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An index decomposition analysis of China's interregional embodied carbon flows

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ABSTRACT

Being the largest emitter of carbon dioxide in the world, China also possesses enormous regional disparities in terms of carbon dioxide emissions. Significant carbon emission flows from developed regions to undeveloped regions through inter-regional trade have been observed in China. In order to examine the determining factors of such virtual carbon flows, an index decomposition analysis was conducted to investigate emissions embodied in trades among eight regions, which were grouped with recourse to the latest available provincial I/O tables in China. This paper finds that trade balance and energy intensity are two most salient factors with regard to interregional carbon flows. In the largest outsourcing region, the northwest region of China, the two factors account for 35.6–59.1% of the total carbon surplus, respectively. Thus, China is experiencing more 'efficiency losses' than 'efficiency gains' resulting from carbon transfers. In order to switch to a future "efficiency gain" situation, policies and supports for technology innovation in and transfer to inland regions, as well as enhanced technology standards for expanded carbon intensive productions in less developed regions are suggested to complement the current policy of carbon intensity target.

1. Introduction

With its rapid economic development and high industrial energy consumption, China is now the world's top emitter of Greenhouse Gasses (GHGs), accounting for 23.9% of the world's emissions in the year 2010 (IEA, 2012). In order to relieve the pressures caused by high carbon emissions inside China, the government has proposed several carbon mitigation plans. In 2009, a voluntary reduction of GHGs emissions was put forward by the national government, in which China set a goal to reduce the intensity of carbon dioxide emissions per unit of GDP by forty to forty five percent by 2020 (from the 2005 emissions rate) (Wei, 2010). Besides the national targets, regional reduction plans have also been launched (Wang et al., 2013). Considering the economic development and infrastructure gaps that exist between different regions (Feng et al., 2012), the provinces in the developed east coast region are required to reduce their carbon intensity by 19%, Less developed western provinces are required to reduce their carbon intensity by 10% by 2015 (from the 2010 levels). Furthermore, low carbon pilot programs have also been established in some provinces and cities (Wang et al., 2013).

Although actual carbon dioxide emissions occur in the producing regions, consumption in other regions can also impact producing regions' carbon emissions through trade, thus inducing carbon displacements among regions. This is called 'embodied carbon trade'. The area of embodied carbon trade has attracted attention by many researchers. Davis and Caldeira (2010) evaluated consumption-based carbon emissions in different countries and found that some wealthy countries tended to outsource their carbon to developing countries like China. Peters et al. (2011) demonstrated that the net carbon emission transfers via international trade from developing to developed countries increased from 0.4 Gt in 1990 to 1.6 Gt in 2008, exceeding the Kyoto Protocol emission reduction levels. Vetőné Mózner (2013) analyzed the embodied emissions both on national and on sectoral level for international trades specifically, and gave some opinions on allocations of carbon mitigation burdens. Su and Ang (2014) investigated interregional embodied carbon transfers in China in 1997 and found that developed regions were generally net importers of embodied emissions from trade. Feng et al. (2013) did pioneering work in calculating the interprovincial virtual carbon trades in

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2007, where it is found that up to 80% of emissions related to goods consumed in highly developed coastal provinces were imported from less developed provinces. He asserted that further outsourcing would cause developing regions to struggle to meet their mitigation targets.

Consumption-based emissions and interregional carbon transfer calculations provide a method of reconsidering where the responsibility should lie in terms of carbon emissions and explain how interregional trade affects regional carbon emissions. However, data of embodied carbon trades alone cannot provide enough information to answer questions concerning what drives carbon transfers between regions, or how transfers can be regarded as efficiency loss. The answers to these questions are very important in designing fair and effective regional carbon mitigation policies in China. Thus it is vital to consider not only the embodied carbon itself, but also the determining factors of these carbon emissions. Are they caused by distinct industrial specializations or just differences in energy efficiencies? Only after acknowledging the determining factors behind carbon transfers can we gain a better understanding of carbon outsourcing inside China. In our study, we adopted an 'Additive Refined Laspeyres Index Decomposition' (Sun, 1998) to derive the driving forces of interregional carbon trade. A decomposition analysis has been widely used to understand China's energy related issues and to detect the decisive factors in issues of increased carbon emissions (Wang et al., 2005), historical carbon intensity (Zhang, 2009) and embodied carbon trades with one countries (Du et al., 2011) and multi-countries (Xu et al., 2011). The approach is also applied to sub-national or city level analysis (e.g., Tian et al., 2011).

