Study on the mechanism of the influence of structural change on China's carbon emissions

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Abstract. Revealing the influential mechanism of important factors on carbon emissions of economy or industry is the premise of formulating effective emission reduction policies and implementing positive emission reduction measures, and also a hot research topic in academic circles. This dissertation constructs a theoretical model for analysing the mechanism of carbon emission impacts considering structural factors. The impacts of changes in demand and supply linkages in the production links of the economic subsystem are incorporated into the decomposition model, and key industries and factors affecting carbon emissions at the production and demand sides are identified and quantitatively analysed from the perspective of the subsystem. The main conclusions are as follows: The change in energy use structure and production efficiency is the main reason for the downward trend of carbon emissions. The effect of the change of demand structure on emission reduction is far less than that of the change of production structure factors, and the change of demand structure is not always advantageous to emission reduction during the research period. In the short term, promoting the optimization of production and demand structure is still an important effort to promote emission reduction. In the long run, the emission reduction effect of energy structure optimization is the most significant.

1. Introduction
To promote sustainable economic development and achieve phased energy conservation and emission reduction targets, in recent years, the Chinese government has focused on promoting energy-saving renovation and industrial upgrading of high-energy-consuming industries, exerting supply-side reforms and optimizing energy structure. At the same time, China’s economy has slowed down during the “Twelfth Five-Year Guideline” period, economic development has entered a new normal, and economic growth has shifted from high-speed growth to high-quality growth. During the “Twelfth Five-Year Guideline” period, China’s carbon dioxide emissions per unit of GDP fell by more than 20%, coal consumption fell by 5.2 percentage points, and coal consumption experienced negative growth during 2014-2016. However, in the case of steady growth in economic growth, coal consumption in 2017 showed an increasing trend, corresponding to the acceleration of the growth rate of total energy consumption at the time, and the growth rate of power consumption was a sharp rebound. It can be seen that energy consumption demand is significantly affected by the industrial structure and economic growth model. With the stabilization and recovery of China’s economy, it is foreseeable that energy consumption demand still has sustained growth momentum [1]. The pressure of emission reductions caused by the growth of carbon emissions related to energy consumption...
cannot be ignored. Considering the impact of industrial correlation, identifying the impact mechanism of structural factors on carbon emission growth has practical significance for achieving emission reduction targets.

The current methods used to analyze the factors affecting the overall carbon emissions of the economy include IDA and SDA. Compared with the IDA decomposition method, the structural decomposition method based on the input-output model facilitates the analysis of the correlation of production within the economic system. The model can not only measure the direct impact of influencing factors on carbon emissions, but also measure the impact of structural changes between industries [2-3]. At present, structural decomposition analysis methods have received extensive attention in the study of the assessment of the impact mechanism of economic system production and consumption-side emissions changes, especially on the changes in the structure of production and demand in the economic sector and the impact of changes in final demand [4].

The core of the input-output model is the Leontief inverse matrix model and the Ghosh model. The Leontief inverse matrix model is mainly used for the analysis of energy and carbon emissions from the demand perspective [5-7]. In contrast, the Ghosh model is widely used for the analysis of energy and carbon emissions from supply angles [8-9]. From an industry perspective, the results obtained based on different measurement principles will vary greatly. Therefore, many studies have simultaneously evaluated the impact of relevant factors from both the demand and supply perspectives [10-11]. However, these studies focus on the factors that influence the change in emission intensity. Besides, most of the articles using SDA for the analysis of driving factors will analyze the change of the direct consumption coefficient matrix in the input and output as a whole or split it into manufacturing factors and substitution factors. Few studies have included changes in the subsystem’s production demand structure into the analysis of carbon emissions impacts. In fact, the changes in the consumption relationship in the economic industrial structure reflect both the changes in the industrial structure and the changes in the industrial linkages.

This paper proposes a new processing method, combined with subsystem analysis ideas, to divide the economic sectors of input-output tables, to a certain extent, to further analyze the economic and environmental impacts of industrial clusters in the economic system. Exploring the impact of these changes on carbon emissions from the perspective of subsystems can provide a new perspective for fully understanding the mechanism of carbon emission changes in China, and provide a reference for the formulation of low-carbon development policies at the industrial system level.

