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Recalculating CO_2 emissions from the perspective of value-added trade: An input-output analysis of China's trade data

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ABSTRACT

Using traditional trade statistics to calculate CO_2 emissions embodied in international trade results in significant miscalculations and a deeper divide between countries. The aim of this research is to provide a reasonable estimate of carbon emissions to help policymakers in each country address their actual share of responsibility. This study employs 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. The result shows that reliance on traditional statistics caused a significant overestimation of China's imports and exports: US$ 398.77 billion and US$ 504.46 billion for China's imports and exports, respectively. Our findings suggest that 177.24 million tons of carbon emissions embodied in imports and 907.636 million tons of carbon emission embodied in exports were over calculated. The result obtained with traditional calculation methods has artificially increased the responsibility share of China in the global emissions reduction. We also compare the CO_2 emission coefficients of China with those of other countries. Our findings suggest that the high emission coefficients of most Chinese industrial sectors determine the carbon emissions embodied in China's exports to be higher than in its imports.

1. Introduction

Data from the International Energy Agency show that China is the world's largest emitter of CO_2 emissions, since 2007, surpassing the United States (US). Since the 2009 Copenhagen Climate Change Conference, alongside a few other developing countries, China is under significant pressure to commit to reducing its CO_2 emissions. Scholars have pointed out that export trade is a key driver of China's carbon emissions (Du et al., 2011; Lin and Sun, 2010; Ma and Wang, 2015; Sun et al., 2015; Weber et al., 2008; Ye et al., 2008).

With the advent of a deeper international division system and increasing foreign trade, the final product consumed in one country is processed by a few other countries and crosses multiple borders. This transfer of intermediate goods between countries may lead to an overvaluation of foreign trade according to traditional statistical analysis, especially for countries that lie in the downstream of the global value chain. The multiple flows of intermediate goods are accompanied by multiple flows of implicit carbon emissions, potentially causing an overestimation of the carbon emissions embodied in international trade. Therefore, this study proposes an alternative method to calculate the CO_2 emissions embodied in international trade, in terms of the value-added trade. New emission estimates are provided to help developing countries like China to commit to the responsibility of a consistent reduction in carbon emissions.

2. Literature review

There are two major approaches to measure trade-embodied CO_2 emissions: life-cycle assessment (LCA), and the input-output method. The LCA process has opened the way for measuring embodied carbon. However, this methodology is suitable for microscopic quantification as it requires integrated data, significantly limiting its employment. On the other hand, the input-output method has lower data requirement, and intuitively and comprehensively reflects the dependencies of sectors or products. It is more suitable for macro analysis and is favored by scholars. The input-output table shows the direction of product use, the vertical column displays the source of the product, and intuitively and comprehensively reflects the relationship among the sectors and the technology-related aspects in a country or a region. In addition, the input-output table can be created as a matrix or a linear algebraic equation, in order to carry out a macroeconomic analysis or a prediction (ten Raa, 2005; Hendrickson et al., 2006). However, the input-output method also has limitations. For example, various input coefficients (for at least one year) have to be fixed; the preparation

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process of an input-output table is difficult as it is labor intensive and involves hours of data collection and processing. American economist Wassily Leontief pioneered the development of the input-output method in 1936. Hendrickson et al. (2006) developed this method to analyze economic and environmental issues, and applied the input-output approach to LCA analysis.

The input-output method describes the relationship between industry sectors and environmental pollution, especially in the assessment of trade-implied carbon. The method can be used as a single-region input-output model or a multi-region model, based on the number of countries under analysis. A single-region input-output model studies a single country's trade-embodied carbon emissions, assuming the same carbon coefficient both nationally and internationally, as in Julio and Rosa (2004), and Machado et al. (2001). A multi-region input-output model can be a bilateral or multilateral trade input-output model. The former studies trade implicit carbon emissions between two countries, which are a potential target for policy makers; Shui and Harriss (2006) focused on China-US trade and Ma et al. (2016) on China-Japan trade. However, the bilateral trade input-output model does not describe complex multinational environments, economic globalization, and multiple foreign trade links. The multilateral trade input-output model was introduced to address these potential scenarios. Su and Ang (2014) divide China into eight areas and analyze the impact of regional trade on regional CO_2 emissions. Their results show that China has formed a pattern of "west→middle→eastern coast" in implied carbon exports. Using a multi-region input-output model and a consumption-based approach, Yan et al. (2013) measure China's trade implied carbon intensity with its six largest trade partners, and suggest a consumption-based emissions approach to reduce the country's responsibility. Su et al. (2010, 2013) and Liu and Wang (2014) stated that both the single-region and multi-region input-output model analyze the macroeconomic aspect, while researchers have attempted to improve the micro measurement dimension. Zhao and Liu (2011) study the embodied carbon in imports of intermediate goods and conclude that such measures may lead to overestimation of emission results. Subsequently, the authors introduce the method of vertical specialization to eliminate the influence of import of intermediate goods. The same framework has also been applied by Xiang and Wen (2014) and Yan and Zhao (2012). However, this method is based on the assumption that "each industry has the same proportion of imported intermediate inputs from a particular industry." Wang et al. (2012) compare three measurements based on a direct emission coefficient, total demand coefficient, and complete consumption coefficient; they find that calculating the intensity of carbon emissions based on the total demand coefficient appears more realistic. The carbon emission coefficients of importers are often measured applying a typical country or a weighted average of major importers' coefficients. Qi et al. (2008) and Wei et al. (2009) use the Japanese emission coefficient for importers.

