Making 'dirty money' out of exports:
Estimating value-added and pollution exports in China

Wencheng ZHANG[1] Rui WEI[2]

[1] Nankai Institute of International Economics (NKIIE), Nankai University, Tianjin 300071, China;
[2] Academy of Mathematics and Systems Science (AMSS), Institute of Systems Science, Beijing 100190, China
E-mail: wenchengzhang86@163.com (Wencheng ZHANG); weirui870220@163.com (Rui WEI)

Abstract: As the world's largest exporting country, China is also one of the largest air pollutant emissions emitters in the world. Exports contribute both to income creation and environmental degradation in China. However, rare studies explore both of them in a consistent framework. In the present paper, we analyzed simultaneously the economic benefit and environmental burden of exports in China using a *global input-output model* based on World Input-Output Database (WIOD). We compare China's environmental burdens of exports with those of the other major economies in multiple aspects. Particularly, we analyze the environmental efficiency gaps between China and the other countries using *structural decomposition technique*. In this paper, the economic benefit is measured by the *value-added exports* which are income (wage and capital return) created in the export production, while the environmental burden is measured by the *emissions exports* of 8 types of air pollutants which are generated by China's export production.

The results show that value-added exports in China increased significantly during 1995-2009. The share of value-added exports in Chinese GDP increased from 16.8% to 32.3% in this period, indicating that exports are of great importance for the income creation in China. Meanwhile, remarkable emissions were generated by export production in China. Emissions exports of CO_2 and NO_X increased by 232% and 211%, respectively, during 1995-2009. For the other pollutants, emissions exports also increased by over 100%. Shares of emissions exports in total emissions from production of China also rose up greatly. In 2009, emissions exports accounted 22%~35% of total emissions from production in China.

By the comparison across countries, we find that China's share of value-added exports in the global value-added trade reached 10.4% in 2007 which was the second largest in the world. However, the global share of emissions exports of China was significantly greater than that of the other countries and much greater than the share of value-added exports for most types of pollutants. While the emission intensities of exports (PIE, ratio of emissions exports to value-added exports) in China were continuously declining for all pollutants in study period, they were still significantly greater than those of developed countries and of some developing countries.

We use structural decomposition technique to analyze the factors determining the PIE gaps between China and selected countries. Although there are some varieties in results for different air pollutants or different country pairs, the decomposition analysis shows that the gaps in PIE are mainly caused by the differences in emissions intensity, input structure and value-added ratio between China and selected economies. On the contrary, differences in export structures generally narrowed the gaps in PIE between China and selected economies. In other words, the relatively higher PIE of China mainly results from its dirtier technology reflected by the higher

direct emissions intensity of production and more emissions-intensive input structure, while relatively cleaner export structure of China generally reduces the gap in PIE between China and selected countries.

Keywords: Emission exports, value-added exports, emissions intensity of exports, multi-regional input-output analysis

1. Introduction

Exports in China have shifted to the fast lane since China's accession to the World Trade of Organization (WTO) in 2001 (Figure 1). China's export share in the global trade increased from 4% in 2000 to14% in 2009. China has been the largest exporter of commodities in the world since 2009. In fact, export has been a powerful engine of China's economic growth since China adopted the reform and opening-up policy in 1978(Chen and Feng, 2000;Yu, 1998). Lots of jobs are created in China by the export production particularly via transferring China's huge rural surplus labor to manufacturing sectors (Chen et al., 2012; Feenstra and Hong, 2010).

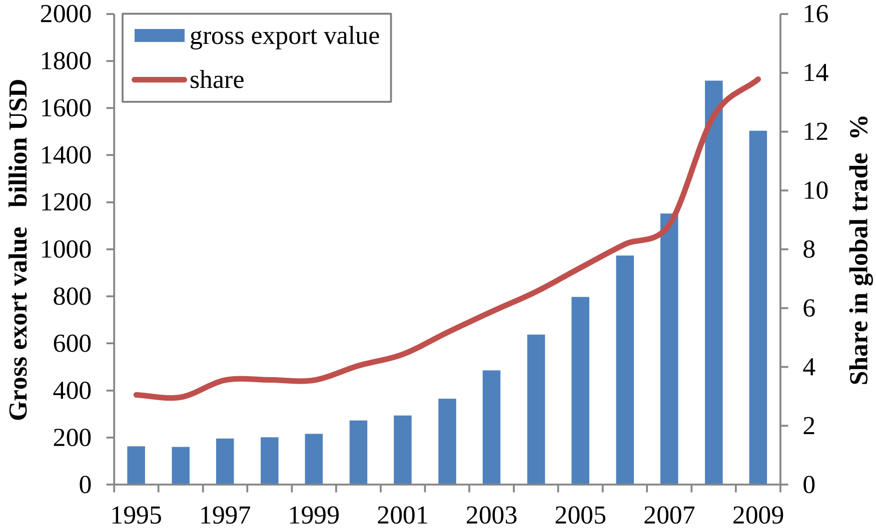

Figure 1. China's exports and its share in the global trade during 1995-2009.
Note: Export data was expressed in constant 2002 US dollars.
Source: WIOD

While exports create substantial economic benefits for China, it has been recognized that export production cause a great deal of energy consumption and air pollution (e.g., Arto et al., 2014; Davis and Caldeira, 2010; Dietzenbacher et al., 2012; Liu et al.,2010; Liu and Wang,2015; Peters et al., 2007; Su and Ang, 2014; Wang and Watson, 2008;Weber et al., 2008). As the largest exporter of goods, China is also the world's largest exporter of carbon emissions (Arto et al., 2014; Davis and Caldeira, 2010; Kagawa et al., 2015; Peters and Hertwich, 2008; Wiebe et al., 2012). Although both economic benefits and environmental cost are important for China's sustainable development, very few studies analyze exports of China from both economic and environmental perspectives. Arto et al.(2014), as an exception, analyzed both employments and greenhouse gas(GHG) emissions embodied in China's foreign trade based on a global input-output model.

