Factorizing Changes in Chinese Carbon Emission over 1994-2007

A LMDI Decomposition Analysis

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Abstract: As the second biggest CO_2 emission countries in the world, China has to find a way of low carbon economic development. This paper uses LMDI approach to decompose the factors influencing the changes of carbon emission into economic activity, economic structure, energy intensity, energy mix and emission factor. The result shows that during 1994-2007, the increase of Chinese carbon emission mainly dues to the economic activity effect and the economic structure effect, while the decline of carbon intensity has decreased carbon emission to some extent. The effect of energy mix is pretty minor.

Keywords: carbon emission; LMDI; influncing factors

1. Introduction

According to IPCC (2007), the Earth's surface temperature has risen by about 1 degree Fahrenheit in the past century, with accelerated warming during the past two decades. There is new and stronger evidence that most of the warming over the last 50 years is attributable to human activities. Human activities have altered the chemical composition of the atmosphere through the buildup of greenhouse gases – primarily carbon dioxide (CO_2), methane, and nitrous oxide. The amount of CO_2 emitted into the atmosphere by fossil fuel combustion accounts for more than 95% of the total CO_2 emission since industrialization period. Global warming will cause problems on energy, food, water resources, ecology and public health, etc., and has serious direct influence on human lives and development.

China is now the world's second largest emitter of energy-related CO_2 gas, only next to the United States, and is under great international pressures of controlling and mitigating CO_2 emission. In order to make proper and effective energy and environmental policies on reducing CO_2 emission of China, it is very necessary to investigate the driving forces governing CO_2 emission levels and their evolution, and to have a more comprehensive understanding of the inter-relationships of economic development, technology improvement, energy consumption and CO_2 emission. This is the purpose of our study in this paper.

The remainder of this paper is organized as follows. In section 2 we give a brief literature review on related topics. In section 3 we introduce the LMDI approach, which is applied in this paper and the resources of the data. In section 4 we present the decomposition result and make some discussions. Section 5 concludes the entire paper.

This paper is sponsored by The Social Science Funds of Ministry of Education of Jiangsu Province (2010SJB790024)

2. Literature Review

Decomposition of CO2 emission has recently been an actively researched topic. Many studies have attempted to identify quantitatively the relative impact of different factors on the changes in CO_2 emissions. Ang et al. (1998) introduce a method of Logarithmic Mean Weight Divisia (LMDI) for factorizing changes in energy demand or gas emissions over time. They compare this new method with three existing methods and summarize the respective decomposition formulae for various applications. Three application studies using data for Singapore, China, and Korea are presented and LMDI method is shown to be superior to any of the three existing methods and may be generally applied in energy and environmental decomposition studies. Ang (2004) give an overview of the application and methodology development of decomposition analysis and present a summary of the recommended ones in a simple framework based on the Divisia index and the Laspeyres index. The paper discusses the properties of these methods and conclude by recommending the multiplicative and additive LMDI I methods due to their theoretical foundation, adaptability, ease of use and result interpretation, and some other desirable properties in the context of decomposition analysis. Adams(2008) uses an energy balance framework to project future energy requirements and import needs of China in 2010 and 2020. The estimates suggest that Chinese fuel requirements may loom very large in the world energy economy if present trends continue. This growth is not so sensitive to the rate of economic growth as to increases in motorization. It can be offset, but probably only in small part, by increasing domestic energy production or by improve-

978-1-935068-37-2

ments in the efficiency of use, particularly in the production of electric power. Fisher-Vanden et al.(2004) employ a unique set of panel data for approximately 2500 of China's most energy intensive large and medium-sized industrial enterprises during 1997–1999. They show that rising relative energy prices, research and development expenditures, and ownership reform in the enterprise sector, as well as shifts in China's industrial structure, emerge as the principal drivers of China's declining energy intensity and use.

Xu Guoquan (2006) uses the LMDI method to decompose the carbon emission per capita during 1995-2004 in China. They show that the economic growth contributes to the increase of carbon emission per capita in an exponential way, while contributions of energy structure and energy intensity on decreasing the carbon emission have an inverted U shape. Wen Jingguang (2010) does a similar analysis on Jiangsu province from 1996 to 2007 and their results are alike. Wang Junsong (2010) uses LMDI to decompose the CO_2 into four factors which are energy consumption, energy intensity, economic growth and population growth. Their study divides China into the eastern parts and the middle-and-western parts and they show that the influencing effects differ in these two areas of China. The effect of economic development and energy intensity in the eastern areas are higher than that in the middle-and-western areas. The population growth increases the emission in the eastern areas but lowers that of the middle-and-western areas. The intensity structure plays a negative role in carbon emission in the east while the effect is modest in the middle and the west. Zhang Lei(2010) apples two basic evaluation models of the industry-energy and energy-carbon emission correlations to analyze the reasons for the change of regional emission pattern in China.

