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Determinants of Carbon Emissions Growth in China: A Structural Decomposition Analysis

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Abstract

Based on 1992-2005 input-output tables at comparable price and using structural decomposition method (SDA), the paper decomposes carbon emissions growth from energy consumption in China into 4 categories of factors: carbon emissions intensity, technology, domestic final demand and trade. Carbon emissions have a trend of accelerated growth and the decisive factor is domestic final demand, not trade. Intensity of carbon emissions plays a significant restrain effect, entirely benefit from energy efficiency, rather than energy substitution. The effect of technical change leads to the growth of carbon emissions, reflecting the technology structure developed towards high energy consumption and emissions.

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Keywords: Carbon Emissions; Input-Output Method; Structural Decomposition; General Equilibrium;

1. Introduction

In recent years, extreme weather has appeared frequently. Greenhouse gas emissions have caused great attention over the world. It was reported by IEA [1] that China's carbon emissions from the consumptions of fossil fuels exceeded the emissions of U.S. in 2007, which made China face tremendous political pressure in the international climate negotiations.

How to effectively reduce carbon emissions is the realistic problem. Exploring the determinants of growth in carbon emissions is prerequisite to solve the problem. There were some studies decomposing the changes in carbon emissions into 4 effects-the production scale, the energy structure, emissions

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intensity and energy intensity by using index decomposition analysis (IDA) (Shrestha et al.[2]; Ang et al.[3]). Most of these studies supported that the growth of total output or the drop of energy intensity was determinant factor in increasing or decreasing carbon emissions, respectively. However, IDA has some significant disadvantages. Firstly, the decomposition path is limited that most of the studies get the same items of decomposition. Secondly, it is difficult to understand the economic structural factors behind the changes of carbon emissions, such as the effects of demand, supply, trade and other factors. Method based on structural decomposition analysis (SDA) can compensate the shortcomings of index decomposition method (Gould et al.[4];Wier[5]; Lim et al.[6]). The major decomposition items of SDA method include technology, demand, trade, economic output, etc., and these items can be decomposed further into volume growth and structural changes.

The paper decomposes China's carbon emissions growth in the period of 1992-2005 by the use of SDA. The remainder of the paper is organized as follows. Section 2 describes an overview of structural decomposition analysis. Sources of data of this study are included in Section3. Section 4 reports the results. Section 5 provides the conclusions.

2. Method

Considering the most simple input-output model (excluding export): $X=BY$, where X, B and Y represent total output vector, the Leontief inverse matrix and the final demand vector, respectively. Let t and 0 represent the comparative year and the base year respectively, so the change of the total output can be expressed as follows:

$$X_t - X_0 = B_tY_t - B_0Y_0 = (B_t - B_0)Y_0 + B_0(Y_t - Y_0) + (B_t - B_0)(Y_t - Y_0) \quad (1)$$

Let $\Delta X=X_t-X_0$, $\Delta B=B_t-B_0$, $\Delta Y=Y_t-Y_0$, then:

$$\Delta X = \Delta BY_0 + B_0\Delta Y + \Delta B\Delta Y \quad (2)$$

$\Delta B\Delta Y_0$, $B_0\Delta Y$ and $\Delta B\Delta Y$ respectively represent the effect of changes in intermediate inputs, in final demand and the interaction. As the interaction effect is generally large in the analysis of actual experiences, and it's a problem to explain the change in total output clearly, so it is divided into the items of various decomposition factors in practice. There are two treatment methods following:

$$\Delta X = \Delta BY_t + B_0\Delta Y \quad or \quad \Delta X = \Delta BY_0 + B_t\Delta Y \quad (3)$$

ΔBY_t and ΔBY_0 can be expressed as the impact of B's changes on X, but because of different base year selected, the two results usually differ. To overcome this problem, Li [7] proposed a weighted average decomposition method, but it is too complicated to use. There is an easier approximate solution of the method - bipolar decomposition method. The basic idea of this method is to calculate the arithmetic mean value of two periods, namely:

$$\Delta X = \frac{1}{2}\Delta B(Y_0 + Y_t) + \frac{1}{2}(B_0 + B_t)\Delta Y \quad (4)$$

Referring to the study by Chang et al. [8], we decompose the growth of carbon emissions by bipolar decomposition method into 9 factors, including energy efficiency, energy substitution, technological change, domestic final demand growth, structural changes of domestic final demand, growth of export and import, structural changes of export and import.

