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Accounting and structure decomposition analysis of embodied carbon trade: A global perspective

Guangyao Deng [a, *], Yan Xu [b]

[a] School of Statistics, Lanzhou University of Finance and Economics, Lanzhou 730020, PR China
[b] School of Finance, Henan University of Economics and Law, Zhengzhou 450002, PR China

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ABSTRACT

In this paper, a multi-regional input-output model is built to estimate the global embodied carbon trade from 1995 to 2009 based on the World Input-Output Database (WIOD). The method of structure decomposition analysis (SDA) is applied to quantify the changes in the scale and structure of embodied carbon trade in China, India, Japan, and the United States. According to the results, the top three countries with the most embodied carbon trade were: the United States, China and Japan in 1995, and the United States, China and India in 2009. In 1995 and 2009, the sectors which have the highest direct carbon emission coefficients and total carbon emission coefficients in China, India and the United States are electricity, gas and water supply sectors, while each country maintained a different coefficient. A decrease of direct carbon emission coefficient will result in a reduction of the imports and exports, as well as the self-consumption of embodied carbon. Therefore, it is suggested that countries should develop low-carbon industries, and reduce the carbon emissions per unit of output. In addition, those countries with higher carbon emission coefficients should consider of importing products to lower carbon emissions.

1. Introduction

The demands for fossil fuels are growing in recent years with the development of world economy. Nevertheless, their widespread use has also produced a lot of carbon emissions. As international trade develops, product production and consumption have been separated. The traditional emission reduction mode that producers bear the responsibility may cause "carbon leakage" problem [1–3]. Although replacing domestic production with import of products can somewhat make the producers avoid taking responsibility for carbon emissions, it weakens the effectiveness of carbon emissions reduction policies, but also is unfair to exporting countries [4,5]. From a global perspective, the issue of carbon emissions embodied in trade is worthy of attention.

In order to properly reflect each country's responsibility for carbon emissions reduction, many scholars have estimated carbon emissions embodied in trade by using input-output table. Since the input–output table can be divided into single regional input-output table and multi-regional input-output table, the method of calculating carbon emissions embodied in trade is able to be divided into single regional input-output method and multi-regional input-output method. (1) Single regional input-output method. Chung et al. [6] estimated the carbon emissions embodied in trade in Korea during 1990–2004. Linder and Guan [7] utilized the input-put method in combination with the life cycle theory to compute the carbon emissions embodied in trade of all Chinese sectors in 2007. Zhang and Huang [8], as well as Dong et al. [9] respectively studied the embodied carbon trade and consumption in Jiangsu Province and Beijing Municipality of China in 1997, 2000, 2002, 2005, and 2007. (2) Multi-regional input-output method. Peter et al. [10] compared the difference in the applications of EEBT (Emissions embodied in bilateral trade) model and MRIO (Multi-Region Input-Output) model in the calculation of carbon emissions embodied in trade. Wiebe et al. [11] computed the carbon emissions embodied in trade of Brazil, Russia, India, China, South Africa, Argentina and other countries in 1995, 2000 and 2005 based on GRAM (Global Resource Accounting Model). Su and Ang [12] calculated the carbon emissions embodied in trade of eight regions of China in 1997. Mundaca et al. [13] computed the carbon emissions embodied in trade of Sweden during 2000–2009. Asane-Otoo [14] described the carbon emissions embodied in trade

* Corresponding author.
E-mail address: dgy316203@163.com (G. Deng).

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and the carbon footprint of African countries in 2007. Arce et al. [15] studied embodied carbon trade of the post-China countries in 2007. Zhang et al. [16] made accounting and structural decomposition analysis of the embodied carbon trade between the United States and China during 1995–2009. Xu et al. [17] employed the World Input-Output Database and the gross export decomposition methodology to recount the CO_2 emissions embodied in China's international trade from the perspective of value-added trade. Zhong et al. [18] studied emissions embodied trade in four Chinese mega-regions between 2002 and 2010. The literature shows that the carbon emissions embodied in trade are calculated by the input-output method as follows: Firstly, computing the direct carbon emission coefficient; secondly, multiplying it by the Leontief inverse matrix to obtain the total carbon emission coefficient; thirdly, multiplying the total carbon emission coefficient by trade volume. However, single regional input-output methodology can facilitate to calculate the carbon emissions embodied in trade of only one single region, while the multi-regional input-output methodology can obtain the scales of carbon emissions embodied in trade of different regions, and find out the situation of embodied carbon trade among multiple regions. With the multi-country (region) input-output table in the World Input-Output Database (WIOD), this study has taken into account the variations in the carbon emission coefficients among different countries (regions), in order to better estimate the import of embodied carbon. The previous studies generally assumed on an about equal contribution of the carbon coefficients of imported products due to the limitations of the input-output table and data available across countries [7] [9].

