Energy Policy 100 (2017) 138–148

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Interregional carbon emission spillover–feedback effects in China

Youguo Zhang[a,b,*]

[a] Institute of Quantitative & Technical Economics, Chinese Academy of Social Sciences, Address: No. 5, Jianguomennei Street, Beijing 100732, China
[b] Center for Environment and Development, Chinese Academy of Social Sciences, Address: No. 5, Jianguomennei Street, Beijing 100732, China

ARTICLE INFO

Jel classification:
C67
O18
Q54
Q56
R11
R15

Keywords:
Carbon emissions
Interregional spillover-feedback effects
Multi-regional input-output model

ABSTRACT

A three-region input–output model was applied in this study to analyze the emission spillover–feedback effects across the eastern, middle, and western regions of China. Results revealed that the interregional trade has important spillover effects (SEs) on the emissions of each region, particularly in the middle and western regions, but the feedback effects are few. Although the eastern regional final demands have a smaller economic SE per unit than those of the middle and western regions in 2002–2010, its emission SE gradually exceeded that of the two other regions. The interregional trade policy has to be enforced in the future, but the emission SEs should be controlled efficiently. Therefore, the central government should continue to implement the policies on the reduction of energy and carbon intensities from the past decade, limit coal consumption, and encourage renewable fuel development. At the same time, the central government and the eastern region can help the middle and western regions control their carbon intensity by providing fiscal, technological, and training assistance. The middle and western regions should set strict admittance standards for energy-intensive plants that transferred from the eastern region.

1. Introduction

China, as the largest developing country in the world, had experienced not only an accelerated economic growth but also a rapid increase in its carbon emissions over the past decade. Our estimation based on the data from the National Bureau of Statistics of China (NBSC) indicates that China's carbon emissions increased annually by 7.5% in 2000–2014. China has implemented many policies to control its carbon emissions growth rate and aims to reach its peak carbon emissions by 2030 or earlier. One of China's strategies for emissions mitigation is implementing regional-specific policies. Thus, the interregional emission spillover–feedback effects (SFEs) arising from interregional trade should be seriously considered when designing the emissions mitigation policies for China.

On one hand, the interregional spillover effect (SE) was considered one of the important factors in China's economic growth (Bai et al., 2012). Previous literature (e.g., Chen and Yang, 2015) also proposed that emissions growth in China is mainly caused by economic growth. In other words, the interregional SE had contributed to the overall emissions growth of the country. On the other hand, using the input–output (I–O) method, previous studies (Zhang and Zhao, 2006; Pan and Li, 2007; Pan, 2012; Peng and Wu, 2009; Wu and Zhu, 2010) determined significant interregional economic SFEs between the coastal (or eastern) region and the inland (or the middle and western) regions in China. These results imply that interregional trade has a direct influence on the SFEs and consequently on regional emissions.

Substantial interregional emissions transfer in China were also observed by other earlier studies using the multiregional input–output (MRIO) model (e.g., Feng et al., 2013; Su and Ang, 2014; Zhang et al., 2014; Zhang and Tang, 2015), which partly proves the same theory on interregional trade. International exports in the coastal region were even considered by some other studies to enhance SEs on emissions in China's other regions (Meng et al., 2013; Tang et al., 2014); however, they failed to consider the SEs of other final demands, such as consumption and capital formation.

Furthermore, the studies focusing on economic SFEs (e.g., Pan and Li, 2007) indicated that the economic spillover multiplier (SM) of the inland region was greater than that of the coastal region. However, the studies focusing on interregional emissions transfer (e.g., Feng et al., 2013) determined that the carbon intensity of domestic imports to the inland provinces was larger than their domestic exports. Thus, the emission SM of the inland region may not be greater or smaller than that of the coastal region. In addition, several studies (Su and Ang, 2011; Zhang et al., 2015) analyzed the emission feedback effect (FE) or SM at the international level.

