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The Driving Forces of CO_2 Emission in China: 2002-2007*

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This paper provides a computation on both the China's aggregate CO_2 emission volume and the emission of each sector over the period of 2002-2007, based on the input-output analysis. Further analysis is also given on the various determinants of the change in the emission volume, with the aid of structural decomposition analysis (SDA) based on a residual-free method. Based on the input-output table of China in 2002 and 2007, the merge of sectors and the adjustment of price change have been made during the study. The emissions of carbon dioxide in China increased from 2,887.3 million ton to 5,664.6 million ton during 2002-2007. The average rate of increase is 13.3%, faster than the average rate of gross domestic product (GDP) growth 11.6% slightly. According to the process of SDA, the changes in emission are analyzed in terms of four different factors. Among the four factors studied in the paper, it is found that the change of emission intensity and structure of demand are the main reason of the decrease of emission, while production technology and scale effect increase the emission volume. The paper also finds that although the direct emission intensity decreased during the study period, the total emission intensity increased with the annual rate of 3.8%, which reflects the result of energy policy is not equal in different sectors.

Keywords: carbon emissions, input-output table, hybrid units, structural decomposition analysis, trading structure, emission intensity

Introduction

A much debated issue over the last decade was the environment. For the consideration of global warming and the challenge of environmental change, carbon cycling and carbon emission become an important issue recently. How to stabilize the level of greenhouse gases (GHGs) led to increased research in the CO_2 emission in China.

Since the beginning of economic reform in 1979, China has experienced rapid economic growth. Her gross domestic product (GDP) had increased by 9.9% annually over the year from 1979 to 2009. Despite the great shock of the financial crisis of 2008, the growth rate of GDP in China is 10.7% annually over the year 2001 to 2009. On the other hand, along with the rapid economic growth of China, total energy consumption increased from 1,518.0 Mtce in 2002 to 2,655.8 Mtce in 2007, with the annual growth rate of 11.8%. It is estimated that in China energy-related CO_2 emission increased by 59% in the period of 2000-2004. China's

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increase in CO_2 emission accounted for about 56% of the increase of CO_2 emission in the world. The newly approved Five-Year Plan of China (2006-2010; 2011-2015) makes a reduction in energy intensity and energy use in a national development objective, and decomposes the object into province level.

There are many issues studying the energy intensity of the GHGs, but seldom focus on the absolute indicator of emission. This paper will analyze this absolute indicator, using the tools of input-output model and structural decomposition analysis.

Literature Review

To analyze and understand historical changes in economic, environmental, employment, or other social-economic indicators, it is useful to assess the driving forces of determinants that underlie these changes. Two techniques for decomposing indicator changes at the sector level are structural decomposition analysis (SDA) and index decomposition analysis (IDA). Both methods use the index theory for decomposition. The main difference between them is the fundamental data used and the decomposed effects.

In the studies of China’s energy intensity, Huang (1993) used AMDI method to study the six industrial sectors in 1980-1988, and Sinton and Levine (1994) used Laspeyres index to study the industrial sectors in 1980-1990, they found a similar result: The technological effect is the main factor in reducing the energy intensity, while the structural effect had little contribution to the total change. Ma and Stern (2008) applied LMDI method to the Chinese energy intensity between 1980 and 2003. They studied three industries and found that the technological effect played an important role in reducing the energy intensity, and structural effect increased the intensity. The increase of intensity after 2000 would attribute to the negative increase of technology. Huang (2009) used LMDI to study the four waste emissions in 18 industrial sectors in 1994-2007, she found that scale effect is the main reason of emission, technological effect is the most important force for reducing the emission and structural change has a certain effect on increasing the emission.

Except for these IDA studies, Dietzenbacher and Los (1998) used two polar decomposition methods to input-output model. They decomposed the emission volume into three factors: energy intensity, production technique, and economy scale. Zhang (2003) used Laspeyres method to study the industrial sectors in China between 1990 and 1997, they merge the industrial sectors in 29, and decompose the use of energy into three factors: scale, production technique, and structure. They found that production technique is the most important factor.