3. Methodology and Data

3.1. LMDI Method

The total national energy-related carbon emission in period t can be expressed as an extended Kaya identity,

$$C^t = \sum_{ij} C^t{}_{ij} = \sum_{ij} Q^t \times \frac{Q^t{}_i}{Q^t} \times \frac{E^t{}_i}{Q^t{}_i} \times \frac{E^t{}_{ij}}{E^t{}_i} \times \frac{C^t{}_{ij}}{E^t{}_{ij}} \qquad (1)$$

The sub-categories of the aggregate are industrial sector and fuel type. C^t is the total carbon emission of China in period t; Q^t is the GDP of China in period t; Q_i^t is the gross industrial product of sector i in period t; E_i^t is the total energy consumption of sector i in period t; E_{ij}^t is the type j fuel consumption of sector i in period t; C_{ij}^t is the carbon emission by type j fuel combustion of sector i in period t.

Define $S_i^t=Q_i^t/Q^t$ as the economic share of sector i in period t; $I_i^t=E_i^t/Q_i^t$ the energy consumption every unit of gross industrial product of sector i in period t; $M_{ij}^t= E_{ij}^t/E_i^t$ the share of type j fuel of total energy consumption of sector i in period t; and $F_{ij}^t= C_{ij}^t / E_{ij}^t$ the carbon emission factor of the type j fuel.

$$C^t = \sum_i Q^t \times S_i^t \times I_i^t \times M_i^t \times F_i^t \qquad (2)$$

Therefore changes of the national carbon emission between a base year *0* and a target year T can be studied by quantifying the impacts of changes in five different factors: overall economic activity (activity effect), industry activity mix (structure effect), sectoral energy intensity (intensity effect), sectoral energy mix (energy-mix effect), and carbon emission factors (emission-factor effect).

In multiplicative decomposition, we decompose the ratio:

$$D_C = \frac{C^T}{C^0} = D_{act} D_{str} D_{\text{int}} D_{mix} D_{emf} \qquad (3)$$

In additive decomposition we decompose the difference:

$$\begin{aligned}\Delta V_C &= C_T - C_0 \\ &= \Delta V_{act} + \Delta V_{str} + \Delta V_{\text{int}} + \Delta V_{mix} + \Delta V_{emf}\end{aligned} \qquad (4)$$

The subscripts *act, str, int, mix* and *emf*, respectively, denote the effects associated with overall activity, activity structure, sectoral energy intensity, sectoral energy mix and emission factors.

According to Ang(2005), the formulae for each effect in the right hand side of Eq. (3) and (4) can be computed as follows

$$D_{act} = \exp\left(\sum_{ij} \frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \times \ln\left(\frac{Q^T}{Q^0}\right) \right)$$

$$D_{str} = \exp\left(\sum_{ij} \frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \times \ln\left(\frac{S_i^T}{S_i^0}\right) \right)$$

$$D_{\text{int}} = \exp\left(\sum_{ij} \frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \times \ln\left(\frac{I_i^T}{I_i^0}\right) \right)$$

$$D_{mix} = \exp\left(\sum_{ij} \frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \times \ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right) \right)$$

$$D_{emf} = \exp\left(\sum_{ij} \frac{\left(C_{ij}^T - C_{ij}^0\right) / \left(\ln C_{ij}^T - \ln C_{ij}^0\right)}{\left(C^T - C^0\right) / \left(\ln C^T - \ln C^0\right)} \times \ln\left(\frac{F_{ij}^T}{F_{ij}^0}\right) \right)$$

$$\Delta C_{act} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln\left(\frac{Q^T}{Q^0}\right)$$

$$\Delta C_{str} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln\left(\frac{S_i^T}{S_i^0}\right)$$

$$\Delta C_{\text{int}} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln\left(\frac{I_i^T}{I_i^0}\right)$$

$$\Delta C_{mix} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right)$$

$$\Delta C_{emf} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln\left(\frac{F_{ij}^T}{F_{ij}^0}\right)$$

It is necessary to make clear the different factors caused the changes in carbon emission. The activity effect reflects the economic development. The structure effect is used for analyzing the shifting of industrial structures. Energy consumption is mainly related to variables such as economic structures, the efficiency of the energy systems, energy utilization technologies, energy prices, energy conservation and energy-saving investments, which are composed of energy intensity effect. The energy mix effect is used to analyze the changes of fuel structure. The emission-factor effect evaluates fuels quality, fuels substitution and the installation of abatement technologies.