2. Method

2.1 Subsystem Extension Model

Subsystem input-output model was first proposed by reference [12], and has been widely used in the study of emission drivers in economic systems. Current subsystem models often focus on only one department or system, and do not consider the impact of structural changes within subsystems. Referring to the framework of the subsystem model, this study constructs an extended subsystem model, which divides the departments in the input-output model into six subsystems: energy production and supply, agriculture, industry, construction, transportation and other subsystems. Combined with the basic input-output model, the following subsystem extension model is constructed:

\[
\begin{bmatrix}
A_{EE} & A_{EN} & A_{EM} & A_{EJ} & A_{ET} & A_{EO} \\
A_{NE} & A_{NN} & A_{NM} & A_{NJ} & A_{NT} & A_{NO} \\
A_{ME} & A_{MN} & A_{MM} & A_{MJ} & A_{MT} & A_{MO} \\
A_{JE} & A_{JN} & A_{JM} & A_{JJ} & A_{JT} & A_{JO} \\
A_{TE} & A_{TN} & A_{TM} & A_{TJ} & A_{TO} & A_{TO} \\
A_{OE} & A_{ON} & A_{OM} & A_{OJ} & A_{OT} & A_{OO}
\end{bmatrix}
\begin{bmatrix}
Y_E \\
Y_N \\
Y_M \\
Y_J \\
Y_T \\
Y_O
\end{bmatrix}
= \begin{bmatrix}
f_E \\
f_N \\
f_M \\
f_J \\
f_T \\
f_O
\end{bmatrix}
\]

Subscripts E, N, M, J, T and O represent energy production and supply sectors, agriculture, industry, construction, transportation and others.

2.2 Extended Structural Decomposition Model.

The decomposition analysis method is widely used to analyze the influencing factors of energy and
emission. If \( L = (I - A)^{-1} \) the demand-oriented carbon emission measurement formula can be expressed as:

\[
\hat{\varrho} = e(I - A)^{-1} f = \rho \cdot E_i \cdot E_i \cdot L \cdot FS \cdot F
\]

(2)

It represents the total emission matrix of the economic system generated by the final demand, in which \( \rho, E_i, E_i, L, FS \) and \( F \) respectively represent the total emission of the economic system or industry, carbon emission coefficient, energy structure, energy consumption intensity, production-technology relationship, final demand structure and final demand scale.

Based on formula 2, the changes of carbon emissions during \( t_1 \) and \( t_0 \) can be calculated by the following expressions:

\[
\Delta \hat{\varrho} = \hat{\varrho}^1 - \hat{\varrho}^0
\]

(3)

We can decompose the emission effects of energy intensity \( \Delta E_i \), Leontief inverse matrix \( \Delta L \), and final demand structure \( \Delta FS \), respectively. In order to deeply analyze the impact of changes in economic relations of production, this study will further decompose the changes of Leontief inverse matrix \( \Delta L \).

The basic properties of Leontief inverse matrix show that:

\[
\Delta L = L^1 - L^0 = L^1 (A^1 - A^0) L^0
\]

(4)

In this study, \( \hat{A} \) is introduced, where \( \hat{A}^i = A^i S_i^{-1} S_i \), \( S_i = \text{diag}(e_i \cdot A) + I - E_i \); \( e_i \) is the column vector of element 1; \( I \) is the unit matrix, and \( E_i = \hat{E}_i(A^i) \) means that the distribution of matrix column is the same as that of period \( t_1 \), and column is the same as that of period \( t_0 \).

Total emissions from supply-oriented sources can be measured by the following formula:

\[
\beta = V \cdot V_s \cdot (I - H)^{-1} \cdot \hat{E}_i \cdot \rho = V \cdot V_s \cdot G \cdot \hat{E}_i \cdot \rho
\]

(5)

\[
H = \hat{X}^{-1} Z = \begin{bmatrix}
Z_{11} & \ldots & Z_{1u} \\
x_1 & \ldots & x_1 \\
Z_{21} & \ldots & Z_{2u} \\
x_2 & \ldots & x_2 \\
\vdots & \vdots & \vdots \\
Z_{u1} & \ldots & Z_{uu} \\
x_u & \ldots & x_u
\end{bmatrix}
\]

(6)

\[
G = (I - H)^{-1}
\]

(7)

Based on formula 7, the emission changes during \( t_1 \) and \( t_0 \) periods can be measured by the following expressions:

\[
\Delta \beta = \beta^1 - \beta^0
\]

(8)

Similarly, the average complete decomposition method is used to calculate the emission change. Referring to the decomposition form of \( \Delta \hat{e} \), we can decompose the emission change into GDP impact (\( \Delta \hat{e} \)), industrial structure impact (\( \Delta ed \)), supply structure impact (\( \Delta G \)), energy structure impact (\( \Delta E_i \)), energy intensity impact (\( \Delta E_i \)) from the perspective of supply. Volume decomposition form reference table.