In brief, the studies of decomposition in energy emission have three virtues: first, focusing on the indicators in relative form; second, there are mainly four kinds of decomposing factors: energy intensity, production technique and structure and scale; third, the use of the index varies, but almost based on Divisia index. By contrast, this paper will focus on the volume of carbon emission, which is an indicator in absolute form. And our decomposed factors include five effects: energy intensity, production technique, domestic demand structure, trade structure, and economic scale, where the trade structure effect can be more persuasive in explaining the embodied carbon emission in China. At last, we used the two-polar decomposition method in the decomposing procedure.

This paper is organized as follows. In the next section, the Intergovernmental Panel on Climate Change (IPCC) method to calculate the CO_2 emission is described, and use the proposed decomposition approach to decompose the change of CO_2 emission over time is employed. The sector disaggregation and data used are discussed in section three. The analysis and some main results are presented in section four. In section five, conclusion is made in this study.

Methodology and Data

Calculation of CO_2 Emission

Following the method presented in IPCC (1996, 2006), the total CO_2 emission can be calculated based on energy consumption, net calorific values of the energy and carbon emission factors (EFs). The calculation can be expressed as follows:

$$C^t = \sum_i C_i^t = \sum_i \sum_j C_{ij}^t = \sum_i \sum_j E_{ij}^t NCV_j EF_j \left(1 - CS_j^t\right) M \tag{1}$$

where the subscript *i* represents the *i*th sector, the subscript *j* represents the *j*th fuel used, *t* is the time symbol in years. C^t denotes the total scale of CO_2 emission (in million tons, Mt) of the economy in year *t*, C_i^t denotes the emission (in million tons, Mt) of the *i*th sector in year *t*, C_{ij}^t denotes the emission (in million tons, Mt) of the *i*th sector based on the *j*th fuel in year *t*. E_{ij}^t is the total energy consumption (in physical unit, million tons or m^3), NCV_j is the lower-net calorific values (TJ/unit) of the *j*th fuel, EF_j is the default carbon (kg/GJ) in the *j*th fuel, CS_j^t is the fraction of the *j*th fuel that is not oxidized as raw materials in year *t*, *M* is the molecular weight ratio of carbon dioxide to carbon (44/12).

In the version of IPCC 2006, the fraction of carbon oxidized is set to be 1. Because the fuel used as a raw material for manufacture of products is excluded from the total energy consumption, *CS* is zero. The values of *NCV*, *EF*, and *CS* are assumed to be constant over the time period of the study.

Structural Decomposition Analysis Based on Input-Output Model

Based on the basic input-output model, the total social product X and the final demand y can be linked with the direct consumption coefficient matrix A:

$$X = \left(I - A\right)^{-1} uy \tag{2}$$

where *u* is known as the structure effect of the final demand; y is a scalar which captures the changes in total volume demand.

If the carbon emission intensity vector is denoted as f, and the volume of carbon emission as C, we have:

$$C = fX = f\left(I - A\right)^{-1} uy = fDuy \tag{3}$$

By the denotations above, the volume of emission can be expressed as:

$$C = fDuy = \sum_i \sum_j f_i d_{ij} u_j y \tag{4}$$

The second step is to decompose the change of *C* into four effects:

$$\Delta C = f_t D_t u_t y_t - f_0 D_0 u_0 y_0 \tag{5}$$

⊿ implies the change of the corresponding variable, and 0 and *t* imply the period of base and report. Using the MRCI decomposition method recommended by Rhee and Chung (2006):

$$\begin{aligned}\Delta C &= \Delta C_f + \Delta C_d + \Delta C_u + \Delta C_y \\ &= \sum_{ij} M_{ij}(*)\left(\frac{\Delta f_i}{f_i}\right) + \sum_{ij} M_{ij}(*)\left(\frac{\Delta d_{ij}}{d_{ij}}\right) + \sum_{ij} M_{ij}(*)\left(\frac{\Delta u_j}{u_j}\right) + \sum_{ij} M_{ij}(*)\left(\frac{\Delta y_i}{y}\right)\end{aligned} \tag{6}$$

