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Research article

Embodied carbon dioxide flow in international trade: A comparative analysis based on China and Japan

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ABSTRACT

Carbon dioxide embodied flow in international trade has become an important factor in defining global carbon emission responsibility and climate policy. We conducted an empirical analysis for China and Japan for the years 2000–2014, using a multi-region input-output model and considering the rest of the world as a comparison group. We compared the two countries' direct and complete carbon dioxide emissions intensity and bilateral economic activities such as imports and exports, production and consumption to analyze the difference between China and Japan. The results showed that the intensities of carbon emissions in all sectors of China were higher than that in Japan and that China's annual production-based emissions were greater than consumption-based emissions, the opposite of these relationships in Japan. China was a typical net carbon export country, and carbon embodied in its imports and exports continued to increase throughout the study period. In contrast, Japan's volume and growth rate of embodied carbon emissions were far less than China's and Japan was a typical net carbon import country. Finally, the conclusions of this study support recommendations for the formulation of international carbon emission responsibility allocation, domestic abatement policy as well as China's trade policy.

1. Introduction

With the vigorous development of international trade and deepening of international division of labor, the carbon emissions embodied in trade are also increasing. Rapid economic development has made China the world's biggest trading nation, but also the world's largest emitter of carbon dioxide. Many studies have shown that while China benefited from a trade surplus, the imbalance resulted in China assuming carbon emissions from other nations such that domestic carbon emissions are seriously inconsistent with carbon consumption. According to the Japanese Ministry of Finance data, China has become Japan's largest trading partner. China and Japan are Asia's largest developing and developed countries, respectively, and play a pivotal role in the development of Asia and other regions. Japan was the first country in Asia to announce the establishment of a low-carbon society and has made many efforts to reduce carbon emissions; these efforts have achieved remarkable results in the development of Japan's low-carbon economy. The study of embodied carbon emissions in international trade between China and Japan enables China not only to understand the gap between the two countries, but also to learn from Japan's measures taken in developing a low-carbon society, and thereby efficiently reduce China's own carbon emissions while achieving low-carbon development. Therefore, it is greatly significant to analyze the relationship and differences between China and Japan from the perspective of carbon flow. This analysis can not only help establish China's energy-saving emission reduction policies in the post-Kyoto era and allocate international emission reduction obligations reasonably, but also provide reference for trade and emissions mitigation policies of other developing countries, such as Russia, India and South Africa.

Many studies have shown that international trade leads to 'carbon transfer' (Davis and Caldeira, 2010) and 'carbon leakage', and the United Nations Framework Convention on Climate Change has emphasized 'producer responsibility', discouraging the transfer of carbon emissions that occurs through international trade by which developed countries import carbon intensive products from developing countries to avoid the domestic production of carbon emissions. How to reasonably apportion responsibility for carbon emissions and to assign reduction standards for carbon emissions attracts much attention globally. Based on the concept of material

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flow, for our study we defined embodied flow (Chen, 2011) as the total specific resources in the process of production, which are directly and indirectly consumed with the product and service flow. As a result, the embodied carbon dioxide flow can be explained as the total amount of carbon dioxide emitted directly and indirectly in the whole production process of goods and services.

The originality of this paper include: we first examined the accounting problems on carbon emissions, considering technological gap of different countries, using their own import emission coefficients, and giving full consideration to imports and exports. Second, for Japan and China, we selected 32 specific industries and calculated their import and export embodied carbon dioxide flows, as well as production-based and consumption-based carbon emissions, to identify the major industries and distribution between the two countries in terms of embodied carbon emissions. Third, adopting the latest data (November 2016 update) of the World Input-Output database (WIOD, www.wiod.org), we took the period 2000–2014 to research various indexes of the Chinese and Japanese economies to explore the quantitative flow of embodied carbon dioxide emissions between the two countries for a long-term comparative analysis.

