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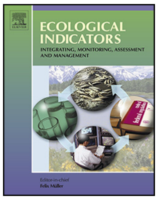

Inter-regional linkage analysis of industrial CO_2 emissions in China: An application of a hypothetical extraction method

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ABSTRACT

As the largest CO_2 emitter in the world, China has faced great pressure to mitigate its CO_2 emissions. Thus, issues related to CO_2 emissions in China have been widely studied. However, the industrial linkages of CO_2 emissions at the regional level have been less concerned. This study integrates hypothetical extraction method with the multi-regional input–output model, and investigates industrial CO_2 emission linkages of China at the regional level. Based on the data of China in 2007, which decomposes China into eight regions, this study first analyzes the production-based emission (PBE) and consumption-based emission (CBE) of each region. The PBE and CBE of 10 branches are then analyzed and decomposed into three parts. Finally, this study decomposes the externally produced embodied emission (EPEE) and internally produced embodied emission (IPEE) of Petrochemicals and Minerals in the East Coast, to illustrate how these two indicators of a branch affect other branches in the economy. Results show that regions with large PBE, such as coastal regions and Central, usually have large CBE, whereas Jing-jin has the smallest PBE and CBE. Branches such as Mining and Petrochemicals and Minerals, have large PBE and are net CO_2 emission exporters; while Construction and Other Services are net importers. According to the decomposition results of PBE and CBE, branches can be classified into four groups. The decomposed IPEE and EPEE of Petrochemicals and Minerals in the East Coast show that from the perspective of regions, CO_2 emissions this branch exports to and imports from East Coast are most. From the perspective of branches, decomposition of IPEE shows that Petrochemicals and Minerals in the East Coast exports a large amount of CO_2 emissions to Construction, while the decomposition results of EPEE show that the studied branch imports least CO_2 emissions from Construction. Policy implications deduced from this study are discussed.

1. Introduction

Given growing concerns about global climate change, CO_2 reduction, especially CO_2 reduction of large emitters, has been receiving increasing attention. In 2006, China surpassed the United States in terms of CO_2 emissions from fuel combustion, and became the largest CO_2 emitter in the world. In 2012, China emitted more than 8250 Mt CO_2, which was 1.63 times that of the United States (IEA, 2014). CO_2 mitigation has become an urgent issue for China. In the China–United States joint statement on climate change issued following the Asia-Pacific Economic Cooperation (APEC) meetings in 2014, Chinese government has pledged to achieve the peaking of CO_2 emissions around 2030 and to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030.

Given that industries are closely linked, to achieve such a challenging target and ensure that reduction measures are effective, a comprehensive understanding of the role each industry plays in CO_2 emissions should be gained in consideration of its linkage with the rest of the economy. However, linkages of industrial CO_2 emissions in China at the regional level have not been studied extensively. Studies of CO_2 emissions in China mainly focus on the amount or driving factors of CO_2 emission in China (Huang et al., 2015; Tang et al., 2014; Wang et al., 2015; Wang and Zhao, 2015; Zhang and Chen, 2014) and emissions embodied in China's trade (Qi et al., 2014; Su et al., 2013; Su and Ang, 2014; Zhao et al., 2014).

The linkage of an industry with the rest of the economy refers to its direct and indirect intermediate purchases and sales. Linkage indices are often constructed and used as criteria for "key" sector identification, which is important to formulate industry policies (Cai and Leung, 2004).

When singling out "key sectors" under input–output framework, two methods have been used primarily, namely, classical

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multiplier method and hypothetical extraction method (HEM) (Guerra and Sancho, 2010). It has to be mentioned that these two methods have many variants, and both analytically and empirically these variants are highly correlated with each other. More details can be found in Temurshoev and Oosterhaven (2014).

Classical multiplier method is based on technical or allocation coefficients, technical coefficient of a sector reflects the proportion of inputs from each sector in the total inputs of this sector; allocation coefficient reflects the proportion of inputs to each sector in the total outputs of this sector. Chenery and Watanabe (1958) first suggested using the column (or row) sums of direct input coefficients matrix as a measure of backward (or forward) linkages. This method neglected the indirect effects of industrial linkages, and was then improved by scholars. For example, Rasmussen (1956) proposed using the column (or row) sums of Leontief inverse matrix to measure backward linkages (or forward linkages); and Jones (1976) defined forward linkages as the row sums of Ghosh inverse matrix.

Adopting the method proposed by Rasmussen (1956), Tian et al. (2012) assessed the impacts of sectors on CO_2 emissions for 19 provincial regions of mainland China, and found that great disparities in CO_2 emissions existed across regions, and sectors such as electricity and steam production, petroleum and chemicals, and mining are “key sectors” for most regions, with both backward and forward linkage above average level.

