ij}}{X_i}$ is the direct input requirement coefficient matrix and *i* and *j* are sectors. This notation is known as the Leontief Matrix 'A' and reveals the economy-wide production function. The relationship between total output and final use can be written as $(I - A)^{-1} \times Y$, where $(I - A)^{-1}$ is the Leontief inverse matrix

Carbon dioxide emissions embodied in domestic production (**EDP**) can thus be defined as:

$$EDP = SX = S \times (I - A)^{-1} \times Y = S^{'} \times Y \qquad (3)$$

where 'S' represents the direct emissions per unit of industrial output for all sectors of an economy. Hence $S_i = \frac{Emissions_i}{X_i}$ represents the emissions intensity for the i^{th} sector. The term $S^{'} = S \times (I - A)^{-1} \times Y$ represents the domestic embodied carbon dioxide emissions per unit of final use. Overall emissions intensity per unit of output multiplied by output for final use represents emissions embodied in domestic production (EDP). As discussed above, this approach ignores emission embodied in imports (EEI).

Emissions embodied in domestic consumption (EDC)

EDC is given by:

$$EDC = EDP - EEX + EEI \tag{4}$$

Following Pan *et al*. (2008), we assume that a portion of exports are imported as intermediate goods before they are reprocessed for final export. To properly account for exported emissions from domestic production, the intermediate imports that are embodied in exports must be excluded. For this purpose, the direct input requirement coefficient matrix 'A' can be decomposed into two components, the inter-industry requirements of domestically produced products (A^d) and the inter-industry requirements of imported products (A^{im}) (see United Nations, 1993).

EEX can be expressed as

$$EEX = S \times [I - (I - M)A]^{-1} \times Ex \tag{5}$$

where $A^d = A - A^{im}$, $A^{im} = MA$ and M is a diagonal matrix with the element $m_{jj} = \frac{\mathrm{Im}_j}{X_j + \mathrm{Im}_j - Ex_j}, (j = 1, 2, ..., n;$ when $i \neq j, m_{ij} = 0)$ and Ex are exports. We assume, as others have done, that the proportion of the imported intermediate inputs from each sector to all other sectors is the same. Given that not all sectors are involved in processing intermediate imported goods, we expect that this will give some sensible results. Overall, EEX reflects the emissions embodied in external demand for domestically produced goods.

EEI is given by:

$$EEI = \hat{S} \times \mathrm{Im} \tag{6}$$

where $\hat{S}$ presents the average emission intensity for the top 20 nations from which China imports intermediate goods, and are total imports whether for domestic consumption or the processing trade. Most studies assume that the emission intensity of imported intermediate goods is the same as would be the case had those goods been produced domestically and hence fail to capture potentially important national differences in both the energy and carbon intensity of foreign production and consumption (Pan *et al*., 2008). Hence many studies produce estimates that typically overestimate emissions embodied in imports because the emission intensity of China is relatively high compared to those of its trading partners.

However unlike Pan *et al*. (2008) who assume that the national average emissions intensity explains the country's exported goods, we apply a weighted average emissions intensity of imports. Our assumption is that the average emission intensity for China's top 20 importers is representative of those of China's total imports of intermediate goods because these countries contribute more than 75% of China's intermediate imports. In order to estimate the quantum of emissions that would have been saved, we also calculate CO_2 emissions embodied in imports by using China's domestic emission intensity in place of the importers' average emissions intensity.

The balance of CO_2 emissions embodied in international trade (BEET) is the difference between EEX and EEI, or the difference between EDP and EDC estimates. If BEET is positive, a country exports more emissions than it imports from other countries (it thus has an emissions surplus) which indicates that domestically produced goods with the embodied emissions are not consumed completely domestically. Conversely if BEET is negative, a country imports more emissions than its exports (it thus has an emissions deficit). With reference to Copeland and Taylor's (1994) scale, technique and composition effects of domestic and foreign consumption, a positive and increasing BEET may reflect a rate of increase in the scale of production within the domestic economy which is faster than that for consumption. On the other hand a falling BEET surplus could indicate a rate of technological progress in the domestic economy that is faster than that of its trading partners. We now present our estimates of China's CO_2 emissions using both production and a consumption based approaches.

