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What drives intersectoral CO_2 emissions in China?

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ABSTRACT

Aiming to identify the intersectoral linkage of larger CO_2 emissions sectors, this paper studies the CO_2 emissions elasticity of technical and final demand coefficients using the input–output technique. The results show that the greatest emission-coefficient elasticities are those related to transactions between *Construction* and *Manufacture of Non-metallic Mineral Products*, between *Gross fixed capital formation* and *Construction*, and between *Agriculture* and *Processing and Manufacture of Food*, and *Production and Supply of Electric Power and Heat Power* and *Mining and Washing of Coal*. All these transactions between these sectors imply that CO_2 emissions control policy only for a specific sector maybe have no obvious CO_2 emissions mitigations if national government promote the growth of those sectors, which have the biggest emission-coefficient sensitivity with it. Now Chinese government formulates the policy to promote new-type urbanization, urbanization will cause the *Gross fixed capital formation* in *Construction*, and the more demands for the products of *Manufacture of Non-metallic Mineral Products Production, Smelting and Pressing of Ferrous Metals* and *Supply of Electric Power and Heat Power*, so how to balance the carbon emissions in larger emissions sectors and rapid urbanization is a big challenge for decision-makers.

1. Introduction

China's booming economy, particularly in the manufacturing sectors, has driven rapid growth in CO_2 emissions. Based on CDIAC (Carbon Dioxide Information Analysis Center) data, China surpassed the United States in 2006 to become the largest CO_2 emitter in the world. China released nearly 1.92 billion tons of carbon into the atmosphere in 2008, which is twice as much as it emitted in 2002; China accounts for nearly 20% of global CO_2 emissions and 50% of the global increase from 2002 to 2008 (CDIAC, 2013). According to the IEA, China's CO_2 emissions will equal the sum of the emissions of the United States and the countries comprising the European Union in 2015 and will surpass the total emissions of the OECD countries in 2030 (IEA, 2011). Understandably, China faces great pressure to reduce its CO_2 emissions.

China set a goal of reducing its CO_2 emissions per unit of gross domestic product (GDP) in 2020 by 40–45% compared to 2005 levels (Cong and Wei, 2010). In addition, in its twelfth five-year plan, China has set a target of reducing CO_2 emissions per unit of GDP in 2015 by 17% compared to 2010 levels. To efficiently achieve its targets in 2015 and 2020, the following questions should be answered: Which sectors should be responsible for carbon emissions reductions? Which factors primarily affect emissions in key sectors? What are relationships between these key sectors? To answer the above questions – at least in part – it is useful to undertake a quantitative analysis of China's sectoral carbon emissions.

There is abundant literature on the forces driving changes in carbon emission. In the literature, three methods have been widely used to determine the identity of such forces: (1) the "IPAT" and "STIRPAT" methodologies, which show the relative effects of different factors, such as population, GDP, energy intensity, etc.; (2) decomposition techniques, including structural decomposition analysis (SDA) and the index decomposition analysis (IDA), which show the contribution of every factor including GDP, economic structure, energy mix, etc.; and (3) a sensitivity analysis that is based on an input–output method, which can identify those transactions between economic sectors and final demands which lead to the highest growth in emissions – but the literature is scant on this final methodology. Only Tarancón and Del Río (2007a, b, 2012) undertook this type of methodology, and analyzed the elasticity of technical and final demand coefficients for carbon emissions in Spain.

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Table 1 shows the references for Chinese carbon emission studies, which can tell us that the first two methods (IPAT/STIRPAT and IDA/SDA) were widely applied, but sensitivity analysis focusing on Chinese carbon emissions is lacking. The studies based on the IDA/SDA method show the quantitative impacts of the main drivers, such as economic growth, energy intensity, energy mix and economic structure on the change of CO_2 emissions over time. Those studies based on IPAT or STIRPAT show the relative importance of GDP per capita, carbon/energy intensity, population and other factors on total national carbon emissions or sectoral emissions, but cannot identify intersectoral relationship "map" related to CO_2 emissions, therefore, it is difficult to provide comprehensive policy suggestions because of methodological limitations. In fact, the production behavior in one sector is not isolated, but is driven by the intermediate demands of other sectors and final demands from urban household, rural household, export, government expenditure, etc.

To identify the most important intersectoral relationship "map" for CO_2 emissions and to contribute to the existing literature, this paper uses a sensitivity methodology within an input-out framework that aims to assess the effect of several coefficients on emissions, including the final demand coefficients and technical coefficients that make up the economic system. Accordingly, this paper is organized as follows. In Section 2, we introduce the theoretical analysis framework, sensitivity analysis method based on an input–output model, and data source then describes sectoral CO_2 emissions in detail. The empirical sensitivity analysis results for Chinese CO_2 emissions are discussed in Section 3. Finally, we present conclusions and policy implications.