Following the methodology in Arto et al.(2014), the present study analyzed economic benefits and environmental cost in a consistent framework. We used the value-added exports (VAE) instead of employment exports as the indicator for measuring economic benefit of exports, while we use 8 types of air pollutant emissions exports (EE) as indicators for measuring environmental cost of exports. The concept of VAE in this paper is the same as that in the literature on value-added trade (Daudin et al., 2011; Johnson and Noguera, 2012; Koopman et al., 2014). While labor inputs of different countries are different in quality, VAE in money value is arguably more comparable between countries. In addition, VAE include economic benefits from exports for workers and capital owners. While most of previous studies focus on GHG emissions, the air pollutants analyzed in this paper include 3 types of GHG emissions (CO_2, CH_4, and N_2O) and 5 types of non-GHG air pollutants (NO_X, SO_X, CO, NMVOC, and NH_3).

We carry out the analysis in three steps. First, we estimate VAE and EE for 8 types of air pollutants during 1995-2009 using a global input-output model. We compare the VAE and EE of China with the other major exporters. Second, we calculate the pollution intensity of exports (PIE) of China, that is, the emissions exports per unit of VAE. We analyze the changes of China's PIE and compare it with those of the other countries. Third, we analyze the gap between China's PIE and those of the other major exporters using structural decomposition analysis (SDA).

2. Methodology

2.1 Measurement of emissions and value-added from exports

Multi-Regional Input-Output (MRIO) analysis is a useful method to assess environmental impacts of trade and consumption (Wiedmann et al.,2007; Wiedmann, 2009). The basic identity of the MRIO model can be written as

$$\begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_m \end{pmatrix} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1m} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{m1} & \mathbf{A}_{m2} & \cdots & \mathbf{A}_{mm} \end{pmatrix} \begin{pmatrix} \mathbf{x}_1 \\ \mathbf{x}_2 \\ \vdots \\ \mathbf{x}_m \end{pmatrix} + \begin{pmatrix} \sum_i \mathbf{y}_{1i} \\ \sum_i \mathbf{y}_{2i} \\ \vdots \\ \sum_i \mathbf{y}_{mi} \end{pmatrix} \tag{1}$$

where $\mathbf{x}_r$ is output vector of region *r*, $\sum_i \mathbf{y}_{ri}$ is vector of total final products supplied by region *r* in which $\mathbf{y}_{rr}$ are final products used for domestic final demand and $\sum_{i\neq r} \mathbf{y}_{ri}$ are final products exported to the other regions for their final demands. $\mathbf{A}_{sr} = \mathbf{Z}_{sr}(\hat{\mathbf{x}}_r)^{-1}$ is coefficient matrix of inter-industry requirements for intermediate products. $\mathbf{Z}_{sr}$ is matrix of inter-industry deliveries of intermediates from region *s* to *r*. $\hat{\mathbf{x}}_r$ is diagonalization of vector $\mathbf{x}_r$ and $(\hat{\mathbf{x}}_r)^{-1}$ denotes the inverse $\hat{\mathbf{x}}_r$. Therefore, trade of final products between region *s* and *r* is modeled in MRIO model in vector $\mathbf{y}_{sr}$ and $\mathbf{y}_{rs}$ while trade of intermediates is modeled in matrix $\mathbf{A}_{sr}$ and $\mathbf{A}_{rs}$.

Key exogenous variable in input-output model is final demand. Using the MRIO model, gross output in region *r*, that is, $\mathbf{x}_r$, can be partitioned to *m* parts according to final demands they support. Suppose $\mathbf{x}_{rs}$ denotes output induced by final demand, $\mathbf{y}_{rs}$, then $\mathbf{x}_r = \sum_s \mathbf{x}_{rs}$. $\mathbf{x}_{rs}$ can be reproduced using the following operation

$$\begin{pmatrix} \mathbf{x}_{11} & \mathbf{x}_{12} & \cdots & \mathbf{x}_{1m} \\ \mathbf{x}_{21} & \mathbf{x}_{22} & \cdots & \mathbf{x}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{x}_{m1} & \mathbf{x}_{m1} & \cdots & \mathbf{x}_{mm} \end{pmatrix} = \begin{pmatrix} \mathbf{I}-\mathbf{A}_{11} & -\mathbf{A}_{12} & \cdots & -\mathbf{A}_{1m} \\ -\mathbf{A}_{21} & \mathbf{I}-\mathbf{A}_{22} & \cdots & -\mathbf{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ -\mathbf{A}_{m1} & -\mathbf{A}_{m2} & \cdots & \mathbf{I}-\mathbf{A}_{mm} \end{pmatrix}^{-1} \begin{pmatrix} \mathbf{y}_{11} & \mathbf{y}_{12} & \cdots & \mathbf{y}_{1m} \\ \mathbf{y}_{21} & \mathbf{y}_{22} & \cdots & \mathbf{y}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{y}_{m1} & \mathbf{y}_{m1} & \cdots & \mathbf{y}_{mm} \end{pmatrix} \tag{2}$$

Following previous studies using the MRIO model (e.g., Arto et al., 2014; Wiebe et al., 2012), ***emissions exports*** and ***emissions imports*** are defined as

$$EE_r = \mathbf{f}_r' \sum_{s\neq r} \mathbf{x}_{rs} \tag{3}$$

$$EI_r = \sum_{s\neq r} \mathbf{f}_s' \mathbf{x}_{sr} \tag{4}$$

where $\mathbf{f}_r$ is emissions intensity vector of region *r*. Its elements are emissions per unit of output in every sector. Total emissions exports of all economies equal total emissions imports. For the purpose in this paper, we focus on the EE.

MRIO model is also widely used in the literature on value-added trade (VAT) (e.g., Daudin et al., 2011; Johnson and Noguera, 2012; Koopman et al.,2014). We use the ***value-added exports (VAE)*** as proxy for the economic benefit from exports, which is constructed by the literature on VAT (e.g., Daudin et al., 2011; Johnson and Noguera, 2012). VAE is defined as domestic value-added induced by foreign final demand. Therefore, VAE and emission exports defined above are consistent in terms of system boundary. The VAE of country *r* can be calculated by

$$VAE_r = \mathbf{v}'_r \sum_{s \neq r} \mathbf{x}_{rs} \tag{5}$$

$\mathbf{v}_r$ is value-added ratio vector whose elements are the value-added per unit of gross output. To focus on the structural and technique effect, we further define ***pollution intensity of exports*** **(PIE)**, that is, the ratio of EE to VAE:

$$PIE_r = \frac{EE_r}{VAE_r} \tag{6}$$

PIE denotes the emissions generated to gain one unit of value-added from export, which can reflect the environmental efficiency of export production.