where:

$$M_{ij}(*) = \frac{C_{ij,t} - C_{ij,0}}{A_{ij}(*)}$$

$$A_{ij}(*) = \left(\frac{\Delta f_i}{f_i}\right) + \left(\frac{\Delta d_{ij}}{d_{ij}}\right) + \left(\frac{\Delta u_j}{u_j}\right) + \left(\frac{\Delta y_i}{y}\right) \tag{7}$$

In the above expression, the difference in total emissions between two periods in the intermediate sectors is decomposed into five terms, where ΔC_f is the difference attributable to the change in emission coefficients or the change in the efficiency of energy use during the period, ΔC_d is the difference due to change in production technology as reflected on the input coefficient matrix sectors, ΔC_u is the difference due to the structural change in final demand sectors, ΔC_y is the difference due to the change in the size of the economy. These four decomposition effects can be noted as: carbon emission intensity effect, production technology effect, structural effect, and economy scale effect respectively.

Data

The data are collected from China Statistical Yearbook (CSY) and China Energy Statistical Yearbook (CESY). In light of the price change over the period, adjustment is made to the 2007 data after compared with the price indices from 2002 to 2007, using the method by Liu and Peng (2010). The price indices come from the CSY 2003-2008.

When comparing the emission changes during the period, we merge the economy into 29 sectors. The sectors and their corresponding code are presented in Table 1.

Table 1

Sectors and Codes

Code	Sector
1	Agriculture
2	Coal mining, washing
3	Petroleum and natural gas extraction
4	Metal ores mining
5	Non-metal ores mining
6	Manufacture of foods and tobacco
7	Manufacture of textile
8	Manufacture of textile wearing
9	Processing of timbers
10	Papermaking, printing
11	Processing of petroleum, coking
12	Chemical industry
13	Manufacture of non-metallic products
14	Smelting and rolling of metals
15	Manufacture of metal products
16	Manufacture of general machinery
17	Manufacture of transport equipment
18	Manufacture of electrical machinery
19	Manufacture of communication equipment
20	Manufacture of measuring instrument
21	Manufacture of artwork, other manufacture
22	Waste
23	Electricity and heat
24	Gas production
25	Water production
26	Construction
27	Traffic, transport and storage
28	Wholesale and retail trades
29	Others

Results and Analyses

The Driving Forces: From the Decomposition View

According to the energy input-output table, we compute the volume of carbon dioxide emission that is from 2,887.3 million ton to 5,664.6 million ton during 2002-2007. The average rate of increase is 13.3%, faster than the average rate of GDP growth 11.6% slightly.

Table 2 demonstrates the decomposition of the total volume of carbon dioxide emission. There are four factors affected the change of emission: carbon emission intensity, production technique, structural change, and economic scale.

Table 2

Change of the Total Emission and its Decomposition

	ΔC	ΔC_f	ΔC_d	ΔC_u	ΔC_y
Change of emission [million ton]	2,812.0	-2,321.1	1,718.4	-8,921.2	12,335.9
Change in ratio	100.0%	-82.5%	61.1%	-327.3%	438.7%

Notes. Data source: CSY, CESY, and authors' calculation. Unit: million tons; Negative values indicate decreasing CO2 emission; The symbols in the first row represent total emission change, carbon emission intensity effect, domestic demand effect, trading structural effect, and economy scale effect respectively.

Conclusions can be drawn from Table 2: Firstly, with comparison to 2002, the emission intensity and domestic demand reduced the emission volume sharply in 2007; they are the positive factors in carbon emission reduction. The contribution of the emission intensity is 82.5%, which reflects the improvement of efficiency of energy use during the period, and the structure of demand contributes 327% reduction to the total change.