The policy implications of carbon outsourcing should be considered carefully with analytical evidence. Due to technological barriers, carbon outsourcing between countries are called 'carbon leakages' as goods are produced with inefficient technology in poor countries (Eichner and Pethig, 2011). This raises the issue of inequity caused by carbon outsourcing between countries (Steckel et al., 2010). However, unlike the global situation, there are fewer technology and population barriers between regions inside China (resources and technology can move freely). Given this situation, it is important to study whether carbon transfers will cause inequities between rich and poor regions. Furthermore, Will carbon transfers benefit or harm the national targets? These arguments should be reconsidered in a more comprehensive discussion with analytical results.

The article proceeds as follows: First in section 2, we introduce the methodology for the embodied carbon calculation and index decomposition as well as data resources and our approach to data management. In Section 3 and 4 we explain and discuss the calculations and their policy implications. Finally, in Section 5 we draw conclusions.

2. Methodology and data

2.1. Methodology for calculating interregional carbon flows

We adopt the Input–Output analysis (IOA) to calculate interregional carbon flows. The IOA method has been used to calculate the displacement of water (Hubacek et al., 2009), domestic carbon displacements (Feng et al., 2013), international carbon (Fang et al., 2012) and pollutant transfers (Zhang et al., 2013) in China. When applied to multi-regions, two such approaches have been adopted in previous studies. One considers total bilateral trade between regions (EEBT) and the other distributes the emissions to final consumers through endogen intermediate consumption (MRIO) (Peters, 2008). Neither method is correct or incorrect, they just differ in the way that they allocate interregional carbon transfers, and serve different purposes. In our study, we analyze interregional carbon trades and compare them with their related monetary value between regions. In an MRIO framework, intermediate consumption is endogenous and one carbon flow may go through many regions before it finally arrives at the final consumer, thus making it very difficult to define the corresponding value of trade. EEBT, however, is more transparent when interpreting indicators related to bilateral trade (Peters, 2008). Additionally, the meaning of sectoral carbon transfers is clearer in the EEBT method. Thus, this method will help identify the key sectors and causes of carbon transfer in the IDA analysis.

In an EEBT framework, interregional bilateral carbon trades are calculated using monetary bilateral trade statistics. Intermediate and final consumption is not distinguished.

The total carbon footprint is the carbon emissions raised by the consumption activities of a region. By analogy to the definitions in water footprint studies by Hoekstra and Chapagain (2007), total carbon footprint of a region can be divided into two components: the part of the footprint that falls inside the region (domestic carbon footprint) and the part of the footprint that presses on other regions (external carbon footprint). First the domestic carbon footprint which refers to the carbon emissions inside a region raised by this region's final consumption, is calculated as

$$\mathrm{df}^r = F^r(I - A^{\mathrm{rr}})^{-1} * y^{\mathrm{rr}} + f^{\mathrm{hh}} \quad (1)$$

where F^r is a row vector with each element representing the direct carbon emissions per unit industry output. A^{rr} represents intermediate consumption where the columns are calculated by dividing the sector input by input from every industry. y^{rr} is the final consumption in region r while f^{hh} represents direct carbon emissions created by households.

The EEBT from region r to region s is represented by

$$f^{\mathrm{rs}} = F^r(I - A^{\mathrm{rr}})^{-1} * e^{\mathrm{rs}} \quad (2)$$

where e^{rs} refers to the monetary value of trade from region r to region s. By summing up all exported carbon, the total carbon transfers from region r to all other regions can be stated as:

$$f^{\mathrm{r}*} = \sum_s f^{\mathrm{rs}} \quad (3)$$

And all carbon imports from other regions to region r – the external carbon footprint of region r – can be calculated as:

$$f^{*\mathrm{r}} = \sum_s f^{\mathrm{sr}} \quad (4)$$

Then, the total carbon footprint can be determined as:

$$\mathrm{tf}^r = f^{*\mathrm{r}} + df^r \quad (5)$$

2.2. Methodology for Index Decomposition Analysis (IDA)

IDA is a method that is used to disaggregate the total amount of change into contributions made by its various components (Ang et al., 2009). When it is adopted in studies like this, we can analyze which factors have caused the changes in the embodied emissions (Xu et al., 2011). Typically, decomposition takes place between time points, but in this paper the analysis is done between regions to help understand what causes the embodied carbon flows from one region to another. The core of our IDA methods are adopted from the pioneering work of Jakob and Marschinski (2013), where they attributed the change to four parts as trade balance, energy intensity of GDP, carbon intensity of energy and trade