2.2 Decomposition of the difference of PIE across countries

We use structural decomposition method to compare more deeply the PIE of China and those of the other countries. First, we use a different expression of EE and VAE. For region *s*, $\mathbf{x}_{is}$ can be obtained by equation below

$$\begin{pmatrix} \mathbf{x}_{1s} \\ \mathbf{x}_{2s} \\ \vdots \\ \mathbf{x}_{ms} \end{pmatrix} = \begin{pmatrix} \mathbf{A}_{11} & \mathbf{A}_{12} & \cdots & \mathbf{A}_{1m} \\ \mathbf{A}_{21} & \mathbf{A}_{22} & \cdots & \mathbf{A}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}_{m1} & \mathbf{A}_{m2} & \cdots & \mathbf{A}_{mm} \end{pmatrix} \begin{pmatrix} \mathbf{x}_{1s} \\ \mathbf{x}_{2s} \\ \vdots \\ \mathbf{x}_{ms} \end{pmatrix} + \begin{pmatrix} \mathbf{y}_{1s} \\ \mathbf{y}_{2s} \\ \vdots \\ \mathbf{y}_{ms} \end{pmatrix} \tag{7}$$

Calculating $\mathbf{x}_{is}$ across rows in equation (7), output of region *r* induced by final demand of region *s* is

$$\mathbf{x}_{rs} = \mathbf{L}_{rr}(\sum_{i \neq r} \mathbf{A}_{ri}\mathbf{x}_{is} + \mathbf{y}_{rs}) = \mathbf{L}_{rr}\mathbf{e}_{rs} \tag{8}$$

where $\mathbf{L}_{rr} \equiv (\mathbf{I} - \mathbf{A}_{rr})^{-1}$, and $\mathbf{e}_{rs} \equiv \sum_{i \neq r} \mathbf{A}_{ri}\mathbf{x}_{is} + \mathbf{y}_{rs}$. Note that $\mathbf{e}_{rs}$ are exports of region *r* satisfying final demand of region *s*. The total exports of region *r* satisfying oversea final demands are $\mathbf{e}_r = \sum_{s \neq r} \mathbf{e}_{rs}$.[1] Therefore, EE and VAE of region *r* can be rewritten as

[1] Note $\mathbf{e}_r$ do not equal total exports of region *r* because they don't include the exported products which are re-imported after processing abroad to satisfy the final demand of region *r* itself.

$$EEE_r = \mathbf{f}'_r\mathbf{L}_{rr}\mathbf{e}_r \tag{9}$$

$$VAE_r = \mathbf{v}'_r\mathbf{L}_{rr}\mathbf{e}_r \tag{10}$$

PIE of region r is rewritten as

$$PIE_r = \frac{\mathbf{f}'_r\mathbf{L}_{rr}\mathbf{e}_r}{\mathbf{v}'_r\mathbf{L}_{rr}\mathbf{e}_r} = \frac{\mathbf{f}'_r\mathbf{L}_{rr}\mathbf{e}_r \,/\, (\mathbf{i}'\mathbf{e}_r)}{\mathbf{v}'_r\mathbf{L}_{rr}\mathbf{e}_r \,/\, (\mathbf{i}'\mathbf{e}_r)} = \frac{\mathbf{f}'_r\mathbf{L}_{rr}\mathbf{s}_r}{\mathbf{v}'_r\mathbf{L}_{rr}\mathbf{s}_r} \tag{11}$$

where $\mathbf{s}_r \equiv \mathbf{e}_r / (\mathbf{i}'\mathbf{e}_r)$, and $\mathbf{i}$ is column summation vector. $\mathbf{s}_r$ indicates the product structure of exports of region r.

To compare PIE in different regions, define ratio R_{kh}, $R_{kh} \equiv PIE_k / PIE_h$. Given the benefit of exports, the larger ratio R_{kh}, the higher environmental cost paid (or lower environmental efficiency) in region k compared to region h.

R_{kh} can be decomposed into four components

$$R_{kh} = \underbrace{\frac{\mathbf{f}'_k\mathbf{L}_{kk}\mathbf{s}_k / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_k}{\mathbf{f}'_h\mathbf{L}'_{kk}\mathbf{s}_k / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_k}}_{R_f} \times \underbrace{\frac{\mathbf{f}'_h\mathbf{L}'_{kk}\mathbf{s}_k / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_k}{\mathbf{f}'_h\mathbf{L}'_{kk}\mathbf{s}_k / \mathbf{v}'_h\mathbf{L}_{kk}\mathbf{s}_k}}_{R_v} \times \underbrace{\frac{\mathbf{f}'_h\mathbf{L}'_{kk}\mathbf{s}_k / \mathbf{v}'_h\mathbf{L}_{kk}\mathbf{s}_k}{\mathbf{f}'_h\mathbf{L}'_{hh}\mathbf{s}_k / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_k}}_{R_L} \times \underbrace{\frac{\mathbf{f}'_h\mathbf{L}'_{hh}\mathbf{s}_k / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_k}{\mathbf{f}'_h\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_h}}_{R_s} \tag{12}$$

Components R_f, R_v, R_L and R_s can be used to analyze respective contribution of differences in emissions intensity, value-added ratio, input structure and export structure to the gap between PIE of region k and that of region h. However, equation (12) is one polar form of decomposition, the other polar form of decomposition is

$$R_{kh} = \underbrace{\frac{\mathbf{f}'_k\mathbf{L}_{kk}\mathbf{s}_k / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_k}{\mathbf{f}'_k\mathbf{L}'_{kk}\mathbf{s}_h / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_h}}_{\hat{R}_s} \times \underbrace{\frac{\mathbf{f}'_k\mathbf{L}'_{kk}\mathbf{s}_h / \mathbf{v}'_k\mathbf{L}_{kk}\mathbf{s}_h}{\mathbf{f}'_k\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_k\mathbf{L}_{hh}\mathbf{s}_h}}_{\hat{R}_L} \times \underbrace{\frac{\mathbf{f}'_k\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_k\mathbf{L}_{hh}\mathbf{s}_h}{\mathbf{f}'_k\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_h}}_{\hat{R}_v} \times \underbrace{\frac{\mathbf{f}'_k\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_h}{\mathbf{f}'_h\mathbf{L}'_{hh}\mathbf{s}_h / \mathbf{v}'_h\mathbf{L}_{hh}\mathbf{s}_h}}_{\hat{R}_f} \tag{13}$$

