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Input–output analysis of CO_2 emissions embodied in trade and the driving forces: Processing and normal exports

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ABSTRACT

In recent years, energy-related CO_2 emissions embodied in international trade and the driving forces have been widely studied by researchers using the environmental input–output framework. Most previous studies however, do not differentiate different input structures in manufacturing processing exports and normal exports. Using China as an example, this paper exemplifies how implications of results obtained using different export assumptions differ. The study posits that the utilization of traditional I–O model results in an overestimation of emissions embodied in processing exports and an underestimation in normal exports. The estimate of CO_2 emissions embodied in China's exports drops by 32% when the extended I–O model is used. The choice of export assumption has more impact on the decomposition results for processing exports. The study further highlights that for a country with an export structure similar to China, it is meaningful to look into the impact of export assumption in embodied emission studies.

1. Introduction

The measurements of CO_2 emissions embodied in international trade and its resulting “consumption-based” emissions (or carbon footprint) have lately been an active research area, particularly using an environmental input–output (I–O) framework (Wiedmann, 2009; Wiedmann et al., 2007).[1] Total CO_2 emissions embodied in world international trade and their percentages of each country's domestic CO_2 emissions generally increased in the last two decades (Peters et al., 2011). The direct and indirect trade balances of emissions have been used in revealing a country's benefit or loss to domestic environment from bilateral trade with other countries (Su and Ang, 2011).[2]

China, the world's largest CO_2 emitter, has attracted much attention in recent years, especially due to the country's rapid economic growth and significant increase in its external trade volumes since the early 2000s. Many empirical studies on China's CO_2 emissions embodied in international trade have been reported in the literature, such as Pan et al. (2008), Weber et al. (2008), Su et al. (2010), Chen and Zhang (2010), Lin and Sun (2010), Su and Ang (2010, 2011) and Guo et al. (2012). Some studies analyze the direct trade balance of emissions from China's bilateral trade with other countries, such as the China–US (Du et al., 2011; Guo et al., 2010; Shui and Harriss, 2006; Xu et al., 2009), China–UK (Li and Hewitt, 2008), China–Japan (Liu et al., 2010) and China–Asian economies (Su and Ang, 2011). Other studies further utilize decomposition techniques, such as the index decomposition analysis (IDA) and structural decomposition analysis (SDA), to derive the driving forces behind historical changes of embodied emissions. These include Dong et al. (2010), Yan and Yang (2010), Minx et al. (2011) and Xu et al. (2011).[3]

For emission studies, both single-region I–O (SRIO) and multi-region I–O (MRIO) models are used by researchers (Miller and Blair, 2009; Wiedmann, 2009; Wiedmann et al., 2007). In measuring a country's

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[1] The environmental I–O framework is developed by Leontief (1970). The methodological developments in the embodied emission studies can be found in Lenzen et al. (2004), Peters (2008) and Su and Ang (2010, 2011).

[2] The trade balance of embodied emissions can be used as a measure to explain the “weak carbon leakage” between non-Annex B and Annex B countries through international trade (Peters and Hertwich, 2008).

[3] Many SDA studies focusing on the changes of China's total energy use and emissions have been reported in the literature. See, for example, Peters et al. (2007), Guan et al. (2008) and Su and Ang (2012b). Comprehensive review of previous SDA studies applied to energy and emissions can be found in Su and Ang (2012a).

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emissions embodied in its exports and studying the underlying driving forces, the SRIO model is usually adopted. The results obtained in previous empirical studies on China vary as a result of different data aggregation and model assumptions, e.g. the influences from sector aggregation (Su et al., 2010), spatial aggregation (Su and Ang, 2010), temporal aggregation (Su and Ang, 2012b), and imports assumption (Su and Ang, 2013). Apart from these issues, a noteworthy characteristic of single country I–O model is export assumption, i.e. how to deal with the input structures of processing and normal exports. In our study, processing exports refer to the exports of the end products of assembling/processing imported intermediate inputs exempted from Chinese tariff which will be eventually sold overseas. For example, the Apple iPhone is assembled in China with domestic inputs as well as components imported from Singapore, Taiwan, South Korea and the United States, and the final products are exported to overseas markets. Normal exports (or non-processing exports) are ordinary exports to be distinguished from processing exports. Two export assumptions available are uniform exports and non-uniform exports. Uniform exports assume the same input structures for processing and normal exports, while non-uniform exports differentiate their input structures.

The traditional I–O model uses the uniform export assumption for processing and normal exports. However, according to their definitions, the intermediate inputs for processing exports are mainly from international imports, while those for normal exports are mainly from domestic supply. Therefore the input structures in manufacturing processing exports and normal exports are quite different, rendering the total emission intensities (or emission multipliers) of these two types of exports to calculate their embodied emissions to be different. For China, processing export account for close to half of its total exports, as can be seen from the historical trend in Fig. 1. Some form of processing exports can also be found in more than 130 countries in the world (WTO and IDE-JETRO, 2011).