III. Chinese CO_2 emissions

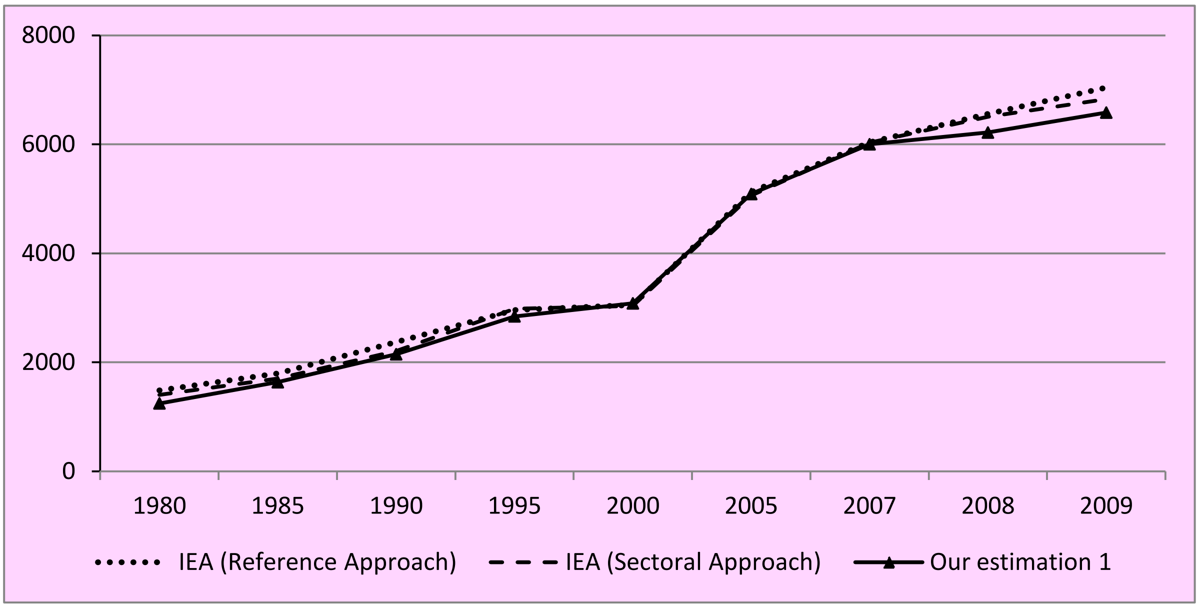
Our primary energy data on Chinese energy consumption (coal, oil and natural gas) are from the China Energy Statistical Yearbook (2002-2009). GDP, population, economic structure and input-output tables are from the China Statistical Yearbook (2002-2009) and from the Comprehensive Statistical Data and Materials on 60 years of New China (2009). We also use I-O tables which the Chinese government has compiled on a five yearly basis from 1987 to 2007. By merging data for real estate and financial sectors we have incorporated 15 sectors in our analysis[2]. Carbon intensity data for China's major trading partners were obtained from the World Bank (2011).

China's aggregate CO_2 emissions

CO_2 emissions have been estimated at the national and sectoral level by using equation (1) and are plotted in Figure 2. Our estimated national CO_2 emissions are consistent with the relevant International Energy Agency (IEA) data which provides some supports for the method we have used. Chinese CO_2 emissions have increased rapidly since 2002 and this is mainly explained by the rapid industrial sector growth (manufacturing, mining and utility) following China's membership of the World Trade Organisation.