Geometric average of the two polar forms of decomposition above is used as the approximation of each component (Xu and Dietzenbacher, 2014):

$$R_{kh} = \bar{R}_f\bar{R}_v\bar{R}_L\bar{R}_s = \sqrt{R_f\hat{R}_f} \times \sqrt{R_v\hat{R}_v} \times \sqrt{R_L\hat{R}_L} \times \sqrt{R_s\hat{R}_s} \tag{14}$$

To change product to summation, take the logarithm on two sides

$$G \equiv \ln R_{kh} = \ln ECI_k - \ln ECI_h = \ln\bar{R}_f + \ln\bar{R}_v + \ln\bar{R}_L + \ln\bar{R}_s \tag{15}$$

Equation (15) is used to analyze factors that determine the discrepancy in PIE between China and the other countries. For example, the contribution from differences in direct emissions intensity to the discrepancy in PIE between region k and h is $\varphi(\Delta f) = 100 \times (\ln\bar{R}_f)/G$.

3. Data

Both the input-output data and emissions data used in this paper are from World Input-Output Database (WIOD). [2] Comprehensive introduction of WIOD on its contents, data sources and construction methods can be found in Dietzenbacher et al.(2013) and Timmer et al.(2015). WIOD offers World Input-Output Table (WIOT) series for the years 1995-2009. The WIOT covers 1435 sectors and 41 countries and regions. Emissions accounts of the WIOT include 8 types of air pollutant emissions in each sector. To compare value-added and emissions intensities in different years, we need to express the value-added in constant prices. Therefore, WIOTs in current prices are converted to 2002 (the middle year of the study period) constant price using double deflation method. Gross value-added in each sector is obtained by subtracting total intermediate input from the gross output in constant prices.

4. Main results

4.1 Value-added and emissions exports of China

As is shown in the Table 1, value-added exports (VAE) of China increased remarkably from 140.1 billion US dollars in 1995 to 1054.8 billion dollars in 2009. The share of VAE in Chinese GDP also rose from 16.8% to 32.3% in this period, indicating that export production is of great importance for the income creation in China. However, there were also tremendous emissions generated by export production in China. For all 8 types of pollutants, emissions exports of China increased by over 100% during 1995-2009.Emissions exports of CO_2 and NO_X increased particularly by 232% and 211%, respectively. The steep rising of emissions exports began in the year 2001 when China joined the WTO. Shares of emissions exports in total emissions from production of China also rose up greatly. For example, the share of emissions exports of CO_2 in total emissions increased from 21.8% in 1995 to 31.7% in 2009. For the other pollutants, the shares of emissions exports also rose up by 5 to 9 percentage points. In 2009, emissions exports accounted 22%~35% of total emissions from production in China. For CO_2, CO, and NMVOC, the shares of emissions exports were over or close to the share of VAE in GDP of China. Therefore, China has

[2] The database can be accessed free of charge at http://www.wiod.org/new_site/data.htm

borne significant environmental loads for gaining the economic benefits from exports.

Table 1. Value-added and emissions exports of China during 1995-2009

	Value-added	CO_2	CH_4	N_2O	NO_X	SO_X	CO	NMVOC	NH_3
	billion US Dollar	Mt	10^4 tonnes	10^4 tonnes	10^4 tonnes	10^4 tonnes	10^4 tonnes	10^4 tonnes	10^4 tonnes
1995	140.1	593.2	778.1	21.8	185.5	475.4	924.7	247.6	71.7
	(16.8)	(21.8)	(18.7)	(14.2)	(20.8)	(21.7)	(25.8)	(24.7)	(13.2)
1997	169.4	577.1	714.3	18.9	185.0	433.7	869.9	246.9	59.9
	(16.9)	(20.9)	(17.2)	(12.5)	(19.6)	(20.7)	(23.0)	(21.9)	(11.2)
1999	184.4	538.6	618.3	17.9	180.3	372.2	1421.3	290.6	55.0
	(16.2)	(19.1)	(14.9)	(11.1)	(17.9)	(18.9)	(23.5)	(21.4)	(9.7)
2001	240.7	592.2	708.9	18.7	190.9	382.0	789.6	240.0	56.4
	(18.0)	(20.8)	(17.1)	(11.7)	(19.7)	(20.2)	(23.1)	(20.9)	(10.0)
2003	378.7	909.8	998.6	26.3	293.5	569.2	1086.4	332.9	81.1
	(23.0)	(25.5)	(21.8)	(15.3)	(24.4)	(25.1)	(28.6)	(25.9)	(13.4)
2005	590.7	1402.6	1362.8	36.1	377.8	705.0	2511.1	646.5	116.2
	(27.9)	(29.9)	(25.5)	(19.6)	(23.5)	(23.8)	(40.5)	(36.8)	(17.7)
2007	837.9	1758.0	1556.6	42.7	464.6	859.4	2789.2	559.3	140.5
	(30.0)	(31.8)	(26.6)	(21.8)	(25.0)	(24.9)	(43.2)	(31.6)	(20.1)
2009	1054.8	1971.2	1796.3	49.6	577.5	1119.9	2013.1	579.2	166.1
	(32.3)	(31.7)	(27.4)	(23.5)	(28.0)	(27.2)	(34.5)	(30.9)	(22.0)

Note: Value-added is in price of 2002. Values in the brackets are share of value-added exports in GDP or emissions exports in the total emissions from production.

The environmental burdens of exports in China look more noteworthy when they are compared with those of the other countries. Table 2 shows that the share of emissions exports of China in the global emissions trade (total emission exports of all countries) was significantly greater than the other big exporters of goods, such as the US, Germany, Japan, etc. For instance, share of CO_2 emissions exports of China reached 24.7% in 2007, while the shares of the US and Germany was only 6.9% and 4%, respectively. Similar results can be observed for the other pollutants, particularly SO_X. Meanwhile, the VAE share of China in the global value-added trade was 10.4%, which was 3 percentage points lower than that of the US (13.4%) and only 2 percentage points higher than that of Germany. Table 2 suggests that China paid significantly greater environmental cost than the developed countries given the same economic benefit it obtained.

