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Analysis on Carbon Emission Decoupling Effect and Driving Factors of Environmental Pollution in China's Transportation Industry

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In order to study the relationship between carbon emission and economic growth in China's transportation industry and the driving factors of carbon emission, the Logarithmic Mean Divisia Index (LMDI) decomposition model of carbon emission elastic decoupling and carbon emission driving factors is established. The results show that the carbon emission decoupling value of China's transportation industry has obvious spatial disequilibrium characteristics, and the decoupling state of "weak decoupling-expansion negative decoupling-growth linkage" appears from coastal areas to inland are as a whole. From 2009 to 2016, there are five types of carbon emission Kuznets curves of China's transportation industry, namely linear type, U type, inverted-U type, inverted-N type and wave type. The carbon emission intensity of transportation industry in many provinces still tends to increase with the increase of economy. The energy structure effect and the energy intensity effect have a relatively weak negative impact on the carbon emission in the transportation industry. However, the industry scale effect has a significant positive impact, which is the main factor to promote the growth of carbon emission.

1. Introduction

Since the industrial revolution, the consumption of a large number of fossil energy has made the global carbon dioxide emission increase rapidly with the rapid development of economy, which severely restricts the sustainable development of human society. In 2006, China's CO_2 emission China made up 20% of the world's total carbon emission, surpassing the United States to become the world's largest greenhouse gas emission country. Therefore, there is still a long way to go for the realization of China's economic and social low-carbon development (Hu and Tang, 2015; Lu et al., 2012; Liu and Yang, 2012). Transportation industry is one of the three major industrial systems characterized by low carbon emission, which is determined in the national plan for dealing with climate change. The establishment of low carbon transportation system plays an important role in coping with climate change and achieving carbon emission reduction target in China (Lin and Huang, 2011).

Decoupling theory is used to measure whether there is a synchronous relationship between material consumption and economic growth in the course of industrialization development or not. Tapio put forward the elastic decoupling theory on the basis of decoupling theory to analyze the decoupling between carbon emission and economic growth of transportation industry. On this basis, Andreoni conducted a decoupling analysis of the relationship between carbon emission and economic growth in Italy's agriculture, industry, and transportation industry from the perspective of carbon emission intensity, energy intensity, energy structure, and economic growth. Domestic scholars started to study the decoupling theory late. used OECD decoupling index and Tapio elastic decoupling model to study the relationship between industrial carbon emission, energy consumption and industrial added value, providing reference for similar analysis in other provinces. Tapio elastic decoupling model lays particular emphasis on the analysis of individual years. It is easy to observe the difference between carbon emission and economic growth in each year, which is helpful to clarify the change of performance before and after implementation of policy, and to refine decoupling indexes. The OECD model focuses on the analysis of the whole year. The result of the decoupling analysis is different for the different

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selection of the base period. In order to understand the decoupling of carbon emission in transportation industry more comprehensively, it is necessary to conduct decoupling analysis of carbon emission in each year. Thus, Tapio decoupling model is selected to analyze the carbon emission in transportation industry.
Structural decomposition approach (SDA) and index decomposition approach (IDA) are widely used in the study of driving factor decomposition of carbon emission. Compared with SDA, IDA, especially LMDI is simple and easy to operate, which can not only eliminate the residual term and solve the zero problem in data processing, but also facilitate the time series analysis and the comparison between provinces.
To sum up, the related researches on carbon emission in transportation industry are at the national level or single provincial level and haven't calculated the carbon emission in transportation industry or analyzed decoupling effect and driving factors from 30 provinces in China. Therefore, an empirical analysis of the decoupling effect and driving factors of carbon emission in transportation industry in 30 provinces of China is of great significance to the decomposition of emission reduction indexes and the targeted guidance of energy conservation and emission reduction in each province.