According to input-output analysis, the total output can be expressed as follows:

$$X = (I - D)^{-1}Y \quad (5)$$

X is the output vector ($n\times1$), $(I-D)^{-1}$ represents the Leontief inverse matrix ($n\times n$), I refers to the unit matrix ($n\times n$), D is the direct consumption coefficient matrix ($n\times n$), Y represents the final demand vector ($n\times1$). E is energy intensity vector ($1\times n$), which equals energy consumption divided by gross output, and reflects the level of energy efficiency. P represents the carbon emissions coefficient of per unit energy consumption（$1\times n$）, which equals carbon emissions divided by energy consumption.

Therefore, the total carbon emissions (C) can be expressed as the following formula:

$$C = E\widehat{P}(I-D)^{-1}Y \tag{6}$$

Where $\widehat{P}$ is the diagonal matrix ($n\times n$) of P. The changes of carbon emissions between two different periods can be expressed as follows:

$$\Delta C = E_t\widehat{P}_t(I-D_t)^{-1}Y_t - E_0\widehat{P}_0(I-D_0)^{-1}Y_0 \tag{7}$$

Let $\Delta E=E_t-E_0$, $\Delta P=P_t-P_0$, $\Delta Y=Y_t-Y_0$ and $\Delta(I-D)^{-1}=(I-D_t)^{-1}-(I-D_0)^{-1}$. According to the bipolar decomposition method, the following equation can be gotten:

$$\Delta C = E_t\widehat{P}_t(I_t-D_t)^{-1}Y_t - E_0\widehat{P}_0(I-D_0)^{-1}Y_0$$

$$=\frac{1}{2}\Delta E[\widehat{P}_0(I-D_0)^{-1}Y_0+\widehat{P}_t(I-D_t)^{-1}Y_t] \tag{7-a}$$

$$+\frac{1}{2}\Delta P[E_t(I-D_0)^{-1}Y_0+E_0(I-D_t)^{-1}Y_t] \tag{7-b}$$

$$+\frac{1}{2}\Delta(I-D)^{-1}[E_t\widehat{P}_tY_0+E_0\widehat{P}_0Y_t] \tag{7-c}$$

$$+\frac{1}{2}\Delta Y[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}] \tag{7-d}$$

Eq. (7-a) represents the effect of the change in energy efficiency on carbon emissions. Intuitively, it reflects the impact of the energy intensity on carbon emissions. However, as energy intensity reflects the efficiency of energy use, so Eq. (7-a) is essentially a measure of energy efficiency on changes of carbon emissions.

Eq. (7-b) directly reflects the influence caused by the change of carbon emissions coefficient on the changes of carbon emissions, but it essentially expresses the effect of energy substitution on changes of carbon emissions. Since this paper only considers the carbon emissions of energy consumption, the comprehensive carbon emissions coefficient can be calculated by the sum of the weighted carbon emissions coefficients of all kinds of energies:

$$P=\sum_{j=1}^{m}a_jp_j,(j\ refers\ to\ \text{coal, electricity, oil, gas and other energy}) \tag{8}$$

Where a_j represents the proportion of energy j's consumption in the total energy consumption, p_j is the carbon emissions coefficient of energy j. As the carbon emissions coefficient of single energy is usually fixed, the change of P is simply caused by the substitution among different energies. Therefore, Eq. (7-b) essentially reflects the effect of energy substitution.

Eq. (7-c) reflects the impact of the changes in intermediate input coefficients on the changes of carbon emissions. Intermediate input coefficient matrix reflects the direct technological link of economic sectors, so Eq. (7-c) represents the impact of technical change on carbon emissions.

Eq. (7-d) indicates the effect of carbon emissions caused by change of final demand. If considering the effects of trade, the Eq. (7-d) can be further decomposed. We will divide the final demand Y into the domestic final demand and the net foreign demand, that is $Y=Q+S-M$, where Q refers to the domestic final demand, S represents exports and M reflects the imports. Let's give a definition:

$$Y_i^{t0}=\frac{Y_{it}}{\sum_{i=1}^{n}Y_{it}}\sum_{i=1}^{n}Y_{i0},i\ \ refers\ \ to\ \ 1\sim 24th\ \ indutry \tag{9}$$

The meaning of Eq. (9) represents the corresponding final demand of the industry i when the changes of the final demand of industry i's share of total final demand from year 0 to year t, at the same time keep the total final demand (the level of year 0) unchanged. Although a virtual value of final demand, it reflects the effect of changes in the level of final demand resulting from sole changes in structure of final demand. Similarly, Q^{t0}, S^{t0} and M^{t0} reflect the effects of structural changes on the domestic final demand, exports and imports respectively.