[2] ARG: Agriculture, Forestry, Animal Husbandry & Fishery. MNI: Mining. FBT: Manufacture of Foods, Beverage & Tobacco. TWL: Manufacture of Textile, Wearing Apparel & Leather Products. EHW: Production and Supply of Electric Power, Heat Power and Water. CGP: Coking, Gas and Petroleum Processing. CMI: Chemical Industry. BNM: Manufacture of Building Materials and other Non-metallic Mineral Products. MPM: Manufacture and Processing of Metals and Metal Products. MEM: Manufacture of Machinery and Equipment. OMI: Other manufactures. CSI: Construction. TPT: Transport, Storage, Post, Information Transmission, Computer Services & Software. WHC: Wholesale and Retail Trades, Hotels and Catering Services. OSI: Real Estate, Leasing and Business Services, Financial Intermediation and Other Services.

Figure 2. China's CO_2 Emissions (Mt) 1980-2009



Source: IEA (2011) and authors' calculation. The IEA Reference Approach is a top-down approach using a country's energy supply data and has no detailed information on how the individual fuels are used in each sector (IEA, 2011).

The EDP approach

Chinese emissions embodied in domestic production (EDP) have been estimated by using equation (2) and our estimates are presented in Table 1. Just to reiterate, the EDP estimates represent the production-based accounting method and ignore emissions embodied in imports (EEI). Our own estimations of EDP are consistent with those of the IEA (2011) and from the China Energy Statistical Yearbook (2010).

Table 1. China's CO_2 emissions embodied in domestic production (EDP)

Estimate	**2002**	**2007**
IEA (Mt)	3440	6072
China Energy Statistical Yearbook (Mt)	3456	6047
Own estimation (Mt)	3152	5658

Source: IEA (2011), China's energy Statistical Yearbook (2010), and authors' calculation. The Chinese residential sector is excluded from our estimates due to a lack of data.

Table 2 shows CO_2 emissions, direct emission intensity (S) and embodied emission intensity (S') for 2002 and 2007 by industry sector. It is clear that direct and embodied CO_2 emission intensities (S and S') in China decreased in all industry sectors between 2002 and 2007. Due to a coal dominated electricity generation sector, the electricity, heat and water supply industry (EHW) had the highest emissions intensity in 2002 (5.03kg per US$1) and again in 2007 (2.76kg per US$1), although the reduction in emissions intensity over this relatively short time period is notable. The next most intense sectors, in order, are the coking, gas and petroleum processing sector (CGP), the chemical industry (CMI) followed by the metals manufacturing sector (MPM). Again the rapid reduction in emissions intensity is notable in these sectors also.

Table 2. Chinese CO_2 emissions, and direct and embodied CO_2 emission intensity, by industry sectors: 2002 and 2007

Industrial Sector	2002			2007		
	CO_2 (10000 ton)	S (kg/PPP $)	S' (kg/PPP $)	CO_2 (10000 ton)	S (kg/PPP $)	S' (kg/PPP $)
ARG	3 026.75	0.0345	0.4822	4 360.09	0.0323	0.3922
MNI	27 434.81	0.8655	1.7732	36 424.62	0.4522	1.4514
FBT	4 844.21	0.1089	0.6424	5 480.94	0.0475	0.5213
TWL	2 681.71	0.0558	0.8075	5 021.75	0.0420	0.7608
EHW	131 019.78	5.0302	6.0321	248 866.53	2.7603	5.0207
CGP	66 042.87	3.3337	4.9253	135 661.29	2.2157	3.5489
CMI	24 240.48	0.3658	1.7500	32 264.26	0.1885	1.5573
BNM	16 792.70	0.9417	2.2613	31 944.73	0.5057	1.7766
MPM	25 023.74	0.3812	1.8863	47 380.23	0.2178	1.5693
MEM	2 928.21	0.0215	1.0383	3 430.23	0.0085	0.9784
OMI	4 896.22	0.1147	0.9167	9 091.18	0.0903	0.8509
CSI	1 044.54	0.0121	1.1884	1 054.37	0.0061	1.1298
TPT	2 483.06	0.0553	1.1108	1 752.58	0.0149	0.8676
WHC	1 509.32	0.0202	0.5493	1 619.40	0.0134	0.4206
OSI	1 247.83	0.0073	0.5181	1 513.38	0.0052	0.4783

Source: Authors' calculation.