2. Research Methods and Model Building

2.1 Calculation method of carbon emission in provincial transportation industry

In order to ensure the accuracy of the calculation of carbon emission in transportation industry in each province, this analysis takes 21 kinds of energy sources as statistical object, which is different from that in the past. The carbon emission amount (D) of transportation industry is calculated, as shown in Formula (1).

$$D = \sum A_i \times B_i \times C_i \times N_i \times \frac{44}{12} \tag{1}$$

Where, D is carbon emission from energy consumed by construction industry; A_i is *i* fuel consumption; B_i is conversion standard coal coefficient of *i* fuel; C_i is a carbon emission coefficient of *i* fuel; N_i is oxidation rate of *i* fuel. B_i comes from the conversion coefficient of "General Principle of Comprehensive Energy Consumption Calculation" (GB / T 2589-2008); C_i derives from default value of IPCC carbon emission calculation guidelines.

2.2 Elastic decoupling model of carbon emission and economic growth in transportation industry

Decoupling between carbon emission and economic growth means that carbon emission doesn't increase with economic growth, but tends to decline, and a complete decoupling between the two is ideal. In this analysis, decoupling elasticity mainly refers to the change ratio of the carbon emission in transportation industry to the GDP of the industry. Based on Tapio's elastic decoupling model, this analysis proposes an elastic decoupling model of the relationship between transportation and economic growth in China's provinces, as shown in Formula (2).

$$t_{CO_2, IGDP} = (\Delta CO_2 / CO_2) / (\Delta IGDP / IGDP) \tag{2}$$

Where, t_{CO_2}, IGDP indicates the decoupling elasticity of the relationship between carbon emission in transportation industry and GDP of transportation industry; CO_2 is the carbon emission in transportation industry in each province (10,000 t); IGDP is the annual GDP of transportation industry (billion yuan). In order to eliminate the factor of price change and ensure the comparability of indexes between different periods and regions, the GDP of transportation industry is calculated with a constant price.

2.3 Decomposition model of influence factors of carbon emission

In this analysis, the influence factors of carbon emission are decomposed into four factors: carbon emission intensity effect, energy structure effect, energy intensity effect and industry scale effect by using extended Kaya identical equation and LMDI. According to the research results of Ang B.W et al. and the characteristics of carbon emission in transportation industry, a decomposition model is established.

$$C = \sum \frac{C_i}{E_i} \times \frac{E_i}{E} \times \frac{E}{IGDP} \times IGDP = \sum f_i \times s_i \times n \times g \tag{3}$$

Where, C_i represents the carbon emission (10,000 t) from the consumption of i_{th} energy source; E_i represents the consumption of i_{th} energy source (10,000 t of standard coal); E indicates the total energy consumption (10,000 t of standard coal); *IGDP* expresses the GDP of transportation industry (billion yuan); $f_i = C_i/E_i$ represents the carbon emission intensity effect of i_{th} energy source; $s_i = E_i/E$ represents the consumption ratio of i_{th} energy source in the total energy, which is used to explain the energy consumption structure;

n=E/IGDP is the energy consumption intensity; *g* indicates the impact of the industry scale effect on the carbon emission in the transportation industry.
According to the decomposition analysis of Formula (3) by LMDI, the change ΔC of carbon emission from t to t + 1 in transportation industry in each province can be expressed as Formula (4).

$$\Delta C = C_{t+1} - C_t = \Delta C_f + \Delta C_s + \Delta C_n + \Delta C_g \tag{4}$$

$$\Delta C_f = \sum \frac{C_i^{t+1} - C_i^t}{\ln C_i^{t+1} - \ln C_i^t} \times \ln\left(\frac{f(t+1)}{f(t)}\right) \tag{5}$$

$$\Delta C_s = \sum \frac{C_i^{t+1} - C_i^t}{\ln C_i^{t+1} - \ln C_i^t} \times \ln\left(\frac{s(t+1)}{s(t)}\right) \tag{6}$$

$$\Delta C_n = \sum \frac{C_i^{t+1} - C_i^t}{\ln C_i^{t+1} - \ln C_i^t} \times \ln\left(\frac{n(t+1)}{n(t)}\right) \tag{7}$$

$$\Delta C_g = \sum \frac{C_i^{t+1} - C_i^t}{\ln C_i^{t+1} - \ln C_i^t} \times \ln\left(\frac{g(t+1)}{g(t)}\right) \tag{8}$$