So Eq. (7-d) can be decomposed as follows:

$$\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}]\Delta Y$$

$$=\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](Q_t-Q^{t0}) \quad (7\text{-d-1})$$

$$+\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](Q^{t0}-Q_0) \quad (7\text{-d-2})$$

$$+\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](S_t-S^{t0}) \quad (7\text{-d-3})$$

$$+\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](S^{t0}-S_0) \quad (7\text{-d-4})$$

$$-\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](M_t-M^{t0}) \quad (7\text{-d-5})$$

$$-\frac{1}{2}[E_t\widehat{P}_t(I-D_t)^{-1}+E_0\widehat{P}_0(I-D_0)^{-1}](M^{t0}-M_0) \quad (7\text{-d-6})$$

Eq. (7-d-1) represents the effect of domestic final demand growth on changes of carbon emissions. (7-d-2) refers to the changes of carbon emissions resulting from structural change in domestic final demand. Eq. (7-d-3) and Eq. (7-d-4) are the changes of carbon emissions from export growth and structural change, respectively. Eq. (7-d-5) and Eq. (7-d-6) are the changes of carbon emissions as results of import growth and structural change, respectively.

So far, we decompose the changes of carbon emissions into 9 effects, which are effect of energy efficiency, effect of energy substitution, effect of technological change, effect of domestic final demand growth, effect of the structure change in domestic final demand, effect of export growth, effect of the export structure change, effect of the import growth and effect of the import structure change. We group the 9 effects above into four factors, namely: carbon intensity factor, technical factor, domestic final demand factor, trade factor.

3. Data

The comparable price input-output tables are used, including four tables (1992, 1997, 2002 and 2005), adjusted to 2000 prices. Carbon emissions data are calculated by the data of energy consumptions, which are from "China Statistical Yearbook "in 1992-2005. As the classifications of industries differ slightly in input-output table and energy consumptions, some industries are consolidated. We calculate the carbon emissions of all sectors under the "2006 IPCC Guidelines for National Greenhouse Gas Inventories volume Ⅱ Energy ". The calculated formula is $A^i=\sum_{k=1} E_k^i \times I_k$.

Where, A^i represents the carbon emissions of industry i, in units of tons. E_k^i refers to the consumption of energy k in industry i, according to standard coal in calculation, the unit is tons of standard coal. I_k is the carbon emissions coefficient of energy k, and the unit is ton of carbon / ton of standard coal.

Before calculating, it needs to convert the units of all the energy consumption into standard coal, and the conversion coefficient data is from China Energy Statistical Yearbook in 1992-2005. It is noteworthy that only the thermal power production usually produces large amounts of carbon emissions, the hydropower, nuclear power and other clean power only produce a small amount of carbon emissions, and therefore the share of non-thermal power generation must be subtracted when the power consumption is converted into standard coal amount, otherwise it will overestimate emissions. The share of non-thermal power is from the power balance table in "China Statistical Yearbook". The basic energy consumption of thermal power is mainly coal, only a little of natural gas which can be negligible. So the carbon emissions coefficient of thermal power is the same as coal.

The results of carbon emissions calculated during the period of 1992-2005 indicate that China's carbon emissions of energy consumption have increased from 654.6 million tons to 1926.4 million tons, with an increment of 1271.8 million tons (about 4.66 billion tons CO_2) (Table1).

4. Results

Using SDA model, carbon emissions growth during the 1992-2005 in China is decomposed into 9 effects. It is noteworthy that, we calculate the carbon emissions, not CO2 emissions. Table 1 shows the effects of decomposition items at different periods.

Table 1. The decomposition of carbon emissions growth

Total decomposition (million tons)	1992-2005	1992-1997	1997-2002	2002-2005
Energy efficiency	-599.5	-31.8	-462.5	-105.1
Energy substitution	0.7	-0.8	-2.5	4.1
Technology coefficient	365	4.3	122.3	238.3
Domestic final demand Growth	1387.8	423.1	489.6	475.1
Domestic final demand structure	89.7	67.5	20.3	1.9
Export growth	867	177.9	229.8	459.2
Export structure	28.8	15.2	-2.8	16.4
Import growth	-871	-180.1	-270.1	-420.8
Import structure	3.3	-12.3	2.9	12.7
Total emissions	1271.8	463.1	126.9	681.8

4.1. Carbon intensity factor

Carbon intensity factor includes two effects, the effect of energy efficiency and the effect of energy substitution. During the study period, the effect of carbon intensity contributed -598.8 million tons, showing a strong inhibitory effect on carbon emissions growth. The inhibitory effect is completely from energy efficiency, whose improvement contributes -599.5 million tons and the contribution rate is -47.14%. Meanwhile, the effect of energy substitution don't contribute to carbon emissions reduction, instead lead to an increase of 0.7 million tons of carbon emissions. Although proportion is small, it also reflects that the energy structure has not been fundamentally optimized.