Besides the service sectors, the construction industry (CSI) and the machinery and equipment manufacturing industry (MEM) possess the smallest direct emissions intensities. However, when taking indirect emissions into account ($S^{'}$), emission intensities increased significantly especially in 2007. This increased is much more pronounced in downstream industries such as machinery and equipment manufacturing (MEM) than in upstream industries such as power generation (EHW).

Because China is more carbon intensive in production than are her major trading partners, we cannot use the domestic emissions intensity to estimate imported CO_2 emissions.[3] Rather, we assume that average emission intensity for China's top 20 importers is representative of the emissions intensity of all Chinese imports. The average emission intensity for China's top 20 importers (which make up more than 75% of total imports into China) has been estimated using an import-weighted average of the emissions intensity of the top 20 importers. Our estimations show that the emissions intensity of imports into China fell from 0.50 kg per US$1 in 2002 to 0.40 kg per US$1 in 2007.

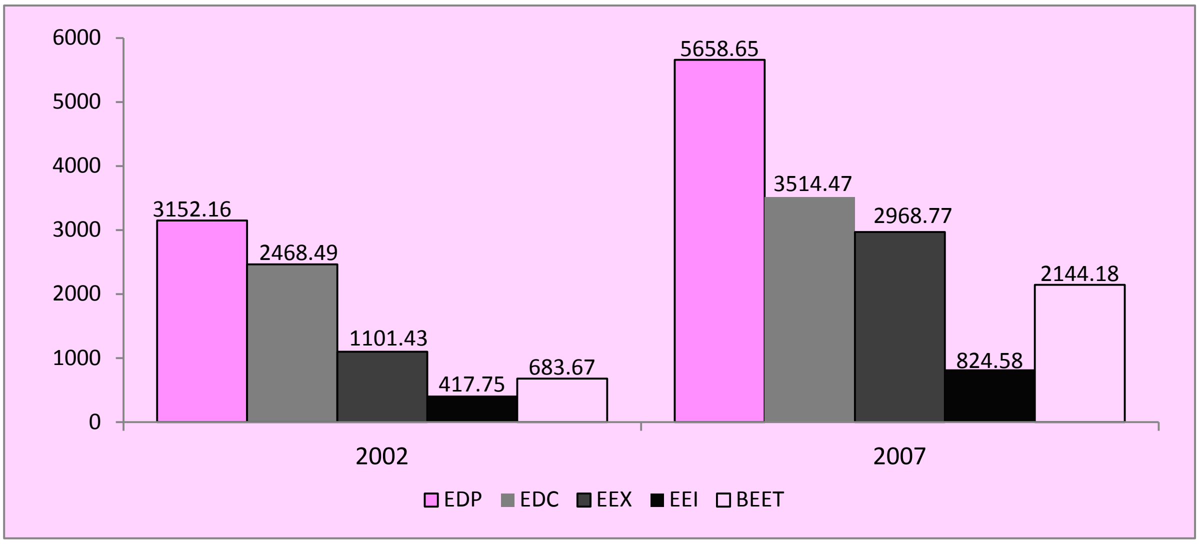
The EDC approach

As noted earlier, EDP + EEI - EEX = EDC. Thus EDP minus EDC will reveal the balance of CO_2 emissions that are embodied in international trade (BEET). EDC has been estimated below using equation (4) and represents the internal demand for embodied emissions whilst EEX represents the external demand for embodied emissions. Figure 2 presents EDP, EDC, EEX and BEET estimates for 2002 and 2007 for the economy as a whole. Not surprisingly, China's embodied CO_2 emissions increased rapidly from 2002 to 2007. China generated around 3152 Mt (million tons) of CO_2 from domestic production (EDP) in 2002. It reached 5659 Mt in 2007, almost doubling the 2002 figure. Consumption-