3. Comparative analysis of the influence mechanism of structural changes

3.1. Sources and composition of carbon emission.

Based on the calculation expressions of demand and supply, the distribution of sub-systems of carbon emission sources can be obtained. The specific results are shown in table 1 and table 2. It can be seen from the table that the total carbon emissions in China increased significantly within the research range. In 2015, the total carbon emissions related to fossil energy consumption exceeded 9 billion tons, an increase of about 50% compared with 2007. In terms of economic subsystem division, whether...
Based on the perspective of demand or supply measuring way, the impact of industrial sectors and other industries (mainly the tertiary industry) on carbon emissions has remained relatively stable on the whole. Among them, the impact of industrial sector emissions is at a high level, but the increase in the scale of industrial imports has gradually increased the impact of China's demand side emissions. Compared with these economic subsystems that are less affected by measurement methods, the emissions of energy sectors, buildings and transportation systems vary greatly under different measurement methods. The contribution of energy supply to emissions is less than 4% under the measurement principle of demand, which is about 10 times different from the result of supply. Similarly, there are considerable differences between different accounting principles in construction and transportation, especially in construction.

Based on the analysis of the types of economic subsystems, it can be found that the production activities of energy and transportation systems mainly provide auxiliary services for the overall production of the economic system, and the products or services used for the final demand account for a small proportion of the total output value. Meanwhile, the final demand of construction increased from 22% of the industry's total output in 2007 to 25.6% in 2015. At the same time, the corresponding demand-side emission proportion increased significantly from 32.2% to 37.4%. The growth rate of the emission proportion was much higher than that of the final demand proportion. Relatively speaking, other sectors corresponding to the proportion of emissions has decreased. The growth of the final demand of the construction industry is mainly reflected in the growth of China's real estate and infrastructure construction investment, which reflects the driving effect of infrastructure investment on emissions. From 2007 to 2015, the proportion of total capital formation in the final use in China increased by about 2 percentage points. The driving effect of fixed asset investment on emissions shows obviously amplification effect. From the perspective of demand, when the construction industry meets the final demand, it consumes a lot of energy, such as steel, cement and other building materials, leading to this result.

Table 1. Carbon emission subsystem distribution from the perspective of demand.
(unit: 10,000 tons)

| Sector   | 2007     | Percent | 2012     | Percent | 2015     | Percent |
|----------|----------|---------|----------|---------|----------|---------|
| Agriculture | 14065.3  | 2.2%    | 16501.9  | 2.0%    | 11369.0  | 1.2%    |
| Energy    | 24816.9  | 3.8%    | 20763.7  | 2.6%    | 27623.4  | 2.9%    |
| Industrial | 264959.8 | 41.1%   | 355578.0 | 43.9%   | 383710.6 | 40.2%   |
| Construction | 207510.0 | 32.2%   | 254554.6 | 31.4%   | 357660.7 | 37.4%   |
| Transport | 20658.2  | 3.2%    | 30181.6  | 3.7%    | 19954.6  | 2.1%    |
| Other     | 113017.2 | 17.5%   | 133019.1 | 16.4%   | 155019.5 | 16.2%   |
| Total     | 645027.4 | 100.0%  | 810599.0 | 100.0%  | 955337.7 | 100.0%  |

Table 2. Carbon emission subsystem distribution from the perspective of supply.
(unit: 10,000 tons)

| Sector   | 2007     | Percent | 2012     | Percent | 2015     | Percent |
|----------|----------|---------|----------|---------|----------|---------|
| Agriculture | 25716.4  | 4.2%    | 24749.8  | 3.1%    | 38292.7  | 4.1%    |
| Energy    | 254273.9 | 41.4%   | 325442.3 | 41.3%   | 314205.0 | 33.6%   |
| Industrial | 201689.4 | 32.8%   | 248527.0 | 31.5%   | 305829.5 | 32.7%   |
| Construction | 2201.6  | 0.4%    | 3308.4   | 0.4%    | 3974.4   | 0.4%    |
| Transport | 40996.2  | 6.7%    | 50171.2  | 6.4%    | 67282.0  | 7.2%    |
| Other     | 89552.9  | 14.6%   | 136377.6 | 17.3%   | 205794.2 | 22.0%   |
| Total     | 614430.4 | 100.0%  | 788576.3 | 100.0%  | 935377.9 | 100.0%  |