Except for CO and NMVOC, Figure 2 further shows that China's shares of emissions exports were much higher than the share of VAE in every year during 1995-2007. Before 2000, China's share of VAE increased slightly while the shares of emission exports for all pollutants decreased. However, a 'dirty' growth path of exports in China can be observed during the period 2000-2009, in which both shares of VAE and emission exports increased quickly.

Table 2. Shares of value-added and emissions exports in 41 economies in 2007 (%)

	Value-added	CO_2	CH_4	N_2O	NO_X	SO_X	CO	NMVOC	NH_3
US	13.4	6.9	5.4	6.4	7.0	5.5	4.9	2.8	5.6
China	10.4	24.7	21.7	15.7	16.2	32.1	13.9	10.9	19.5
Germany	8.4	4.0	0.9	2.7	2.0	0.8	0.6	1.4	2.8
Japan	7.9	3.8	0.1	0.3	4.6	2.3	0.6	1.0	0.2
UK	4.6	2.0	0.6	1.0	2.5	1.6	0.2	0.6	0.7
France	4.1	1.3	1.0	2.6	1.1	0.6	0.6	0.5	3.3
Italy	3.0	1.7	0.5	0.9	1.2	0.6	0.2	0.4	1.3
Canada	2.8	2.6	3.1	2.4	2.0	3.0	0.7	1.0	2.5
Taiwan	2.7	2.4	0.1	0.2	2.3	2.9	1.2	0.7	0.1
Korea	2.5	2.7	0.2	0.3	1.8	1.2	1.2	3.0	0.1
Mexico	2.1	1.0	0.6	0.8	1.1	0.9	0.7	0.9	0.9
Netherlands	1.9	1.3	0.7	1.5	1.1	0.5	0.1	0.1	1.5
Spain	1.6	1.2	0.6	0.8	1.2	1.1	0.2	1.1	1.8
India	1.5	3.3	5.0	3.7	2.7	3.6	2.2	3.2	4.1
Russia	1.3	7.6	14.3	1.3	5.1	0.5	3.3	3.1	0.7
Belgium	1.2	0.9	0.3	0.7	0.5	0.3	0.2	0.1	0.7
Sweden	1.2	0.4	0.1	0.3	0.7	0.3	0.0	0.1	0.3
Ireland	1.0	0.2	0.4	0.5	0.1	0.1	0.0	0.0	0.8
Austria	1.0	0.4	0.1	0.2	0.2	0.0	0.1	0.1	0.3
Poland	1.0	1.4	0.8	1.2	1.0	1.1	0.2	0.3	1.0
Australia	0.8	1.3	2.8	0.9	2.6	2.3	4.6	1.4	2.1
Brazil	0.8	0.8	6.0	7.3	2.3	1.6	1.9	2.0	6.9
Indonesia	0.7	1.4	2.2	1.8	1.2	1.5	1.5	1.8	1.8
Denmark	0.6	1.0	0.2	0.6	4.8	1.8	0.1	0.1	0.6
Turkey	0.6	0.7	0.2	0.2	0.6	0.6	0.2	0.5	0.8
Finland	0.6	0.4	0.1	0.3	0.4	0.2	0.0	0.1	0.2
Czech	0.5	0.7	0.3	0.4	0.4	0.3	0.1	0.1	0.3
Hungary	0.4	0.3	0.2	0.5	0.3	0.1	0.1	0.2	0.4
Portugal	0.3	0.3	0.2	0.2	0.3	0.3	0.0	0.2	0.2
Slovak Rep.	0.3	0.3	0.1	0.3	0.2	0.1	0.1	0.1	0.1
Greece	0.2	0.1	0.1	0.1	0.1	0.3	0.0	0.0	0.1
Romania	0.1	0.4	0.4	0.3	0.3	0.7	0.1	0.1	0.3
Slovenia	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Luxembourg	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Bulgaria	0.1	0.4	0.2	0.2	0.3	1.6	0.1	0.1	0.2
Lithuania	0.1	0.1	0.1	0.4	0.1	0.1	0.0	0.0	0.2

Estonia	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1
Latvia	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RoW	20.1	21.9	30.5	42.7	31.7	29.7	59.9	62.1	37.2

Note: The share of an economy is the percentage of its value-added (emissions) exports in the global value-added (emissions) trade.

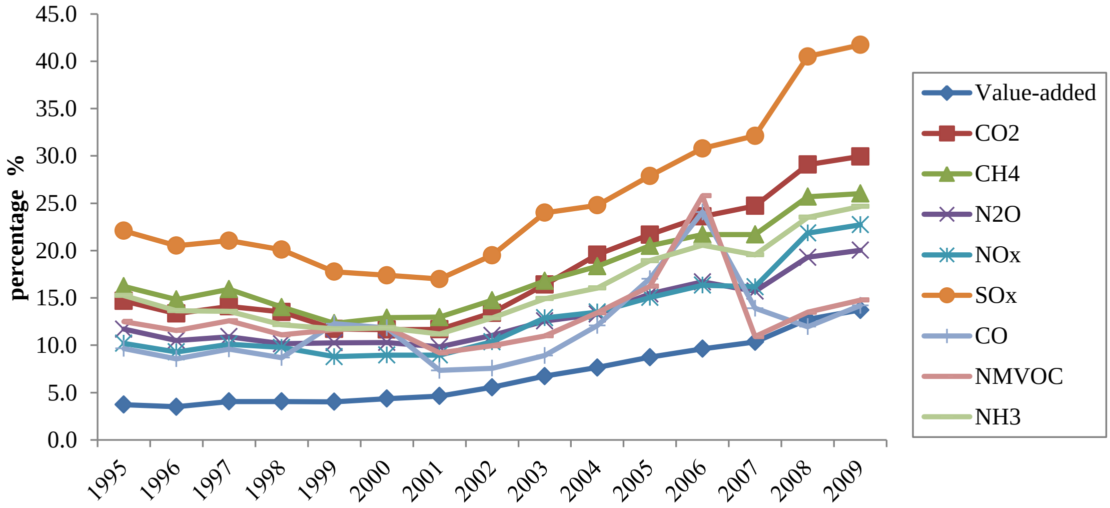

Figure 2. China's shares of value-added and emissions exports during 1995-2009

Note: The shares are the percentages of China's value-added (emissions) exports in the global value-added (emissions) trade.