Where, $\Delta C_f, \Delta C_s, \Delta C_n$, and ΔC_g are the contribution values of carbon emission intensity effect, energy structure effect, energy consumption intensity effect and industry scale effect to carbon emission change in transportation industry respectively. The carbon emission coefficients of various energy sources are kept constant, so $\Delta C_f = 0$ in Formula (4).

3. Empirical Analysis

3.1 Decoupling analysis of carbon emission and economy in transportation industry

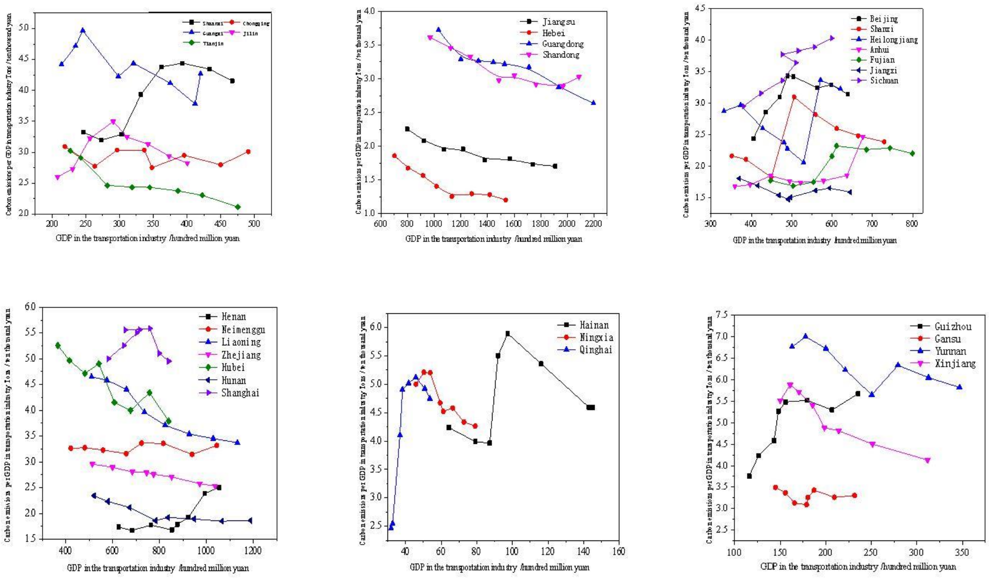

Figure 1: EKC of carbon emission in China's transportation industry over the years

The carbon emission in transportation industry in 30 provinces of China from 2009 to 2016 is calculated by formula (1), and the mean GDP, carbon emission and the average rate in transportation industry from 2009 to 2016 are calculated. Based on the elastic decoupling model of carbon emission in transportation industry, the elastic decoupling value of carbon emission in transportation industry is calculated by Formula (2). The results show that the change of carbon emission in transportation industry and the change of GDP in transportation industry are both positive from 2009 to 2016, indicating that the carbon emission and GDP of transportation industry in China show an increasing trend.

In order to more intuitively explain the dynamic relationship between carbon emission intensity and economic growth in transportation industry in each province, the environmental Kuznets curve (EKC) analysis is carried out for each province. The EKC curve of carbon emission is an empirical curve obtained by statistical actual data and reflects the relationship between carbon dioxide emission and economic growth. Based on the indexes of carbon emission, mean value of GDP and average change rate of transportation industry, 30 provinces are classified into 6 categories by K-means cluster analysis. GDP of transportation industry of each province (price is comparable and 2009 is base period) is taken as abscissa and unit GDP carbon emission of transportation industry is taken as ordinate, we can obtain EKC of carbon emission in transportation industry in each province from 2009 to 2016, as shown in Figure 1.