Secondly, the growth of the economic scale contributes 438.7% to the total change of emission, which has the most important effect. This implies that the growth of the economy causes the pollution of the environment and the overexploitation of natural resources. It also reflects the adjustment of industrial structure that did not come up with the growth of the economy.

Thirdly, the change of production technique increases the carbon dioxide emission. It almost offsets the effect of the positive factors as the first statement shows.

The Emission Intensity Analysis

When it comes to judging the effect of an energy policy, we should consider not only the reduction of a certain sector's emission, but also the effect on the other sectors. The total emission intensity (TEI) is calculated to reflect this indirect relationship between sectors. Figure 1 shows the change of total emission intensity (DTEI) and the change of direct emission intensity (DEI) during 2002-2007.

$$TEI = f\left(I - A\right)^{-1} \tag{8}$$

$$DEI = f \tag{9}$$

$$IDI = TEI - DEI \tag{10}$$

Using the weight of total products, we have the weighted average of emission intensity. During the year 2002-2007, the average of DEI decreased from 0.092 kg/RMB to 0.0739 kg/RMB, while the average of TEI increased from 0.352 to 0.424, with an average annual rate of 3.8%. This implied that the indirect consumption among different sectors cannot be neglected, especially in the establishment of an energy policy.

During 2002-2007, although the most sectors' emission intensity decreased, some sectors' condition did not improve. This reflects the energy policy that did not have similar effects on the sectors.

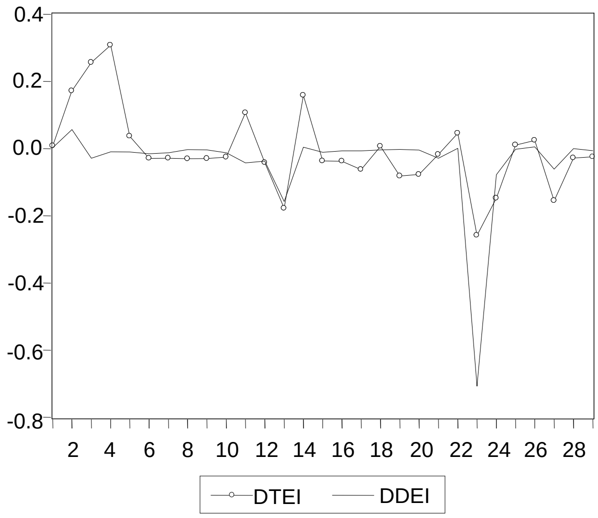

Figure 1. The change of emission intensity by sectors during 2002-2007.

Conclusions

This paper tried to analyze the carbon dioxide emission in China during 2002 to 2007. The model used for this analysis is the familiar input-output model extended to cover carbon emission. For decomposition of the sources of change in emissions over the period, a residual-free composition method has been applied. The method factors total change in emissions over the period into four contributing components, emission intensity, production technique, final demand structure, and size of the economy.

Our results show that the energy uses during the study period grow rapidly compared with Ming (2009). And trade structure changes from 2002 to 2007, with the virtue of carbon emission in trade balance (EETB) from surplus to deficit. By SDA, we find that energy intensity and domestic demand structure are the main reason of the reduction of carbon emission. Economic scale is the most important factor that increases the carbon emission. Because the character of the foreign trade of China, the net export of high carbon emission industry produces much more carbon dioxide when producing, and resulting in the carbon emission increased sharply during the period.

Compared with Huang (1993), Sinton and Levine (1994), and Zhang (2003), our results consider the domestic demand and the trading structure which have a significant effect on carbon emission but have opposite direction. Besides, the production technique effect has increased the emission, which reflects the difficulty in policy making on the control of emission.

Finally, although the DEI decreases during 2002-2007, the TEI increases with the average rate of 3.8%. The driving force may result from some sector which increases the indirect emission during production. These sectors are production and supply of electric power and heat, agriculture, smelting and rolling of metals, mining and washing of coal. These sectors should give more emphasis when establishing energy policy.

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