[3] In 2002, emission of intensity of China as a whole was 1.0077 kg/PPP US$1, which was the 16th highest of all countries; whilst in 2007 it was 0.9255 kg/PPP US$1, the 11th highest of all countries (World Bank, 2011).

based CO_2 emissions (EDC) also increased rapidly from 2468 Mt to 3514 Mt, but these figures are substantially less than the EDP figures. When the consumption based approach is used emissions which China can reasonably be held responsible for decrease by 22% in 2002 and by 38% in 2007 from the figures obtained using the production based approach. This difference represents China's surplus of CO_2 emissions from international trade.

Figure 3. Embodied CO_2 Emissions in China's Domestic Production, Consumption and International Trade in 2002 and 2007 (Mt)



Source: Authors' calculation. Emissions in this figure do not include the emissions from residential consumption. EDP: emissions embodied in domestic production. EDC: emissions embodied in domestic consumption. EEX: emissions embodied in exports. EEI: emissions embodied in imports. BEET: balance of emissions embodied in international trade.

In 2002, EEX was about 1101 Mt of CO_2 emissions while EEI was about 418 Mt in 2002. Being a net exporter of CO_2 emissions, China's BEET was around 684 Mt. In other words, 684 Mt of CO_2 emissions (around 22% of China's total CO_2 emissions) resulted from Chinese production of goods for foreign consumption. In the following five years, with China's membership of the WTO, China's share of international trade, and hence her CO_2 emissions embodied in international trade, increased substantially. By 2007 China's BEET was 2144 Mt, three times that in 2002, whilst her EEX was approximately 38% higher than her EEI.[4] China has continuously displayed a substantial surplus of CO_2 emissions from international trade. China's surging CO_2 emissions are in part derived from the rapidly increasing demand from developed countries for cheap manufactured goods.

Table 3 presents EDP, EDC, EEX and BEET for 2002 and 2007 by industry sectors. In 2002 the most emissions intense export sector is MEM, accounting for 34.8% of EEX, followed by TLF (14%) and CMI (11.3%), the sum of which represents almost 60% of EEX. Also, around 70% of emissions embodied in imports were produced by MEM (48.2%), CMI (13.3%) and MPM (8.4%). In 2007, there were four sectors whose individual shares in EEX was above 10%: MEM (42.7%), MPM (13.7%), CMI (11.3%) and TLF (10.9%), and their overall EEX sums to 79% of the total. The three largest EEI sectors in 2007 were MEM (45.5%), MNI (14.0%) and CMI (12.3%), whose imported emissions accounted for 72% of the national total.

Sectors such as MEM and TLF contributed more EEX (53.6% in 2007) but also more export volume. MEM was China's largest export sector, accounting for 33.8% of EEX in 2002 and 42.4% of EEX in 2007. Part of this sector's exports involves the processing trade, which needs direct and indirect intermediate inputs from abroad. With a relatively high embodied emissions intensity ($S^{'}$), production and reprocessing in the MEM sector is carbon-intensive. Additionally the MEM sector was the largest carbon net-export sector with net exports of 182 Mt of CO_2 in 2002 and 891 Mt of CO_2 in 2007. Carbon intensive sectors, MPM, CMI, and CGP, occupy a relatively small proportion of export volumes but

[4] For the purposes of comparison, we re-estimated but used the EAI assumption instead, as have most other single-region I-O models (see, for example, Sanchez Choliz and Duarte, 2004, Liu et al., 2007 and Weber, et al., 2008). That is, that the emission intensity of the exporting countries are the same as the domestic emission intensity. Using this approach, EEI in 2007 was 2333 Mt which was 2.8 times higher than the 2002 figure of 825 Mt. Because of China's lower energy efficiency and higher carbon intensity compared with the relevant figures of its major trading partners, this simpler method overestimates the imported and re-exported emissions in China (Ahmad and Wychkoff, 2003; Peters and Hertwich, 2008).

contributed a large share to EEX (27.5% in 2007). Carbon intensive sectors, CSI and OSI, are domestically based and contributed a smaller share in EEX. On the other hand the WHC sector provides more export volumes but with less emissions (0.2% in 2007).