SDA is one of the most important tools for understanding the reason why carbon emissions change. Huang and Wu [19] quantified the impact of different factors on the changes of carbon emissions in Taiwan during 1996–2006. Xu and Dietzenbacher [20] utilized the SDA methodology to study the changes of the world's major 40 countries' carbon emissions embodied in trade. Xia et al. [21] assessed China's carbon emissions in export trade in 2002 and 2007, with the SDA methodology. Su and Ang [22] presented a structural decomposition analysis of China's carbon intensity change during 2007–2010. Andreoni and Galmarini [23] took structure decomposition analysis of carbon emission of 33 different countries during 1995–2007. LLop [24] used the demand-driven input-output model and proposed a simple method to decompose the changes in energy gross output into different determinants. As demonstrated by the literature above, for structure decomposition analysis on the change of carbon emissions embodied in trade with SDA methodology, the change should be decomposed into several different parts. Then, the effects of these parts on the carbon emissions embodied in trade will be analyzed accordingly. It should be noted that the decomposition form under SDA methodology is not unique, which can be generally solved with the method of polarization decomposition or mean value method [25]. Furthermore, SDA methodology is often applied in combination with the input-output methodology (IO-SDA methodology). That is a further structural decomposition analysis will be performed based on the calculation of carbon emissions embodied in trade. This paper presents a decomposition analysis of the carbon emissions embodied in trade of China, India, Japan and the United States from 1995 to 2009 with SDA method.

Although, a wide range of research have been published on the embodied carbon trade and made structure decomposition analysis of the changes of embodied carbon trade care needs to be taken onto the following perspectives:(1)Most studies did not take into account the world input-output table. When using the MRIO model to study the implicit carbon trade in many countries, most studies were not sufficient in introducing global perspective and did not reflect enough on the heterogeneity of carbon emissions trading depending on the country-specific characteristics. Considering only the implicit carbon emissions and trade volume of several countries involved in the study, the differences of carbon emissions and trade volume in different countries are not considered. (2) Because of lack of data, the existing studies mainly calculate the implied carbon trade by individual years, and the trade of Embodied Carbon in the year has not been studied.

The main advantages of our approach in this paper are listed as follows: (1) Although there are a large number of literature on the study of embodied carbon trade, most of the literature study the embodied carbon trade in a single country, not from the global perspective. So, it is necessary to assume that the products imported and domestic products are the same coefficient in the calculation of carbon emissions embodied in trade [7] [9]. This paper does not need this assumption, using the input-output table of the world and the carbon emissions data to calculate the embodied carbon coefficient of the imported products directly, so that the results of the embodied carbo111n trading are more accurate. (2) By referring to the related data from the World Input-Output Database (WIOD), a systematical calculation offers a big picture of the trade-embodied carbon emissions in the 27 EU countries, another 13 major economies and other parts of the world (ROW) from 1995 to 2009, by constructing multi-regional input-output model (MRIO model). Moreover, an in-depth research is conducted on the matrix of carbon emissions embodied in trade across China, India, Japan and the United States in a larger trade scale. Then, this paper analyzes the change volumes of the carbon emissions embodied in imports and exports of China, India, Japan and the United States, by using the structural decomposition analysis(SDA). The rest of the paper is organized as follows: Section 2 presents the research method and discusses the adopted data. Section 3 and 4 provides the results and discussion. Section 5 gives the conclusions and implications.

2. Methodology and data

2.1. Estimation of carbon emissions embodied in trade

According to the structure of the input-output table in the World Input-Output Database (WIOD) (Table 1), the following equation can be obtained from the equilibrium relation among the horizontal rows:

$$X^r = A^{rr}X^r + \sum_{s\neq r} A^{rs}X^s + Y^{rr} + \sum_{s\neq r} Y^{rs} \quad (1)$$

where, X^r is a column vector, representing the total amount of productions in country (region) r[1]; A^{rr} is a direct consumption coefficient matrix, representing the amount of intermediate use of the domestic products in country (region) r; A^{rs} is a cross-regional direct consumption coefficient matrix, where the inputs are from country (region) r and the outputs are produced in country (region) s; Y^{rr} is a column vector denoting the amount of final use of the domestic products in country (region) r; Y^{rs} is a column vector in final use part, representing the amount of products exported from country (region) r to country (region) s.

Following Peters et al. [10], Zhang and Anadon [26], Liu and Wang [27], Deng et al. [28], the aggregate vector for all countries (regions) can be obtained after re-arranging Eq. (1), as shown below:

[1] In the world input-output table, there are 35 sectors in each region. Thus, the total output of the area r is 35 × 1 rank vector. Other cases are similar, which will not be described in this paper.