2. Literature review

Chinese and international scholars have analyzed the problem of embodied carbon emissions from different perspectives. Considering emissions from a single nation, Machado et al. (2001), Weber and Matthews (2007), Muñoz and Steininger (2010) and Roach (2013) calculated the embodied carbon emissions in foreign trade of Brazil, America, Austria and other European countries. Some scholars have calculated China's embodied carbon emissions in foreign trade using a Single Regional Input-Output (SRIO) or a Multi-Regional Input-Output Model (MRIO) model, and found that China is a net carbon exporter and that other countries have transferred a large amount of carbon emissions to China (Guan et al., 2008; Weber et al., 2008; Lin and Sun, 2010; Yan and Yang, 2010; Su and Ang, 2014). Second, considering bilateral emissions, Yan et al. (2013) calculated carbon dioxide emissions embodied in China's trade with the European Union. Likewise, Dong et al. (2010), Liu et al. (2010), Wu et al. (2015) and Zhao et al. (2016a,b) among others analyzed the quantification and driving forces of CO_2 emissions embodied in Japanese-Chinese trade. Du et al. (2011), Liu et al. (2016) and Zhao et al. (2016a,b) found that China's net carbon trade with the United States remained positive, and proposed promoting the transformation and upgrading of the processing trade and encouraged the development of service trade and other measures to reduce Chinese carbon emissions. López et al. (2014) studied the Spanish-Chinese case and found that Spain has a significant emissions deficit with China, indicating that post-Kyoto agreements must focus both on traded goods and the environmental efficiency of all domestic production chains. Yu and Chen (2016) suggested that the embodied carbon emissions surplus is not caused by trade surplus, and noted that the trade diversion between China and South Korea helps significantly in reducing global carbon emissions. Liu et al. (2016) calculated China's CO_2 emissions embodied in bilateral trade with the USA, European Union, Japan and other countries, and found that net CO_2 emissions embodied in China's trade in 2007 were only 400 million metric tons, much lower than previous estimations.

Other researchers studied embodied emissions from a multinational perspective. Peters and Hertwich (2008) calculated the embodied carbon emissions of 57 industries for 87 countries and districts in the world. Chen and Chen (2011) studied the embodied carbon emissions of G7 countries, BRIC countries and other countries and found that in 2004 the groups of countries were net carbon exporters, net carbon importers and had carbon balances, respectively. Tian et al. (2015) calculated embodied carbon emissions for 35 sectors of 41 economies in the world and confirmed the carbon flow tendency to neighbors from one country at the center. The calculation of embodied carbon emissions in trade confirmed that the existence of carbon transfer and carbon leakage. Developed countries reduced the cost of carbon emissions, but developing countries and regions such as China assumed much of the responsibility for carbon emissions; as a result, the existing defining principle of shared responsibility for carbon emissions trading remains controversial.

Scholars also have analyzed the principles and methods of carbon emission responsibility from different perspectives. Early scholars such as Gupta and Bhandari (1999) and Neumayer (2000) considered that the responsibility for carbon emissions in international trade should be fully attributable to the producer. In contrast, Munksgaard and Pedersen (2001) believed that consumers should be responsible for the carbon emissions caused by domestic consumption and put forward the “consumer responsibility” principle. Fan et al. (2010) and Yan et al. (2013) thought that the carbon emission system based on consumption accounting should be a new way of energy saving and emission reduction. Other studies have focused on the “shared responsibility” principle from the perspective of the international fair, such as those by Lenzen et al. (2007), Peters et al. (2011), Chang (2013) and Steininger et al. (2013). These researchers hold the view that neither purely producer responsibility nor purely consumer responsibility is reasonable in the process of emission reduction; therefore, the producer-consumer sharing principle makes the principle of shared responsibility for defining the carbon emissions countries more equitable and effective. Cadarso et al. (2012) thought shared responsibility is fairer and more effective because global product chains are the networks through which environmental impacts arise and are transmitted from one stage of production to another, from producer to consumer, from one country to another; furthermore, overall responsibility involves all the agents that participate or benefit.

The number of studies that compare Chinese production- and consumption-based carbon emissions is increasing. Xu and Zou (2010) and Peng et al. (2015) have shown that China's production- and consumption-based carbon emissions increased significantly, and that production-based emissions were higher than consumption-based emissions; the scientists proposed corresponding energy-saving emission reduction policy recommendations. Yan and Zhao (2014) presented a consumption-based emissions inventory, calculated the consumption-based emissions and analyzed the interregional carbon spillover of G7, BRIC and other countries. Wang and Lu (2016) estimated China's production and consumption-based emissions and the Balance of Carbon Emissions Embodied in Trade (BCEET) between China and 40 countries and allocated the BCEET by using trade benefits as the allocation factor.

To sum up, international trade has a great impact on global carbon emissions. There are still some limitations on current research about embodied carbon, ignoring the huge differences of production technology between developed and developing countries, as well as the fact that carbon intensity of merchandise produced by developing countries is much higher than that of developed countries. Kander et al. (2015) explained the problems well, and formulated three important and intuitively compelling conditions in carbon accounting (i.e., sensitivity, monotonicity and additivity), and provided accurate and adequate feedback on how local and national decisions affect global emissions. Thus, it is