3.2. Data

To prepare the data for undertaking the complete decomposition analysis by sector, the economy of China has been divided into three distinct sectors: the primary sector; the secondary sector; and the tertiary sector. The primary sector includes farming; forestry; animal husbandry; fishery and water conservancy. The secondary sector is comprised of mining and quarrying; manufacturing; electric power, gas and water production and supply; and construction. The tertiary sector is subdivided into transport, storage and post sector; wholesale, retail trade and hotel, restaurants; and others. The data of the national GDP and the gross industrial product of the above three sectors during 1994-2007 are collected from *China Statistical Yearbook (2009)* and they are all in 1990 price.

Concerning the energy consumption, we mainly take eight types of fuels into account, including coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel oil, natural gas. The data of fuel consumptions of each sector from 1994-2007 are collected from *China Energy Statistical Yearbook (1997-1999, 2000-2002, 2008)* respectively. The original data of coal, coke, crude oil, gasoline, kerosene, diesel oil and fuel oil consumptions are measured in mass unit(10 thousand tons) and the natural gas data are measured in volume unit(10^8 m^3). For the sake of convenience in computing carbon emissions, we use the average low calorific values(ALCV) to convert the original data into those measured in energy unit (GJ). The values of ALCV are from *China Energy Statistical Yearbook(2008).*

To compute the carbon emission based on energy consumption, the carbon emission factors(EF) are needed. These data are collected from *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol.2* and they don't change with time. The ALCV and EF used in this paper are listed in Tab.1.

Table 1. carbon emission factors and average low calorific values

Fuel	EF (kgC/GJ)	ALCV (KJ/kg)
Coal	25.8	20908
Coke	29.2	28435
Crude oil	20.0	41816
Gasline	20.2	43070
Kerosene	19.6	43070
Diesel oil	20.2	42652
Fuel oil	21.1	41816
Natural gas	15.3	38931(KJ/m^3)

4. Results and Discussion

4.1. Results

The time series of carbon emission in China over 1994-2007 are shown in Fig.1. The national carbon emission of China has increased by 120301 ten thousand tons over 1994-2007.

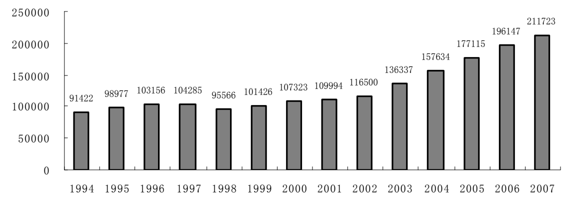

Figure 1. Chinese carbon emission over 1994-2007 (in 10^4 tons)

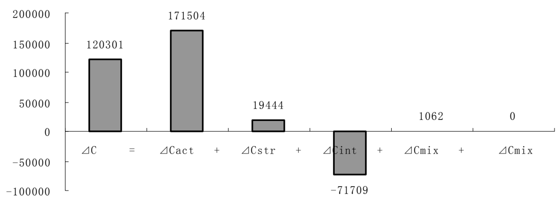

Figure 2. Additive decomposition results of 1994-2007

From the additive decomposition results (Fig. 2) we can see that the economic activity effect is the dominate factor, which causes the carbon emission in China to increase by 171504 ten thousand tons. The structure effect also plays a positive but much smaller role in increasing carbon emission, which is 19444 ten thousand tons. The energy intensity effect is the only one that shows negative impact, which reduces the carbon emission by 71709 ten thousand tons. The energy mix effect increase the carbon emission very slightly, only 1062 ten thousand tons. Since the emission factors used in this paper don't change with time, the emission factor effect is zero.

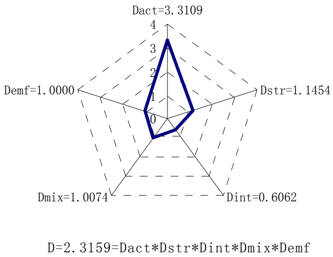

Figure 3. Radar chart of multiplicative decomposition results of 1994-2007

The multiplicative decomposition implies similar results (Fig.3). The carbon emission in 2007 is 2.32 times, or 132% higher than it was in 1994. Among the total effect the economic activity effect causes the carbon emission to increase by 231%, which is much larger than the other effects. The structure effect increases the carbon emission by only 14%. The energy intensity effect decreased the carbon emission by 40%. The energy mix effect almost has minor effect on the carbon emission.