4.2 China's pollution intensities of exports

Although both the absolute volume of emissions exports and their shares in total emissions from production increased significantly in the study period, there is good news too. In reality, we see that environmental efficiency of export productions is improving continuously in China when we isolating the effect of export scale. As is exhibited in Figure 3, **pollution intensity of exports (PIE)** in China for most pollutants decreased significantly and steadily during 1995-2009.[3] For example, PIE of CO_2, SO_X, and CO decreased 55.9%, 68.7%, and 71.1%, respectively. Therefore, given the benefit from value-added creation, environmental cost paid by China in 2009 are significantly lower than that in 15 year ago.

While significant decrease of PIE had been achieved in China during 1995-2009, China's PIE

[3] Some high peaks of PIE for CO and NMVOC have appeared in some year (1999, 2000, 2006). They are likely caused by outliers in pollution data.

for all types of air pollutants is still much higher compared with the PIE of most countries, particularly the developed countries. Figure 4 shows PIE of CO_2 in China in 2007 is significantly higher than all the other economies except Russia, Bulgaria and Romania. PIE of CO_2 in China is 209.8 kg per hundred US dollars, which is six times higher than that in France, and four times higher than that in Japan. PIE of the other pollutions in China is also greatly higher than those in Korea and G7 countries (Table 3). Therefore, the room for improving environmental efficiency of exports in China is still very large.

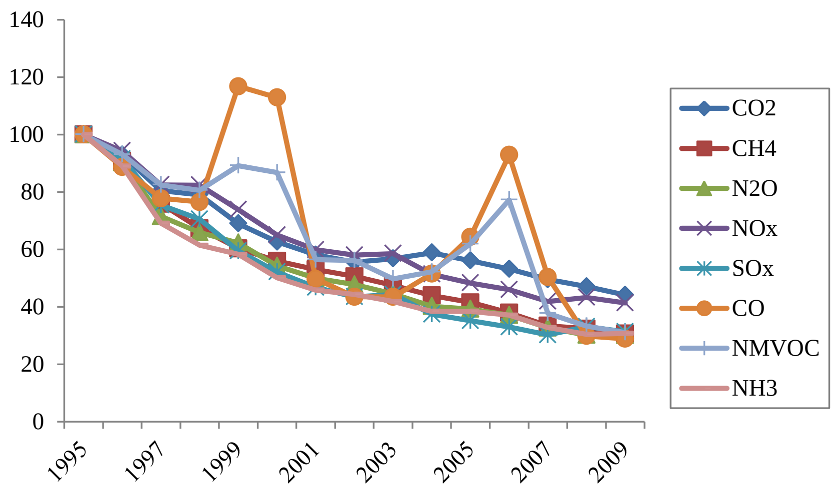

Figure 3. Changes of pollution intensities of export in China during 1995-2009.
Note: Pollution intensities of export in 1995 are standardized to 100.

Figure 4. Pollution intensities of exports in 41 economies (for CO_2 in the year 2007)

Table 3. Ratios of the PIE of China to those of selected economies (for the other pollutants in the year 2007)

	CH_4	N_2O	NO_X	SO_X	CO	NMVOC	NH_3
Russia	0.2	1.4	0.4	7.4	0.5	0.4	3.6
India	0.6	0.6	0.9	1.3	0.9	0.5	0.7
Taiwan	72.9	24.4	1.8	2.9	3.0	4.2	69.3
Korea	25.5	12.9	2.2	6.8	2.8	0.9	33.9
US	5.2	3.2	3.0	7.5	3.7	5.1	4.5
Japan	164.3	35.8	2.7	10.6	17.3	8.6	98.4
Canada	1.9	1.7	2.2	2.8	5.2	2.9	2.1
Germany	18.8	4.7	6.6	31.0	19.2	6.4	5.7
UK	15.7	7.0	2.9	9.1	24.8	8.6	12.5
France	8.9	2.4	5.6	22.0	9.1	8.9	2.4

Note: PIE stands for pollution intensity of exports. Ratios in table 2 are results of China's PIE divided by PIE in the other economy.

4.3 Decomposition of gaps in pollution intensities of exports across countries

According to equation (11), PIE is determined by four factors: direct emissions intensity, value-added ratio, input structure and export structure. In this subsection, we analyze how the discrepancies in the four factors contribute to the gaps in environmental efficiency of exports between China and the other economies by decomposing the PIE ratio, R_{kl}, based on equation (15).

Table 4 shows PIE of CO_2 in China was significantly higher than selected economies (G7+ Korea, Mexico, and Brazil). Decomposition shows the gap in PIE is mainly caused by the varieties in emissions intensity, input structure and value-added ratio between China and selected economies. However, differences in export structures narrowed the gaps in PIE between China and selected economies except the US. For example, PIE of China is four times higher than the PIE of Japan. The difference in emissions intensity between China and Japan contribute 63.5 % to the gap in PIE of two countries, while the difference in input structure contributes 27.4% to the gap. In addition, the difference in value-added ratios between two countries contributes 16.9% to the PIE gap. On the contrary, the difference in export structure between China and Japan contribute -7.2% to the gap, that is, narrow the gap in PIE. In a word, Table 4 indicates that the dirtier production technology (higher emission intensity and dirtier input structure) in China compared with selected economies is the major cause of higher PIE of China, whereas the cleaner export structure of China narrows the PIE gaps.

Contributions from four factors to the PIE gap are different for different country pair. For example, higher direct emissions intensity in China is the most important factor to explain the gaps in PIE between China and Germany (or Japan/UK/France/Italy). However, more emissions intensive input structure in China is the most important factor to explain the gap in PIE between China and the US (or Canada/Korea). In addition, export structure in China is also more emissions intensive than that of US due to the high share of service exports in the latter, contributing to the gap in PIE between them. Similarly, the difference in export structure between China and Mexico also contribute positively to the gap in PIE between the two countries.

Figure 5 shows decomposition of gaps in PIE between China and four major exporters for the other air pollutants. The Major conclusion from the results of Figure 5 is similar to that from Table 4, that is, the higher PIE of China compared with the other countries mainly results from dirtier technology, while relatively cleaner export structure of China generally narrows these gaps. However, for some air pollutants, the difference in export structure also contributes positively to the gaps in PIE between China and the US (or Japan).