2. Methodology and data

2.1. Research framework

Within the input–output model, CO_2 emissions can be calculated based on Eq. (1).

$$e = \widehat{C}BHg \tag{1}$$

where e is the $(n \times 1)$ vector of CO_2 emissions by sector; $\widehat{C}$ is the $(n \times n)$ diagonal matrix of carbon intensity; B is Leontief inverse matrix, $(I - A)^{-1}$, that identifies the direct and indirect resources used in one unit of output per sector; H is the $(n \times m)$ final demand coefficients matrix; and g is the $(m \times 1)$ final demand aggregates vector. For detailed information about Eq. (1), please refer to Tarancón and Del Río (2007a).

Based on Eq. (1), we can know that CO_2 emissions depend on CO_2 emissions intensity and on economical scale, as shown in Fig. 1. Within an input–output framework, economic scale refers to the final demand including household consumption, governmental consumption, gross fixed capital formation, changes in inventory, and exports to other countries; CO_2 emissions intensity is total carbon emissions intensity, which is computed by multiplying direct carbon intensity with the Leontief inverse matrix.

2.2. Sensitivity analysis based on an input–output framework

(1) Sensitivity analysis of the technical coefficients

From Eq. (1), we can infer the elasticities for non-zero technical coefficients with Eq. (2),

$$\varepsilon_{e_i a_{kl}} = \frac{\Delta e_i / e_i}{\Delta a_{kl} / a_{kl}} \tag{2}$$

In view of the relationship between technical coefficients and Leontif inverse matrix, the change of the former will have an effect on the latter. Based on Sherman and Morrison (1950),

$$\Delta b_{ij} = \frac{b_{ik} b_{lj} \Delta a_{kl}}{1 - b_{lk} \Delta a_{kl}} \tag{3}$$

Then Eq. (2) can be expressed as Eq. (3).

$$\varepsilon_{e_i a_{kl}} = \frac{a_{kl} x_l b_{ik}}{(1 - a_{kl} b_{lk}) x_i} \tag{4}$$

where $\varepsilon_{e_i a_{kl}}$ expresses the percentage of increase in carbon emissions in sector i in response to a 1% change in the technological coefficient; e_i expresses the emissions of sector i, $i = (1, 2, \ldots, n)$; a_{kl} represents the technological coefficients, $a_{kl} = (x_{kl}/x_l)$ with $k = (1, 2, \ldots, n)$ and $l = (1, 2, \ldots, n)$; x_i and x_l express the output of sectors i and l; b_{ik} and b_{lk} are the elements of the Leontief inverse matrix B.

(2) Sensitivity analysis of the final demand coefficients

The elasticity of demand coefficients can be expressed as following:

$$\varepsilon_{e_i h_{kl}} = \frac{\Delta e_i / e_i}{\Delta h_{kl} / h_{kl}} = \frac{b_{ik} h_{kl} g_l}{x_i} \tag{5}$$

where $\varepsilon_{e_i h_{kl}}$ expresses the percentage of increase in carbon emissions in sector i in response to a 1% change in a final demand coefficient; h_{kl} expresses the final demand coefficients, $h_{kl} = (y_{kl}/g_l)$; g_l expresses the final demand aggregate l; and y_{kl} expresses the production of sector k bought by the final demand aggregate l, $l = (1, 2, \ldots, m)$.

(3) The calculation of sectoral CO_2 emissions

Sectoral CO_2 emissions are calculated as:

Table 1
The studies for the driving forces of China's carbon emissions.

Method	Studies	Characteristics
Decomposition method including SDA and IDA	Dong et al. (2010), Du et al. (2011), Fan et al. (2007, 2013); Guan et al. (2008), Lee and Oh (2006), Liang and Zhang (2011), Peng and Shi (2011), Liu et al. (2007, 2011, 2012), Loo and Li (2012), Meng and Niu (2012), Steenhof (2007), Sun et al. (2011), Tan et al. (2011), Wang et al. (2005, 2011b), Wu et al. (2005, 2006), Xu et al. (2011, 2012), Yan and Yang (2010), Zha et al. (2010), Zhang et al. (2009a, b, 2011, 2013a, b), Zhang (2009, 2010), Zhu et al. (2012), Wei et al. (2010)	Based on data during the different periods, this method can show the quantitative effects of every factor but cannot present the effects of intersectoral linkage on carbon emissions.
IPA or STIRPAT	Wang et al. (2011a, 2012), Li et al. (2011, 2012), Lin et al. (2009), Fan et al. (2006), Shao et al. (2011), Zhu and Peng (2012), Wei et al. (2010)	Based on an econometric model, this method shows the relative importance of every factor but cannot present the effects of intersectoral linkage on carbon emissions.
Sensitivity analysis	No empirical analysis of Chinese carbon emissions.	This method can allow the identification of those transactions between economic sectors and final demands which lead to the highest growth in emissions.