As can be seen from Figure 1, the relationship between carbon emission and economic growth in China's transportation industry from 2009 to 2016 has five types of curves, namely, linear type, U type, inverted-U type, inverted-N type and wave type. The EKC of Shandong, Guangdong, and other 9 provinces is declivitous to be approximate straight line, which shows that the carbon emission intensity decreases gradually with the increase of GDP, and the effect of energy conservation and emission reduction in transportation industry is obvious. The EKC of Sichuan, Guizhou, Henan, Chongqing, Guangxi and Inner Mongolia is wave type. The EKC of Chongqing and Inner Mongolia is relatively stable while that of Guangxi is declivitous wave type. The carbon emission intensity in Sichuan, Guizhou and Henan increases with the economic growth. It shows that there is a strong coupling relationship between carbon emission and economic growth in these provinces, and the task of energy conservation and emission reduction is arduous. The EKC of Heilongjiang and Anhui is U type while that of Jilin, Shaanxi, Shanghai, Qinghai and Beijing is inverted-U type, which shows that the carbon emission intensity decreases with the economic growth in recent years. The EKC of Hainan, Yunnan, Gansu, Shanxi, Fujian and Jiangxi is inverted-N type, which indicates that during the study period, the carbon emission intensity decreases first, then increases and decreases with the economic growth. Although it shows a downward trend recently, the carbon emission intensity fluctuates greatly. The situation of energy conservation and emission reduction in transportation industry is not optimistic.

3.2 Decomposition model of influence factors of carbon emission in transportation industry

Based on the energy consumption of transportation industry in 30 provinces of China from 2009 to 2016, the dynamic change of the energy consumption of 9 energy sources of transportation industry, including diesel, gasoline, kerosene, natural gas, heating power and electric power are calculated, as shown in Figure 2. From 2009 to 2016, the total energy consumption of the national transportation industry increases from 176 × 106 t in 2009 to 333 × 106 t in 2016 with an average annual growth rate of 12.7%. It can be seen from the dynamic change of various energy consumption that the dynamic change of diesel consumption is the same as that of total energy consumption. This indicates that the transportation energy consumption is excessively dependent on diesel, and the proportion of alternative energy and renewable energy needs to be increased. The consumption of clean energy such as natural gas, electric power and thermal power is slow because of the promotion of the application of new clean energy in passenger service vehicles in recent years. However, the proportion of natural gas, thermal power and electric power in the energy structure is still low, which indicates that the energy conservation and emission reduction of transportation industry is still urgent and has a long way to go.

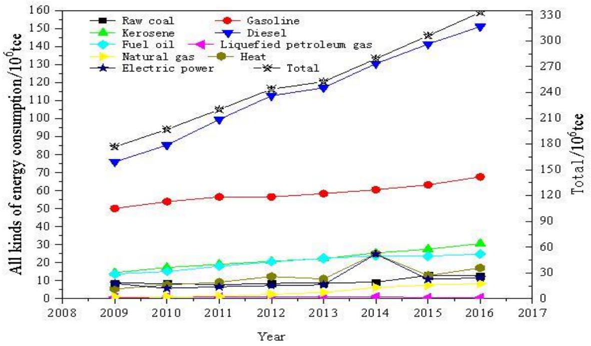

Figure 2: Dynamic change of energy consumption in China from 2009 to 2016

According to the calculation result of carbon emission in transportation industry in China, the annual added value of carbon emission in transportation industry in China from 2009 to 2016 is calculated, and the contribution and contribution rate of energy structure effect, energy intensity effect and output scale effect to carbon emission in transportation industry in China are analyzed respectively. The calculation results are shown in Figure 3.