Table 4. Factors determining the gaps in PIE between China and 10 selected economies (for CO_2 in the year 2007)

		Contribution from the difference of (%)			
	PIE gap (R_{kh},k=China)	direct emission intensity	value-added ratio	input structure	export structure
US	4.6	22.6	21.9	50.9	4.6
Germany	5.0	57.5	16.9	42.1	-16.5
Japan	5.0	63.5	16.3	27.4	-7.2
UK	5.5	48.0	18.5	35.6	-2.1
France	7.3	68.2	10.4	31.0	-9.6
Italy	4.2	73.2	3.9	33.4	-10.6
Canada	2.6	37.7	34.9	59.9	-32.6
Korea	2.3	38.9	15.4	56.6	-10.9
Mexico	4.7	33.6	23.8	37.4	5.3
Brazil	2.4	69.8	17.4	30.6	-17.8

Note: PIE stands for pollution intensity of exports. PIE gap equals the PIE of China divided by the PIE of the other economy.

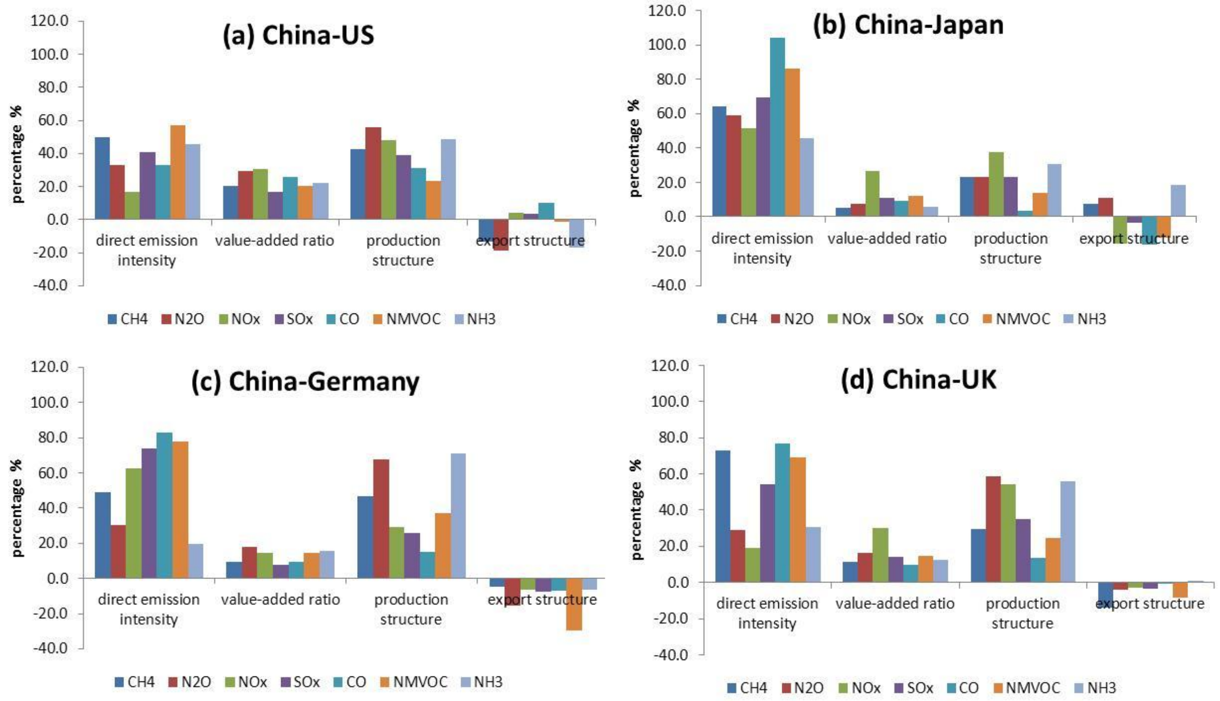

Figure 5. Factors determining the gaps in PIE between China and 4 major economies (for the other pollutants in the year 2007)

Note: PIE stands for pollution intensity of exports.

5. Conclusion

As the world's largest exporting country, China is also one of the largest air pollutant emissions emitters in the world. Exports contribute both to income creation and environmental degradation in China. In the present paper, we analyzed simultaneously the economic benefit and environmental burden of exports in China using a global input-output model. The economic benefit is measured by the value-added exports which are income (wage and capital return) created in the export production, while the environmental burden is measured by the emission exports of 8 types of air pollutant emissions which are pollution generated by China's export production.

The results show that value-added exports in China increased significantly during 1995-2009. The share of value-added exports in Chinese GDP also increased from 16.8% to 32.3% in this period, indicating that exports are of great importance for the income creation in China. Meanwhile, remarkable emissions were generated by export production in China. Emissions exports of CO_2 and NO_X increased by 232% and 211%, respectively, during 1995-2009. For the other pollutants, emissions exports also increased by over 100%. Sharp increase is observed after China joined the

WTO in 2001. Shares of emissions exports in total emissions from production of China also rose up greatly. In 2009, emissions exports accounted 22%~35% of total emissions from production in China.

We have compared China's environmental burdens of exports with those of the other major economies in multiple aspects. We find that China's share of value-added exports in the global value-added trade reached 10.4% in 2007 which was the second largest in the world. However, the global share of emissions exports of China was significantly greater than that of the other countries and much greater than the share of value-added exports for most types of pollutants. While the emission intensities of exports (PIE, the ratio of emissions exports to value-added exports) in China were continuously declining for all pollutants in study period, they were still significantly greater than those of developed countries and of some developing countries. We use structural decomposition technique to analyze the factors determining the PIE gaps between China and selected countries. Although there are some varieties in results for different air pollutants or different country pairs, the decomposition analysis shows that the gaps in PIE are mainly caused by the differences in emissions intensity, input structure and value-added ratio between China and selected economies. On the contrary, differences in export structures generally narrowed the gaps in PIE between China and selected economies. In other words, the relatively higher PIE of China mainly results from its dirtier technology reflected by the higher direct emissions intensity of production and more emissions-intensive input structure, while relatively cleaner export structure of China generally reduces the gap in PIE between China and selected countries.