According to our BEET data the 15 Chinese industrial sectors can be divided into two broad categories. The ARG and MNI sectors are net importers of emissions (they have negative BEET) which indicates that these sectors avoided emitting CO_2 domestically (in net terms) through international trade. Both the AGR and MNI sectors produce low value-added products and materials, which are the intermediate inputs for others industries. The trade balances of these sectors were in deficit. Mainly due to increases in the volumes of oil and other mining products imported, MNI was the largest emissions net-import sector in 2007. The remaining sectors are in the second category (positive BEET), in that they all increased CO_2 emissions from China by providing goods and services for the international market. This is especially so for the MEM, MPM and TWL sectors. Therefore, the manufacturing sectors were responsible for the great majority of China's BEET, which reflected the comparative advantage of these sectors in world markets.

Finally, in light of the rapidly increasing domestic emissions of CO_2, the State Council of China has adopted a binding goal to reduce CO_2 emission intensity by 40-45% of 2005 levels by 2020. Using the I-O table for 2007 we have re-calculated China's embodied CO_2 emissions to determine how many Mt of carbon emissions will need to be reduced to achieve this goal. Not surprisingly, EDP, EDC and EEX will need to fall significantly, to 3112 Mt, 2165Mt and 1771Mt, respectively. And if we assume that the emission intensity of importers does not change, the BEET falls to 947 Mt.

Table 3. Embodied emissions in international trade by industry sectors: 2002 and 2007 (Mt)

	2002					2007				
	EDP	**EDC**	**EEX**	**EEI**	**BEET**	**EDP**	**EDC**	**EEX**	**EEI**	**BEET**
ARG	181.32	184.29	7.59	10.56	-2.97	157.50	175.50	7.93	25.93	-18.00
MNI	-14.95	-14.31	25.24	25.88	-0.64	-384.29	-296.14	27.03	115.17	-88.14
FMI	164.76	153.93	19.00	8.17	10.83	283.87	271.01	30.48	17.62	12.86
TWL	185.67	56.78	154.17	25.28	128.89	394.25	86.00	324.14	15.90	308.25
ETW	194.61	185.16	9.61	0.16	9.45	202.46	193.46	9.19	0.20	8.99
CGP	23.25	-9.33	40.66	8.08	32.59	-37.68	-99.76	78.23	16.15	62.08
CMI	28.94	-39.71	124.28	55.64	68.65	18.53	-215.85	335.81	101.43	234.38
BNM	38.72	11.68	30.11	3.07	27.04	42.86	-29.74	76.80	4.20	72.60
MPM	14.95	-43.34	93.44	35.15	58.29	145.98	-205.46	406.08	54.64	351.44
MEM	442.56	260.08	383.78	201.29	182.49	1382.08	490.69	1266.93	375.53	891.39
OMI	88.17	38.29	63.64	13.76	49.88	182.35	56.98	155.78	30.41	125.38
CSI	959.93	957.03	4.14	1.24	2.91	1893.56	1882.12	13.90	2.46	11.43
TPT	125.79	77.53	52.79	4.53	48.27	283.13	183.62	116.26	16.74	99.52
WHC	171.44	118.06	53.45	0.06	53.39	237.15	182.32	60.65	5.83	54.82
OSI	546.97	532.35	39.52	24.89	14.62	856.90	839.71	59.54	42.35	17.19
Total	3152.16	2468.49	1101.43	417.75	683.67	5658.65	3514.47	2968.67	824.58	2144.18

Source: Authors' calculation. EDP (which is equal to the domestic embodied emission intensity multiplied by the final use) is negative in some sectors, such as MNI and CGP industries, due to the negative final use in these industries. It means the total outputs of these industries are insufficient to meet the domestic production demand of entire economy. Some intermediate input is imported from overseas to satisfy the demand. Therefore, when the total output is less than the intermediate input, the final use is negative.