The above-mentioned studies on trade-embodied carbon emissions started from the emission coefficient, imported intermediate goods, consumption coefficients, and other factors with no significant breakthrough from trade data. With the deepening of global economic ties, traditional trade statistics appeared to lead to misleading results. Some scholars have pointed out that compared with value-added trade statistics, official trade statistics greatly overestimated China's foreign trade dependency and trade imbalance (Li and Xu, 2013; Wang and Sheng, 2014). Chen and Li (2014) introduce an alternative measurement of China's import and export of goods and services, and their final assessment is significantly lower, with exports decreasing by 26% and imports falling by 31%. An overvalued scale of imports and exports will inevitably lead to an overvalued implied carbon, with a negative impact on the determination of China's emission reduction responsibility. Therefore, value-added trade provides a new perspective for calculating carbon emissions embodied in trade.

In manufacturing or production activities, value is added through labor and capital, reflecting the residual output value after deducting intermediate consumption (OECD-WTO (2009), Koopman et al. (2010), Johnson and Noguera (2012), Liu (2013)). Value-added trade is based on the value added content of products generated by different countries in the global production chains. This consideration can avoid the double accounting in cross-border trade and make foreign trade statistics more accurate for all countries. So far, value-added trade has been widely applied to analyze the status or embedded extent in the global value chain for countries or industries. Cheng (2015) quantifies the status quo and dynamics of China's integration into the global value chain from intermediate, value-added, and input-output linkages, according to the transnational input-output analysis. Yin (2016) utilizes the World Input-Output Tables (WIOT) database to discuss China's current manufacturing position in the global value chains. This indicates that even though the status of China's manufacturing in the global value chains is rather low, the outlook is improving. Lu and Gong (2015) states that the measurement of embodied carbon based on value-added trade statistics are a possible research area.

Xiang (2014) analyzes trade-implied carbon from the perspective of value added content. Xiang directly employs trade information obtained from the joint OECD-WTO Trade in Value Added Database, issued in 2009, without a specific analysis procedure; the findings of this research have not been further clarified. In addition, the carbon emissions coefficient and the consumption matrix of importers are substituted for the domestic ones. Only a few studies have addressed trade-implicit carbon emissions from the perspective of value added. With the aim of revealing the real responsibility in reducing carbon emissions, this paper attempts to modify the measurement of carbon emissions embodied in the trade of a general country: (1) from the perspective of value-added trade, we deduct double-counted implicit carbon; (2) from the assumption of Koopman's gross exports' decomposition model (2010), this research uses WIOT to loosen the assumption of an equal proportion of imported intermediate inputs, avoiding the elimination of imported intermediate inputs; (3) we adopt importer's carbon emission coefficients and consumption matrix when considering the carbon emissions embodied in imports, to increase the accuracy of the results.

The remainder of this paper is organized as follows. In Section 3.1, we introduce the input-output methodology developed by Leontief (1986) and we derive the carbon emissions coefficient, *c*. In Section 3.2, we decompose the gross exports of a general country following Koopman (2010). In Section 3.3, we combine these two models, and we use the WIOD data to verify the CO_2 emissions embodied in China's imports and exports based on value-added trade. Section 4 presents the results and discusses the main findings. Section 5 presents the concluding remarks.

3. Model and data

3.1. Trade implicit carbon calculation model

The input-output method has been widely applied to analyze economic and environmental issues and to describe the relationship between industrial sectors and environmental pollution, especially in the research on trade-implicit carbon.

The original input-output model can be described as :

$$X = AX + Y \tag{1}$$

and rearranging the expression:

$$X = (I - A)^{-1}Y = BY \tag{2}$$

where X is a column vector of gross output, A is the direct consumption coefficient matrix providing information on intermediate use, Y is the final demand vector, and $(I - A)^{-1}$ and B are both Leontief inverse matrixes denoting the total consumption coefficient.

The row vector $\mathbf{c}$, whose element $\mathbf{c}_j$ denotes sector j's direct CO_2