We also decompose the change of carbon emission year by year and the results are shown in Tab.2 and Tab.3. The annual carbon emission increase caused by economic activity effect is quite stable around 10%. The structure effect increases the carbon emission only about 1% per year. The energy intensity effect mitigates the carbon emission most of the years but the magnitude fluctuates from 2% to 16%. The energy mix effect is almost zero in most of the years.

Table 2. Additive decompostion of the national carbon emission over 1994-2007

Index	ΔC	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}
1994-1995	7555	9861	2102	-4526	119
1995-1996	4179	9636	1620	-6877	-200
1996-1997	1129	9216	984	-8638	-433
1997-1998	-8719	7527	842	-16674	-415
1998-1999	5860	7229	438	-1546	-260
1999-2000	5897	8445	827	-3022	-353
2000-2001	2671	8664	157	-6213	63
2001-2002	6506	9841	666	-4108	106
2002-2003	19837	12040	2507	4830	461
2003-2004	21297	14096	1140	5963	98
2004-2005	19481	16581	1589	285	1025
2005-2006	19032	20541	1861	-3766	396
2006-2007	15576	24963	2472	-12040	181

Table 3. Multiplicative decompostion of the national carbon emission over 1994-2007

Index	D	D_{act}	D_{str}	D_{int}	D_{mix}
1994-1995	1.0826	1.1092	1.0223	0.9535	1.0012
1995-1996	1.0422	1.1001	1.0162	0.9342	0.9980
1996-1997	1.0109	1.0929	1.0095	0.9201	0.9958
1997-1998	0.9164	1.0783	1.0085	0.8462	0.9958
1998-1999	1.0613	1.0762	1.0045	0.9844	0.9974
1999-2000	1.0581	1.0843	1.0080	0.9715	0.9966
2000-2001	1.0249	1.0830	1.0014	0.9444	1.0006
2001-2002	1.0591	1.0908	1.0059	0.9644	1.0009
2002-2003	1.1703	1.1001	1.0201	1.0390	1.0037
2003-2004	1.1562	1.1008	1.0078	1.0415	1.0007
2004-2005	1.1236	1.1043	1.0096	1.0017	1.0062
2005-2006	1.1075	1.1165	1.0100	0.9800	1.0021
2006-2007	1.0794	1.1303	1.0122	0.9426	1.0009

4.2. Discussions

4.2.1 The economic activity effect

During out study period from 1994 to 2007, Chinese has increased from 2983 billion yuan (BY) to 9978 BY, both in 1995 price, representing an overall annual growth of 9.31%. Because of the rapid economic growth of China, total energy consumption increased from 1227.37 million tons of coal equivalent (Mtce) in 1994 to 2655.83 Mtce in 2007, an annual growth rate reaches 5.84%. Besides, big investment increases in the fields of steel, cement, electrolytic aluminum, etc., also contribute a lot to the large amount of energy consumption. Rapid economic growth and the resulting huge demand for energy consumption explain dominant part of the increase of carbon emission in China.

4.2.2 The economic structure effect

China has experienced changes of industry structure during 1994-2007. The share of the primary sector has decreased from 19.8% to 11.3%, and the share of the tertiary sector has increased from 33.6% to 40.1%. The share of the secondary sector is relatively stable, being from 46.6% to 48.6%. Since the secondary sector is the main source of carbon emission, it is not surprising that the change of the economic structure has only modest effect on increasing the carbon emission over this period.

4.2.3 The energy intensity effect

The energy intensity, which is defined as the energy consumption per GDP, is an index reflecting the energy utilization efficiency. Chinese real energy intensity (in 1995 price) has fallen continuously from 0.4117 Mtce/BY in 1994 to 0.2662 Mtce/BY in 2007, at an annual decreasing rate of 3.18%. The decrease of the real energy intensity is the most important factor to drive the national carbon emission to decline over the study period, although it can not offset the increase of the carbon emission caused by economic growth totally. According to Fisher-Vanden et al.(2004), rising relative energy prices, research and development expenditures, and ownership reform in the enterprise sector, as well as shifts in China's industrial structure, emerge as the principal drivers of China's declining energy intensity and use.