IV. Conclusions

The rapidly increasing worldwide emissions of CO_2 are likely to be a major contributor to the process of global warming and so continue to be a cause for considerable worldwide concern. With this concern may emerge pressure for individual countries to reduce their emissions so as to mitigate the worst potential effects of global warming. Such pressures ought to be based on methodologically sound CO_2 accounting principles. Whilst both the EDP and the EDC approaches have been utilised, we believe that the EDC approach is the more acceptable approach because it allocates 'ownership' rights to countries based on both production and consumption activities. Importantly, the differences between the two approaches are not trivial. In 2007, our estimates reveal that by utilising the EDC approach, China would be responsible for 38% less emissions than would be the case with the EDP approach. This discrepancy is consistent with our estimate of China's BEET surplus for 2007 which was three times higher than in 2002, reflecting China's rapidly increasing scale of production, much of which is for foreign consumption. Thus, in our view, a global based consumption accounting approach gives more appropriate estimates of the CO_2 emissions which China should plausibly be held responsible for.

Addressing the highly emissions embodied sectors is one way to resolve this issue domestically even though this is not an ideal method. MEM (manufacture of machinery and equipment) sector alone accounts for around 42% of China's overall EEX. TWL (manufacture of textile, wearing apparel & leather products), CMI (chemical industry) and MPM (manufacture and processing of metals and metal products) explain around 35 percent of overall EEX. These sectors are highly energy intensive and so any attempts to reduce carbon leakage will need to focus substantially on these sectors. Finally, the full role of processing trade is not completely accounted for in this study because of the need to access and analyse the input-output data for all of China’s major trading partners but at the sectoral level. This is the subject of on-going work.

References

Ahmad, N., and Wychkoff, A. 2003. Carbon Dioxide Emissions Embodied in International Trade of goods. STI Working Paper, 15. OECD.

China Energy Statistical Yearbook, 2002-2010. National Bureau of Statistics of China: Beijing, China.

China Statistical Yearbook, 2002-2010. National Bureau of Statistics of China: Beijing, China.

Comprehensive Statistical Data and Materials on 60 Years of New China. 2009. National Bureau of Statistics of China: Beijing, China.

Copeland, B. R. and Taylor, M. S. 1994, North-South Trade and the Environment, Quarterly Journal of Economics, 109 (3): 755-787.

Fang, Y.P., and Deng, W. 2011. Affecting Elements and Regional Variables based on the Objective of Carbon Intensity Reduction in China. International Journal of Sustainable Development and World Ecology, 18 (2):109-117.

Ghertner, D.A., and Fripp, M. 2007. Trading Away Damage: Quantifying Environmental Leakage through Consumption-based, Life-cycle Analysis. Ecological Economics 63 (2-3): 563-577.

Houghton, J.T., Meira Foilho, L.G., Lim, B., Treanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J., and Callander, B.A. 1996. Greenhouse Gas Inventory Reference Manual. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Vol. 3. Agriculture, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Hu, C.Z., and Huang, X.J. 2008. Characteristics of Carbon Emission in China and Analysis on Its Cause. China Population, Resources and Environment, 18 (3): 38-42.

IEA. 2011. CO_2 Emissions from Fuel Consumption Highlights. Paris, International Energy Agency.

Li, Y., and Hewitt, C.C. 2008. The Effect of Trade between China and the UK on National and Global Carbon Dioxide Emissions. Energy Policy 36: 1907-1914.