The purpose of this study is to evaluate the carbon emission SFEs of the eastern, middle, and western regions in China by using the MRIO model and attempt to fill the gap in recent academic discussion on

* Correspondence address: Institute of Quantitative & Technical Economics, Chinese Academy of Social Sciences, Address: No. 5, Jianguomennei Street, Beijing 100732, China.
E-mail address: zhyouguo@cass.org.cn.

http://dx.doi.org/10.1016/j.enpol.2016.10.012
Received 12 May 2016; Received in revised form 8 September 2016; Accepted 14 October 2016
0301-4215/

interregional environmental SFEs.[1] We conducted an empirical analysis of the emission SFEs and their changes during the period of 2002–2010 and compared interregional emission and economic SFEs. The remainder of this paper is organized as follows: Section 2 presents the method for calculating the interregional emission SFEs. Section 3 reports the empirical results. Section 4 concludes the study and discusses the policy implications of the results.

2. Methodology

2.1. Interregional multiplier decomposition

The study on SFEs can be traced back to the work of Miller (1963, 1966, 1969), who introduced the method for analyzing interregional FEs with the I–O model. Stone (1985) and Pyatt and Round (1979) developed a framework for analyzing SFEs based on the social accounting matrix (SAM) of an economy. Round (1985) proposed a method utilizing a three-region SAM. Finally, Round (2001) and Dietzenbacher (2002) presented their analysis method based on a two-regional I–O model, which is the most frequently used method in previous studies. However, to the best of our knowledge, no method for more than three regions exists.[2] Following Round (1985), Round (2011), and Dietzenbacher (2002), we established our method with a three-region I–O model.

Without loss of generality, we assume a closed economy divided into three regions, namely, A, B, and C, with interregional trade. Each regional economy consists of n sectors. In the popular Leontief IO model, the final demand categories are generally regarded as the exogenous variable. For convenience, we take region A as an example. To produce its final demands, region A may use three types of inputs: intraregional intermediate input, intermediate inputs from regions b and c, and primary inputs.

Many interaction mechanisms exist across regions. From the perspective of economics, interregional SFEs are caused by various economic activities in each region and transmitted via interregional trade or interregional intermediate inputs. First, the changes in the final demand of region A bring intraregional effect (IE) on changes in its total output and related emissions via intraregional intermediate inputs. Second, intermediate inputs from other regions are adjusted to meet the requirement of the modified final demand of region A. Such adjustment gives rise to SEs, that is, the changes in the total outputs and emissions of other regions. Third, the incurred changes in other regions lead to FEs on the economic activities and emissions of region A. According to the Leontief IO model (Miller and Blair, 2009), the relationship between final demands and total outputs can be expressed as follows:

$$\begin{pmatrix} x^a \\ x^b \\ x^c \end{pmatrix} = \begin{pmatrix} A^{aa} & A^{ab} & A^{ac} \\ A^{ba} & A^{bb} & A^{bc} \\ A^{ca} & A^{cb} & A^{cc} \end{pmatrix} \begin{pmatrix} x^a \\ x^b \\ x^c \end{pmatrix} + \begin{pmatrix} y^a \\ y^b \\ y^c \end{pmatrix} \tag{1}$$

In Eq. (1), $\boldsymbol{x^r}$ is the output vector of region r (r=a, b, c), and its element x_i^r denotes the output of the ith sector in region r; $\boldsymbol{y^r}$ is the final demand vector of region r, and its element y_i^r denotes the final demand supplied by the ith sector in region r; $\boldsymbol{A^{rs}}$ (s=a, b, c) is the interregional intermediate input coefficient matrix and its element a_{ij}^{rs} ($a_{ij}^{rs}=z_{ij}^{rs}/x_j^s$) denotes the ratio of the intermediate input of the jth sector in region s supplied by the ith sector in region r to the total input of the jth sector in region s; and z_{ij}^{rs} represents the intermediate input supplied by the ith sector in region r and used by the jth sector in region s.