It's of great importance for China to properly balance the economic benefits and environmental costs of exports to realize sustainable development of trade and the whole economy. The social cost of environmental degradation has been overlooked or underestimated in China for a long time in process of pursuing the economic growth, which naturally helps the boom of exports in China. In recent years, as the public pays increasing attention to environmental issues, also because of climbing pressure of carbon mitigation faced by Chinese government, exports of energy-intensive, pollution-intensive and resource-intensive products (such as steel, non-ferrous metal, cement, etc.) are more strictly constrained by the Chinese government. However, the present study shows that China's exports are actually cleaner in product structure than many countries. The more prominent factor to blame is the relatively dirtier production technology in China, including high direct emissions intensity and emission-intensive input structure.

Therefore, the most effectively measure for reducing environmental cost of exports is adopting cleaner technology in production. Since the gaps in PIE between China and developed countries are still very large, there is great room for China to improve its technology of production by stimulating innovation of domestic firms and by directly importing cleaner technology and equipment from developed countries. Facilitating and promoting international cooperation in reducing GHG emissions, like Clean Development Mechanism (CDM), can also reduce the other energy-related emissions, such as SO_X, NO_X, etc. In addition, coal-dominated energy structure is one of the major causes for the high direct emission intensity for CO_2, SO_X and NO_X because emission factors of coal are much greater than the other energy (Peters et al., 2006). There is still half of energy consumption in China coming from coal.[4] Therefore, it's significant for China to reduce emissions exports by increasing the share of clean energy in the energy mix in the long run. Another solution frequently recommended for decoupling economic benefits from environmental damage is to shift from exports of goods with low value-added ratio to the exports of goods with high value-added ratio like high-tech products and services, since goods with high value-added ratio is also generally cleaner. Unfortunately, while it may be obvious to know the right destination for such win-win path, it's by no means easy to figure out the right direction.

References

Arto, I., Rueda-Cantuche, J. M., Andreoni, V., Mongelli, I., Genty, A., 2014. The game of trading jobs for emissions. Energy policy 66, 517-525.

Chen, X., Cheng, L. K., Fung, K. C., Lau, L. J., Sung, Y. W., Zhu, K., Yang, C., Pei, J., Duan, Y., 2012. Domestic value added and employment generated by Chinese exports: A quantitative estimation. China Economic Review 23(4), 850-864.

Chen, B., Feng, Y., 2000. Determinants of economic growth in China: Private enterprise, education, and openness. China Economic Review 11(1), 1-15.

Daudin, G., Rifflart, C., Schweisguth, D., 2011. Who produces for whom in the world economy? Canadian Journal of Economics 44(4), 1403-1437.

[4] Calculation based on the WIOD.

Davis, S. J., Caldeira, K., 2010. Consumption-based accounting of CO_2 emissions. Proceedings of the National Academy of Sciences of the United States of America 107(12), 5687-5692.

Dietzenbacher, E., Los, B., Stehrer, R., Timmer, M., De Vries, G., 2013. The construction of world input–output tables in the WIOD project. Economic Systems Research 25(1), 71-98.

Dietzenbacher, E., Pei, J., Yang, C., 2012. Trade, production fragmentation, and China's carbon dioxide emissions. Journal of Environmental Economics and Management 64(1), 88-101.

Feenstra, R.C., Hong, C., 2010. China’s exports and employment. In Chin's Growing Role in World Trade, Robert C. Feenstra and Shang-Jin Wei, ed., 167 -199. Chicago: University of Chicago Press.

Johnson, R. C., Noguera, G., 2012. Accounting for intermediates: Production sharing and trade in value added. Journal of International Economics 86(2), 224-236.

Kagawa, S., Suh, S., Hubacek, K., Wiedmann, T., Nansai, K., Minx, J., 2015. CO_2 emission clusters within global supply chain networks: Implications for climate change mitigation. Global Environmental Change 35, 486-496.

Koopman, R., Wang, Z., Wei, S. J., 2014. Tracing Value-Added and Double Counting in Gross Exports. The American Economic Review 104(2), 459-494.

Liu, Q., Wang, Q., 2015. Reexamine SO_2 emissions embodied in China's exports using multiregional input–output analysis. Ecological Economics 113, 39-50.

Liu, H., Xi, Y., Guo, J. E., Li, X., 2010. Energy embodied in the international trade of China: an energy input–output analysis. Energy Policy 38(8), 3957-3964.

Peters, G. P., Hertwich, E. G., 2008, CO_2 embodied in international trade with implications for global climate policy, Environmental Science & Technology 42 (5), 1401-1407.

Peters, G. P., Weber, C. L., Guan, D., Hubacek, K., 2007. China's growing CO_2 emissions a race between increasing consumption and efficiency gains. Environmental Science & Technology, 41(17), 5939-5944.

Peters, G.P., Weber, C., Liu, J., 2006. Construction of Chinese energy and emissions inventory. IndEcol Report 4/2006, Norwegian University of Science and Technology, Trondheim.

Su, B., Ang, B. W., 2014. Input–output analysis of CO_2 emissions embodied in trade: a multi-region model for China. Applied Energy 114, 377-384.

Timmer, M.P., Dietzenbacher, E., Los, B., Stehrer, R., de Vries, G.J., 2015. An illustrated user guide to the World Input–Output Database: the case of global automotive production. Review of International Economics 23(3), 575-605.

Wang, T., Watson, J., 2008. China's carbon emissions and international trade: implications for post-2012 policy. Climate policy 8(6), 577-587.

Weber, C. L., Peters, G. ., Guan, D., Hubacek, K., 2008. The contribution of Chinese exports to climate change. Energy Policy 36(9), 3572-3577.

Wiebe, K. S., Bruckner, M., Giljum, S., Lutz, C., 2012. Calculating energy-related CO_2 emissions embodied in international trade using a global input–output model. Economic Systems Research 24(2), 113-139.

Wiedmann, T., Lenzen, M., Turner, K., Barrett, J., 2007. Examining the global environmental impact of regional consumption activities—Part 2: Review of input–output models for the assessment of environmental impacts embodied in trade. Ecological Economics 61(1), 15-26.

Wiedmann, T., 2009. A review of recent multi-region input–output models used for consumption-based emission and resource accounting. Ecological Economics 69(2), 211-222.

Xu, Y., Dietzenbacher, E., 2014. A structural decomposition analysis of the emissions embodied in trade. Ecological Economics 101, 10-20.

Yu, Q., 1998. Capital investment, international trade and economic growth in China: Evidence in the 1980–1990s. China Economic Review 9(1), 73-84.