Lin, B.Q., and Sun, C.W. 2010. Evaluating Carbon Dioxide Emissions in International Trade of China. Energy Policy 38 (1): 613-621.

Liu, L.C., Fan, Y., Wu, G., and Wei, Y.M. 2007. Using LMDI Method to Analyse the Change of China's Industrial CO_2 Emissions from Final Fuel Use: an Empirical Analysis. Energy Policy 35: 5892-5900.

McGregor, P.G., Swales, J.K., Turner, K. 2008. The CO_2 'Trade Balance' between Scotland and the Rest of the UK: Performing a Multi-region Environmental Input-Output Analysis with Limited Data. Ecological Economics 66 (4): 662-673.

Mongelli, I., Tassielle, G., and Notarnicola, B. 2006. Global Warning Agreements, International Trade and Energy/Carbon Embodiments: An Input-Output Approach to the Italian Case. Energy Policy 34: 88-100.

Munksgaard, J., and Pedersen, K.A. 2001. CO_2 Accounts for Open Economies: Producer or Consumer Responsibility? Energy Policy 29: 327-334.

Peters, G.P., and Hertwich, E.G. 2008. CO_2 Embodied in International Trade with Implications for Global Climate Policy. Environmental Science and Technology 42: 1401-1407.

Pan, J.H., Phillips, J., and Chen, Y. 2008. China's Balance of Emissions Embodied in Trade: Approaches to Measurement and Allocating International Responsibility. Oxford Review of Economic Policy 24 (2): 354-376.

Sanchez Choliz, J., and Duarte, R. 2004. CO_2 Emissions Embodied in International Trade: Evidence for Spain. Energy Policy 32: 1999-2005.

Shui, B., and Harriss, R.C. 2006. The Role of CO_2 Embodiment in US-China Trade. Energy Policy 34: 4063-4068.

United Nations, 1993. Handbook of National Accounting: Integrated Environmental and Economic Accounting. Studies in Methods. United Nations, New York.

Weber, C.L., Peters, G.P., Guan, D., and Hubacek, K. 2008. The Contribution of Chinese Exports to Climate Change. Energy Policy 36: 3572-3577.

Wiedmann, T. 2009. A Review of Recent Multi-region Input-Output Models Used for Consumption-based Emission and Resource Accounting. Ecological Economics 69: 211-222.

World Bank. 2011. World Development Indictors, Geneva.

Wyckoff, A.W., and Roop, J.M. 1994. The Embodiment of Carbon in Imports of Manufactured Products: Implications for International Agreements on Greenhouse Gas Emissions. Energy Policy, 22 (3): 187-194.

Zhang, L.X., Wang, C.B., Yang, Z.F., and Chen, B. 2010. Carbon Emissions from Energy Combustion in Rural China. Procedia Environmental Sciences, 2: 980-989.

Appendix.

Carbon emission factors from different sources (TC/TCE)

Source / Fuel type	DOE/EIA	IEEJ	CAE	MEP	MST	ERI/NDRC	Average
Coal	0.702	0.756	0.680	0.748	0.726	0.7476	0.7266
Oil	0.478	0.586	0.540	0.583	0.583	0.5825	0.5588
Natural Gas	0.389	0.449	0.410	0.444	0.409	0.4435	0.42241

Source: Hu and Huang (2008); Zhang et al.(2010); Fang and Deng (2011). TC/TCE = ton of CO_2 per ton coal equivalent; TCE refers to the amount of energy released by burning one metric ton of coal. It is widely used in Chinese energy statistics. DOE/EIA: US Department of Energy/Energy Information Administration; IEEJ: Institute of Energy Economics, Japan; CAE: Chinese Academy of Engineering; MEP: Ministry of Environmental Protection of China; MST: Ministry of Science and Technology of China; ERI/NDRC: Energy Research Institute, National Development and Reform Commission of China.