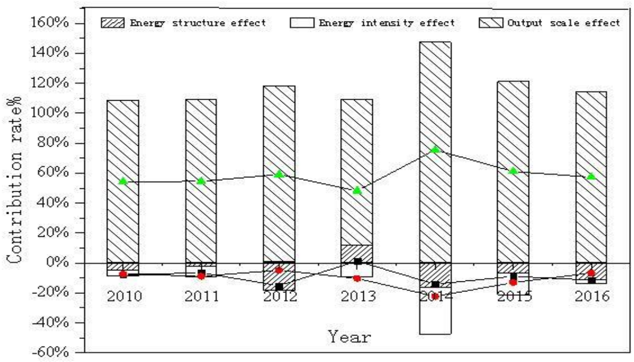

Figure 3: Contribution rates of factors of carbon emission in China's transportation industry

The results shown that, the carbon emission of China's transportation industry shows a fluctuating growth trend from 2009 to 2016, and the growth is relatively stable from 2015 to 2016. From 2012 to 2013, transportation industry develops slowly for economic restructuring and carbon emission declines year after year. Subsequently, Chinese government introduces a series of supply-side structural reform measures so that the transportation industry shows a steady growth momentum from 2015 to 2016.

As can be seen from Figure 3, the contribution rate of industry scale effect to the annual carbon emission in the national transportation industry is over 100%, which is far higher than other factors, indicating that scale effect is the main factor of the growth of carbon emission in transportation industry in China during the analysis period. The energy structure effect and energy intensity effect have relatively weak negative influence on the carbon emission in the national transportation industry year by year, which indicates that the energy consumption structure of China's transportation industry is not adjusted and optimized enough and the energy consumption efficiency is not high. The results show that it is urgent for China's transportation industry to speed up the transformation of development mode so as to realize the remarkable improvement of energy and resource use efficiency, as well as the sustainable improvement of ecological environment.

4. Conclusions

In this analysis, the carbon emission data of transportation industry in 30 provinces of China from 2009 to 2016 are calculated according to the IPCC carbon emission calculating method. The decoupling relationship between carbon emission and economic growth in transportation industry is analyzed by using Tapio decoupling model. Besides, the carbon emission intensity effect, energy structure effect, energy intensity effect and industry scale effect on carbon emission in transportation industry are analyzed by using extended Kaya equation and LMDI model respectively. This plays an important role in introducing differentiated development policies for transportation industry.

It can be seen from the analysis result of the decoupling model that the carbon emission decoupling value of China's transportation industry has obvious spatial disequilibrium characteristics, and the decoupling state of "weak decoupling-expansion negative decoupling-growth linkage" appears from coastal areas to inland areas as a whole. 40% of provinces are in weak decoupling state, which shows that the energy conservation and emission reduction of transportation industry in these provinces are relatively good, and it is expected that the construction of low-carbon transportation system will achieve full decoupling between carbon emission and economic growth in the future. 26.7% and 33.3% of provinces are in the state of growth linkage and expansion negative decoupling respectively. There hasn't been a province with strong decoupling yet. It shows that these provinces will be the focus of building a low-carbon transportation system. Relevant departments can formulate targeted low-carbon objectives for development of transportation industry and introduce differentiated development policies for transportation industry.

The analysis from two level shows that the energy structure effect and the energy intensity effect have a relatively weak negative impact on the carbon emission in the national transportation industry and shows that the energy consumption structure of the transportation industry in China is not sufficiently adjusted and optimized, and the energy consumption efficiency is not high. The industry scale effect has a significant positive impact and is the main factor to promote the growth of carbon emission. Therefore, properly solving the contradiction between economic growth and carbon emission is the key for China's transportation industry to realize low-carbon development. We should accelerate the research and development and promotion of energy conservation and emission reduction technologies of transportation infrastructure, improve energy structure, increase the proportion of new energy and clean energy to total energy, as well as increase the inhibiting effect of energy structure effect and energy intensity effect on carbon emission in transportation industry. What's more, we shall further improve the comprehensive transportation network and build an efficient transportation organization system so as to reduce promoting function of industry scale effect on carbon emissions in transportation industry.

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