From separate period view, the effects of energy efficiency on carbon emissions growth are negative in all periods, but different degrees, that is -31.8 million tons, -462.5 million tons and -105.1 million tons respectively in the periods of 1992-1997,1997-2002 and 2002-2005. It indicates that, the inhibitory effect of energy efficiency during 1997-2002 is most significant.

4.2. Technology factor

Instead of a reductive effect expected, technology change tends to increase carbon emissions. It contributed 365 million tons during 1992-2005, accounting for 28.7% of the total growth of carbon emissions. There is a rising trend of carbon emissions growth caused by technical change, which are 4.3 million tons, 122.3 million tons and 238.3 million tons in the periods of 1992-1997, 1997-2002 and 2002-2005 respectively.

It reflects that intermediate products in various industrial sectors strongly depend on carbon-intensive products. The reason may be capital deepening accelerating with the heavy industrialization. Capital deepening implies improvement of industrial technology, but also the increase of energy consumption per output correspondingly. In other words, industrial technical structure has developed towards the direction of the high energy consumption.

4.3. Domestic final demand factor

The factor of domestic final demand has the determinant effect on the growth of carbon emissions and its contribution rate is 116.2%. Although the growth effect and structure effect of domestic final demand both have played a role in promoting the carbon emissions growth, but the effect of growth rather than structure play a dominant role in all periods. The growth effect contributed 1387.8 million tons during 1992-2005, accounting for 109.1% of total emissions growth. Therefore, the carbon emissions growth has been mainly caused by the expansion of domestic consumption demand.

In comparison, carbon emissions growth resulting from the structure of domestic final demand is only 89.7 million tons during the study period, accounting for 7.06% of total growth, with a small contribution.

4.4. Trade Factor

The effect of trade on carbon emissions can be divided into four effects: effect of import growth, effect of import structure, effect of export growth and effect of export structure.

Export growth is an important factor of carbon emissions growth. During 1992-2005, the export growth effect leads to 867 million tons carbon emissions, accounting for 68.17% of total emissions growth and shows a rapid upward trend, which contributed 177.9 million tons during 1992-1997, 229.8 million tons during 1997-2002 and 459.2 million tons during 2002-2005. The import growth contributed -871 million tons to changes of carbon emissions during 1992-2005, and the contribution rate is -68.48%, which shows that the import growth effectively has inhibitory carbon emissions growth in China, even slightly larger than the promoting effect from export growth. Compared to energy efficiency, import growth has a more significant inhibitory effect on carbon emissions growth.

The effects of changes in export structure and import structure on carbon emissions growth is non-significant during 1992-2005, which indicates that the trade structure of import and export have not been fundamental changed during the study period in China.

Summed the 4 sub-items of trade factor, trade factor is not a determinant factor of China's carbon emissions growth. The growth of carbon emissions caused by trade is only 28.1 million tons during 1992-2005, accounting for 2.2% of the total increment. Although export is an important factor leading the growth of carbon emissions, counterbalanced by the inhibitory effect of the import, carbon emissions growth due to trade are small.

5. Concluding remarks

Using the structural decomposition method, the present paper has decomposed carbon emissions growth from energy consumption in China into 4 factors-carbon emissions intensity, technology, domestic final demand and trade, including 9 kinds of effects. The conclusions are as follow.

Firstly, the growth of carbon emissions from energy use in China is 1271.8 million tons during 1992-2005. The contribution rate of carbon emissions growth during 2002-2005 is 54%, reflecting the acceleration of carbon emissions growth in the context of the heavy industrialization.

Secondly, during the whole period, the carbon intensity effect has played a significant inhibitory effect, mainly coming from the improvement of energy efficiency, which means improvement of energy efficiency is effective to reduce carbon emissions. Energy substitution effect don't inhibit emissions growth, but lead to growth in a certain extent.

Thirdly, the effect of technical change has a notable tend to increase carbon emissions, indicating that the structure of technology in China developed towards the direction of high energy consumption and emissions. It is the result of heavy industrialization.

Fourthly, the factor of domestic final demand has a determinant impact on the growth of carbon emissions, which is mainly from the effect of domestic final demand growth, rather than changes in the structure. Therefore, the carbon emissions growth in China is mainly the result of the expansion of domestic consumption demand.

Finally, the trade is not a dominant factor of carbon emissions growth in China. Although export growth has greatly led to the growth of emissions, the effect of net export growth is small due to the significant inhibitory effect of imports. In addition, the effects of the changes of import structure and export structure on carbon emissions growth are not obvious.

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