Eq. (1) can be transformed into the following equations:

$$x^a = F^{aa}M^{aa}y^a + F^{aa}U^{ba}M^{bb}y^b + F^{aa}S^{ca}M^{cc}y^c \tag{2}$$

$$x^b = F^{bb}M^{bb}y^b + F^{bb}U^{cb}M^{cc}y^c + F^{bb}S^{ab}M^{aa}y^a \tag{3}$$

$$x^c = F^{cc}M^{cc}y^c + F^{cc}U^{ac}M^{aa}y^a + F^{cc}S^{bc}M^{bb}y^b \tag{4}$$

where

$$F^{aa} = [\mathbf{I} – D^{ab}D^{ba} – S^{ca}(D^{cb}D^{ba} + D^{ca})]^{-1}S^{ca} = (D^{ab}D^{bc} + D^{ac})(\mathbf{I} – D^{bc}D^{cb})^{-1}$$
$$U^{ba} = D^{ab} + S^{ca}D^{cb}D^{ab} = (\mathbf{I} - A^{bb})^{-1}A^{ab}M^{aa} = (\mathbf{I} - A^{aa})^{-1}$$

Similarly, we can define the expressions of $\boldsymbol{D^{ba}}$, $\boldsymbol{D^{cb}}$, $\boldsymbol{M^{bb}}$, $\boldsymbol{M^{cc}}$, $\boldsymbol{F^{bb}}$, $\boldsymbol{F^{cc}}$, $\boldsymbol{S^{ab}}$, $\boldsymbol{S^{bc}}$, $\boldsymbol{U^{cb}}$, and $\boldsymbol{U^{ac}}$.

Eqs. (2)–(4) can be combined into the following expression:

$$\begin{pmatrix} x^a \\ x^b \\ x^c \end{pmatrix} = \begin{pmatrix} F^{aa} & & \\ & F^{bb} & \\ & & F^{cc} \end{pmatrix} \begin{pmatrix} \mathbf{I} & U^{ba} & S^{ca} \\ S^{ab} & \mathbf{I} & U^{cb} \\ U^{ac} & S^{bc} & \mathbf{I} \end{pmatrix} \begin{pmatrix} M^{aa} & & \\ & M^{bb} & \\ & & M^{cc} \end{pmatrix} \begin{pmatrix} y^a \\ y^b \\ y^c \end{pmatrix} \tag{5}$$

Feedback effects Spillover effects Intraregional effects.

On the basis of Eq. (5), the interregional Leontief inverse can be written as follows:

$$L = \begin{pmatrix} L^{aa} & L^{ab} & L^{ac} \\ L^{ba} & L^{bb} & L^{bc} \\ L^{ca} & L^{cb} & L^{cc} \end{pmatrix} = \begin{pmatrix} F^{aa} & & \\ & F^{bb} & \\ & & F^{cc} \end{pmatrix} \begin{pmatrix} \mathbf{I} & U^{ba} & S^{ca} \\ S^{ab} & \mathbf{I} & U^{cb} \\ U^{ac} & S^{bc} & \mathbf{I} \end{pmatrix} \begin{pmatrix} M^{aa} & & \\ & M^{bb} & \\ & & M^{cc} \end{pmatrix}$$
$$= \begin{pmatrix} F^{aa}M^{aa} & F^{bb}U^{ba}M^{bb} & F^{aa}S^{ca}M^{cc} \\ F^{bb}S^{ab}M^{aa} & F^{bb}M^{bb} & F^{bb}U^{cb}M^{cc} \\ F^{cc}U^{ac}M^{aa} & F^{cc}S^{bc}M^{bb} & F^{cc}M^{cc} \end{pmatrix}$$