3.2. Subsystem carbon emission variation difference analysis and typical industry identification.

On the whole, the increase of demand-side emissions is mainly attributed to the influence of the increase of demand of construction, industrial and tertiary industry. The contribution rate of
construction industry to total emissions reached 71.2% in 2012-2015, 28.4% in 2007-2012 and 48.4% in 2007-2015 respectively. The growth of industrial demand also has a significant impact on emissions, and the corresponding emission contributions in the research range are 19.4%, 54.7% and 38.3% respectively. The impact of the demand growth of the tertiary industry on emissions remains relatively stable, with the corresponding contribution of 15.2%, 12.1% and 13.5% respectively in the research range. Compared with construction industry, industry and tertiary industry, the relative contribution rates of energy supply industry, agriculture and transportation are all relatively weak in each research interval.

From the perspective of supply, the production activities of energy production and supply industry, industrial and tertiary industry contribute the most to the change of total emissions of the whole society. Among them, the contribution of energy production and supply to total emissions shows a downward trend. Specifically, the contribution of emissions in 2012-2015, 2007-2012 and 2007-2015 was 33.6%, 32.2% and 23.5% respectively. The overall contribution of industrial emissions showed an upward trend, and recently exceeded the emission impact of energy supply, corresponding to the emission contribution of 29.6%, 44.4% and 42.4% in the same research interval respectively. The emission from the production activities of most industrial production sectors shows an increasing trend year by year, which leads to the overall emission growth of the industrial system. The impact of the tertiary industry's production activities on emissions fluctuates to a certain extent, and the corresponding contributions within the corresponding range are 26.0%, 16.5% and 23.8% respectively. In addition, similar to the demand-oriented calculation results, the relative contribution rates of agriculture and transportation are also weak in each corresponding research interval. It is worth noting that the contribution rate of transportation sector to emissions relative to demand guidance is increased by several times under the supply-oriented calculation method.

From the results of the impact of the change of intermediate input structure, it can be found that the change of the direct demand structure of the economic sector for the energy supply industry significantly promotes the decline of the emissions from the demand perspective of the industry, construction and the tertiary industry, reflecting the overall energy structure optimization of emission reduction effect. It can be seen that the optimization of energy use structure significantly promotes the overall process of emission reduction. The actual emission reduction effect produced by the optimization of energy use structure is reflected in most subsystems. In addition, economic sectors have a relatively weak impact on the emission caused by the change in the consumption structure of industrial system products, and this change has a greater impact on the emission of the tertiary industry than the industry itself. At the same time, the impact of structural changes of consumption on buildings and agriculture is also weak.

From the perspective of supply, the change in the supply structure of agriculture and the tertiary industry promotes the emission reduction, which is the main cause of promoting the overall emission reduction of subsystems and society. The feedback effect of changes in the supply structure is greater than the spillover effect in most systems, except in the construction industry. Energy, industrial and tertiary industry are most affected by the change of their own intermediate demand rate, indicating that the proportion of the products of these industries used for intermediate consumption in the research range has more impact on their own emissions. Comparatively speaking, the emission impact brought by the change of demand rate in the construction sector is more affected on the industrial sector.

4. Conclusion
With the development of social economy, China's carbon emissions increased significantly from 2007 to 2015. From the demand perspective, the carbon emission mainly comes from industrial systems, but the relative importance of industrial systems does not increase in the research interval. In contrast, the contribution of construction industry to total emissions has increased significantly, and the impact of construction industry on emissions changes from 2007 to 2015 is even greater than that of the industrial system. From the perspective of supply, the energy supply industry, especially the power industry, has the greatest impact on the total social emissions, which reflects the characteristics of the basic industry of the power industry. With the optimization of economic structure and the increase of the proportion of tertiary industry, its impact on emissions cannot be ignored, especially producer services. There is still much room for improvement to reduce the intermediate demand rate of
industrial products and optimize the industrial supply structure.

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