However, classical multiplier method is based on technical or allocation coefficients (Wang et al., 2013), and one problem of this method is the arbitrary use of a unit vector, that is, linkages are computed under the assumption that the gross outputs (in the case of input coefficient matrix), final demands (in the case of Leontief inverse matrix), or value added (in the case of Ghosh inverse matrix) of sector is increased by one unit, this ignores the disparity in size among sectors and can mispresent the relative strength of linkages in different sectors (Clements, 1990). Compared with the classical multiplier method, one advantage of HEM is that it takes into account the relative magnitude of each sector’s final demand and the relative effect of a sector on the overall outputs when identifying the importance of sectors (Andreosso-O’Callaghan and Yue, 2004).

The basic idea of HEM is to extract a sector hypothetically from an economic system and then quantify the degree to which the output of other sectors would decrease after the extraction (Miller and Lahr, 2001). Extraction a sector means it does not sell (or/and buy) any intermediate inputs to (or/and from) other sectors. Thus, generally some coefficients of the extracted sector are replaced by zeros,[1] while other coefficients remain the same, which is evidently not that realistic given that all coefficients are dependent on each other one way or another. This disadvantage of HEM can be alleviated by giving it an economic assumption, that is, when one sector is extracted, all intermediate deliveries from (or/and to) this sector are then satisfied by imports, so the production can continue and the technical production process is held constant (Dietzenbacher and Van Der Linden, 1997).

HEM was originally proposed by Paelinck et al. (1965) and developed by scholars such as Strassert (1968), Schultz (1977), Cella (1984), Clements (1990), and Duarte et al. (2002). Schultz (1977) first used HEM to analyze the economic effect of a sector, that is sector’s impact on GDP, foreign trade and employment, and many studies based on HEM have also focused on the economic effect of sectors (Cai and Leung, 2004; Kay et al., 2007; Ren et al., 2014; Song et al., 2006; Song and Kim, 2007; Yang et al., 2014). With increasing attention to climate change, HEM is also applied to researches on environment and resources, such as water use (Duarte et al., 2002; Pérez Blanco and Thaler, 2014; Temurshoev, 2010), energy consumption (Guerra and Sancho, 2010), and CO_2 emissions (Ali, 2015; Temurshoev and Oosterhaven, 2014; Wang et al., 2013; Zhao et al., 2014).

Based on the data of China in 2007, Wang et al. (2013) adopted HEM to uncover inter-industrial linkages of CO_2 emissions in China, and found that Energy industry has the greatest CO_2 emissions, which mainly flow to Technology industry, Construction and Service. Nevertheless, this study is conducted at national level. And for a large country like China, economic development and CO_2 emission intensities vary greatly among different regions (Su and Ang, 2010). Thus, it is significant to adopt HEM and perform a linkage analysis of industrial CO_2 emissions in China at the regional level, using multi-regional input–output (MRIO) data.

Considering the advantage of HEM compared with the classical multiplier method, this study integrates HEM with the MRIO model and explores CO_2 emission linkages among industries in different regions of China. In fact, Song and Kim (2007) adopted a similar method in their study, but they focused on the economic effect of public agencies relocation on national and regional products, instead of environmental issues such as CO_2 emissions. As far as we know, our paper is the first study that performs a linkage analysis of industrial CO_2 emissions at the regional level based on HEM, in consideration of regional disparities within a country. Almost all studies adopting HEM to study CO_2 emission linkages are conducted at national level. For example, Ali (2015) used HEM to measure CO_2 emission linkages among productive sectors in Italy using the national-level data in 2011. Zhao et al. (2015) and Wang et al. (2013) respectively performed a similar study of South Africa and China.

Through results of linkage analysis at the regional level, we can obtain a thorough understanding of the role each region and industry play in CO_2 emissions, identify key emission regions and key industries that regions share or monopolize, thereby providing more targeted suggestions on CO_2 reduction in China.

The remainder of this paper is organized as follows: Section 2 introduces the model of CO_2 emission linkage analysis at the regional level and data processing. Section 3 presents the results of CO_2 emission linkage analysis. Section 4 offers conclusions and policy implications derived from the empirical results.

2. Methodology and data

2.1. Methodology

We adopt the HEM presented by Duarte et al. (2002), which divides linkages among industries into four basic components, i.e., internal effect, mixed linkage, net backward linkage and net forward linkage. Thus, this HEM allows for a more precise study, compared with HEM that usually draws distinction between two basic components of impact, namely the internal effect and the induced effect (Duarte et al., 2002). This method has been widely used by recent studies on HEM, such as Wang et al. (2013) and Zhao et al. (2014).

To perform a linkage analysis at the regional level, we integrate HEM with MRIO model. Assume a country with G regions and N industries, based on MRIO model, we can draw:

$$\begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} & \cdots & A_{IG} \\ A_{21} & A_{22} & \cdots & A_{2G} \\ \vdots & \vdots & \ddots & \vdots \\ A_{G1} & A_{G2} & \cdots & A_{GG} \end{pmatrix} \begin{pmatrix} X_1 \\ X_2 \\ \vdots \\ X_G \end{pmatrix} + \begin{pmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_G \end{pmatrix} \tag{1}$$

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[1] There are various ways to extract a sector, Miller and Lahr (2001) examined all possible extractions.

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