The total carbon emissions caused by the final demands of region A can be expressed as

$$\begin{aligned}
&[(\boldsymbol{\eta}^{\mathrm{a}})^{\mathrm{T}},\ (\boldsymbol{\eta}^{\mathrm{b}})^{\mathrm{T}},\ (\boldsymbol{\eta}^{\mathrm{c}})^{\mathrm{T}}][(L^{aa})^{\mathrm{T}},\ (L^{ba})^{\mathrm{T}},\\
&(L^{ca})^{\mathrm{T}}] = (\boldsymbol{\eta}^{\mathrm{a}})^{\mathrm{T}}F^{aa}M^{aa} + (\boldsymbol{\eta}^{\mathrm{b}})^{\mathrm{T}}F^{bb}S^{ab}M^{aa} + (\boldsymbol{\eta}^{\mathrm{c}})^{\mathrm{T}}F^{cc}U^{ac}M^{aa}\\
&= (\boldsymbol{\eta}^{\mathrm{a}})^{\mathrm{T}}M^{aa} + (\boldsymbol{\eta}^{\mathrm{b}})^{\mathrm{T}}S^{ab}M^{aa} + (\boldsymbol{\eta}^{\mathrm{c}})^{\mathrm{T}}U^{ac}M^{aa} + [(\boldsymbol{\eta}^{\mathrm{a}})^{\mathrm{T}}(F^{aa} - \mathbf{I})M^{aa}\\
&+ (\boldsymbol{\eta}^{\mathrm{b}})^{\mathrm{T}}(F^{bb} - \mathbf{I})S^{ab}M^{aa} + (\boldsymbol{\eta}^{\mathrm{c}})^{\mathrm{T}}(F^{cc} - \ )U^{ac}M^{aa}]
\end{aligned} \tag{6}$$

where $\boldsymbol{\eta^r}$ represents the sector output-based carbon intensity vector of region r (r=a, b, c), superscript 'T' stands for transposition, $(\boldsymbol{\eta^a})^{\mathrm{T}}\boldsymbol{M^{aa}}$ denotes the emission intraregional multiplier (IM) of region A, $(\boldsymbol{\eta^b})^{\mathrm{T}}\boldsymbol{S^{ab}M^{aa}}$ denotes the emission caused by region A on region b, and $(\boldsymbol{\eta^c})^{\mathrm{T}}\boldsymbol{U^{ac}M^{aa}}$ is the emission SMs caused by region A on region c. The feedback multiplier (FM) of region A can be written as $(\boldsymbol{\eta^a})^{\mathrm{T}}(\boldsymbol{F^{aa}}–\mathbf{I})\boldsymbol{M^{aa}}+(\boldsymbol{\eta^b})^{\mathrm{T}}(\boldsymbol{F^{bb}}–\mathbf{I})\boldsymbol{S^{ab}M^{aa}}+(\boldsymbol{\eta^c})^{\mathrm{T}}(\boldsymbol{F^{cc}}–\mathbf{I})\boldsymbol{U^{ac}M^{aa}}$. We can also obtain the expressions of the SFEs of the other regions, as shown in Table 1. If we define $\boldsymbol{\eta^r}$ as the unit vector, then the above multipliers are economic multipliers, as defined in previous studies (Dietzenbacher, 2002), but not emission multipliers. Hence, emission multipliers can be decomposed into or determined by economic multipliers and sector carbon intensity.

As shown in Fig. 1, the IE denotes the influence of the final demands in a region on the economy and emissions in the same region. We use region A as an example to explain the mechanism of IE briefly. Standard macroeconomic theory states that the final demands, such as consumption, investment, and exports, in region A are the driving factors of the region's economy. Producers in region A will use various means, such as labor, capital, and intermediate materials, to produce final used goods to satisfy the final demands of the people. As a result, emissions will be generated during production. SE occurs because the producer in region A will utilize intermediate materials produced by other regions. Thus, the regional final demands can influence the economies and emissions in other regions. Similarly, other regions also have the need to use intermediate materials supplied by region A to maintain their economic system. Thus, the economic activities in other

[1] On one hand, most of the previous regional spillover–feedback effect studies are conducted at three or two larger regions and focus on economic effect. On the other hand, the decision makers in China are used to analyzing regional development and making related policies at the three larger regions.

[2] According to Round (1985), one problem in establishing the method for more than three regions is that the multiplier decomposition is not unique. Another problem is that generalizing the multiplier decomposition for higher-order regional systems is difficult.