Most previous embodied emission studies and SDA studies on China use only the traditional I–O model or uniform export assumptions. Two exceptions are Su and Ang (2010) and Dietzenbacher et al. (2012). Su and Ang (2010) investigate the effects of spatial aggregation on the estimates of emissions embodied in exports by disaggregating China spatially into several regions. Dietzenbacher et al. (2012) is the first study to look into the impacts of separating processing exports from exports on China's embodied emissions. They compare their aggregate results for 2002 with those reported in Weber et al. (2008). The study also uses fairly aggregate data, i.e. only 28 sectors, although sector disaggregation or the application of "Data Treatment Scheme 2" to give more disaggregate data is advocated in some recent studies (Lenzen, 2011; Su et al., 2010). Besides, the comparison between spatial disaggregation and exports treatment in embodied emissions has not been discussed in

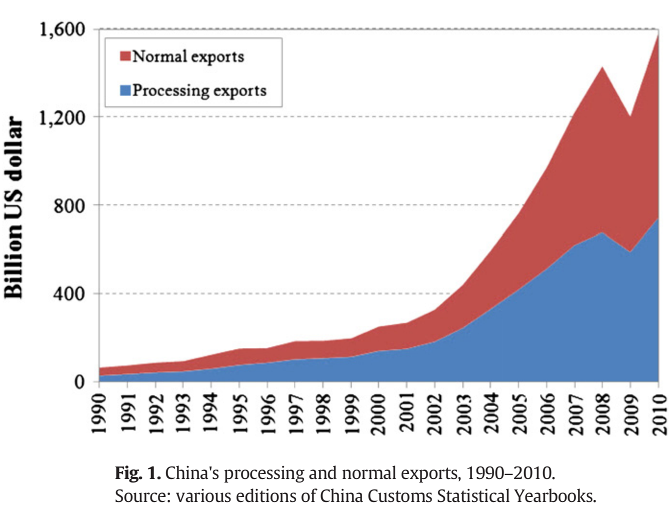

Fig. 1. China's processing and normal exports, 1990–2010.
Source: various editions of China Customs Statistical Yearbooks.

the literature. The possible impacts of export assumptions on the SDA results also deserve further investigation.

The purpose of this study is to fill in this research gap by investigating how the export assumption affects estimates of CO_2 emissions embodied in trade using I–O analysis and the decomposition results over time. We study the problem analytically and highlight the numerical results of an empirical study using the data of China. Finally, key findings and recommendations to future research will be discussed.

2. Embodied Emission Models for Processing and Normal Exports

In this section, we focus only on the I–O models for estimating the emissions embodied in a country's exports. All the imports are treated as non-competitive imports, i.e. using the "Domestic Technology Assumption" in the I–O model (Su and Ang, 2013). The methodology to estimate the emissions embodied in imports can be found in Peters (2008), Andrew et al. (2009) and Su and Ang (2011).

2.1. Traditional I–O Model with Non-competitive Imports

For the I–O table with non-competitive import assumption, i.e. as shown in Table 1, the standard I–O model can be formulated as

$$x = Z_d \cdot 1 + (y_d + y_e) = A_d x + (y_d + y_e) \tag{1}$$

where x is the vector of total outputs, Z_d is the matrix of total domestic intermediate demands, 1 is the vector with all the elements equal to one, $A_d = Z_d \cdot (diag(x))^{-1}$ is the matrix of total domestic production coefficients, y_d is the vector of domestic final consumption, and y_e is the vector of exports. Rearranging Eq. (1) leads to the following basic equation for I–O analysis:

$$x = (I - A_d)^{-1}(y_d + y_e) = L_d(y_d + y_e) \tag{2}$$

where $L_d = (I - A_d)^{-1}$ represents the total domestic Leontief inverse matrix.

With the emission intensity vector f representing the CO_2 emissions per unit of value of industry output, the total amount of CO_2 emissions from industry can be formulated from Eq. (2) as

$$C_{tot} = f'x = f'L_d(y_d + y_e) = f'L_d y_d + f'L_d y_e = C_d + C_e \tag{3}$$

where $C_d = f'L_d y_d$ is the national emissions embodied in domestic final demands, and $C_e = f'L_d y_e$ is the national emissions embodied in exports. Since the exports equal to the summation of normal exports y_{ne} and processing exports y_{pe}, i.e. $y_e = y_{ne} + y_{pe}$, we have the emission embodiments in these two types of exports as $C_{ne} = f'L_d y_{ne}$ and $C_{pe} = f'L_d y_{pe}$. In the traditional I–O model, total emission intensities (or emission multipliers) used for normal exports and processing exports are the same, i.e. $(f'L_d)$.

2.2. Extended I–O Model with Processing Trade and Non-competitive Imports

By further separating the traditional export account in Table 1 into normal exports and processing exports, the extended I–O table is shown in Table 2. The structure of this extended I–O model is first introduced by Chen et al. (2001) on analyzing China's domestic

Table 1
Structure of traditional I–O table with non-competitive imports.

	Intermediate transactions	Final demands	Total outputs
Intermediate inputs	$Z_d = Z_{dd} + Z_{dp}$	$y_d + y_e = y_d + (y_{ne} + y_{pe})$	x
Imports	$Z_i = Z_{id} + Z_{ip}$	y_i	$y_m = Z_i \cdot 1 + y_i$
Value added	$v' = v_d' + v_p'$		
Total inputs	x'		