4.2.4 The energy mix effect

In the energy consumption of China, coal accounts for a dominant part and contribute a lot to the increase of carbon emission. The share of coal in the consumption of the first primary energy is 40% higher than the world's average level, and the shares of clean energy (hydroelectricity, nuclear electricity, etc.) are far lower than the world's average.

Our country has tried to change the energy structure to a cleaner pattern but the speed is slow. During 1994-2007, the share of coal in total energy consumption has declined from 75% in 1994 to 66.32% in 2002, but turned to go up to 69.5% from 2002 to 2007. The shares of the clean energy are quite small and are increasing very slowly, unable to offset the effect of coal increase. Therefore, the energy mix has negative effect on the carbon emission during 1995-2000 and positive effect during 2001-2007, but both effects are very minor in magnitude.

5. Conclusions and policy implications

In this paper, the LMDI method is used to decompose the changes in energy-related carbon emission in China during the period 1994-2007. The decomposed fived factors are economic activity effect, economic structure effect, energy intensity effect, energy mix effect and emission factor effect. The analysis indicates that the largest increase in carbon emission is caused by economic activity effect in the period. The change of industry structure has positive, but comparatively modest effect on Chinese carbon emission, since the share of the secondary sector which is the main source of carbon emission, keeps almost unchanged during the study period. The energy intensity effect is the only one that contributes negatively to the increase of carbon emission. Due to availability limitation of data of emission factors in different periods, the emission factor effect is zero.

As a non-Annex party, China would not be bound in the initial commitment period (2008-2012) to any quantitative restrictions on its greenhouse gas emissions, but China has been making great efforts to mitigate the growth of CO2 emission. Based on the above research results, carbon emission reduction strategies should aim at the following: (1) Energy conservation. GDP growth in China relies a great deal on investment and export markets. Complete restructuring of investment in domestic fixed assets and imposing restrictions on export of energy intensive products will therefore curb energy demand. (2) Adjusting the economic structure. Attention should be paid to promote development of information technology industry, the electronic industry, and other technology intensive industries, in the secondary sector, and the share of tertiary sector should be raised. (3) Further decreasing the energy intensity of products. Funding researches on new energy recycling and energy conservation technologies and encouraging applications. To strengthen the management of production process for a better and more efficient utilization of energy. (4) Adjusting the energy structure. To promote industrial final energy supply towards clean, low-carbon fuels, and decreasing the share of coal. To encourage researches on solar photovoltaic, wind power, biomass power generation, bio-diesel and biomass ethanol development.

References

[1] B.W.Ang, "Decomposition analysis for policy making in energy: which is the preferred method," Energy Policy, 2004, Vol.32, pp.1131-1139.

[2] B.W.Ang, F.Q.Zhang, K.H.Choi, "Factorizing changes in energy and environmental indicators through decomposition," Energy, 1998, Vol.23, No.6, pp.489-495.

[3] CESY 1997–1999, 2000–2002, 2003, 2004. 2005, 2006, 2007. China Energy Statistical Yearbook, National Bureau of Statistics of China, National Development and Reform Commission.

[4] CSY, 1994–2008. China Statistical Yearbook, National Bureau of Statistics of China.

[5] F.G.Adams, Y.Shachmurove. "Modeling and forecasting energe consumption in China: implications for Chinese energy demand and imports in 2020," Energy Economics, 2008, Vol.30, pp.1263-1278.

[6] G.Q.Xu, Z.Y.Liu,Z.H.Jiang. "Decomposition model and empirical study of carbon emissions for China,1995-2004," China Population, Resources and Environment, Vol.16, No.6, pp.158-161.

[7] J.G.Wen. "Decomposition model and emirical study of carbon emissions for Jiangsu province," East China Economic Management, 2010, No.2, pp.29-32.

[8] J.S.Wang, C.F.He. "Energy consumption, economic growth and CO2 emissions in China," Resources and Environment in the Yangtze Basin, 2010, Vol.19, No.1, pp.18-23.

[9] K.Fisher-Vanden, H.J.Gary, H.M.Liu, Q.Tao. "What is driving China's decline in energy intensity?" Resource and Energy Economics, 2004, Vol.26, pp.77-97.

[10] L.Zhang, Y.X.Huang, Y.M.Li, X.L.Cheng. "An investigation on spatial changing pattern of CO2 Emissions in China," Resources Science, Vol.32，No.2, pp.211-217.

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