

Original Research

Provincial Differences on CO₂ Emissions in China's Power Industry: A Quantile Regression Approach

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Abstract

As the world's largest energy consumer today, China is causing increasing pressure on the global environment, and the power industry might bear the primary responsibility for producing nearly 50% of China's CO₂ emissions. Investigating the main drivers of CO₂ emissions in China's power industry is of vital importance for developing effective environmental policies. Based on the panel data of 30 provinces in China, the quantile regression approach was applied in the present paper in order to find out which provinces should pay more attention to mitigating CO₂ emissions in the power industry. Results show that the upper 90th quantile provinces (Guangdong, Jiangsu and Shandong) have to spend more efforts on carbon reduction, and the influences of economic growth, industrialization level and energy efficiency in these provinces are more significant than in others. These findings are extremely helpful for related departments in the power industry to develop appropriate policies pertaining to energy savings and emissions reduction.

Keywords: CO₂ emissions, China's power industry, quantile regression, provincial differences, policy suggestions

Introduction

The greenhouse effect, which brings the world a series of urgent environmental problems, is increasingly drawing global attention. Due to the large consumption of fossil fuels such as coal, atmospheric carbon dioxide concentration continues to rise, and this will affect energy, ecology, water, food and environmental security, and even threaten the survival of mankind [1].

China has become the focus and main force of the world to shoulder the responsibility of reducing CO₂ emissions [2]. China has produced the most carbon emissions in the world, even in the year 2014, and its total carbon emissions run up to 11.5 billion tons, almost occupying one third of total global emissions [3]. At the end of December 2016, in the Beijing-Tianjin-Hebei region, Shandong, Henan and other places, the haze orange warning time broke the historical record and reached 200 hours. Undoubtedly, China's carbon emissions are getting more and more attention from all over the world. However, the difficulty in reducing carbon emissions is the continuing existence

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of large demand for it due to rapid urbanization and industrialization. Thus, China is trying hard to mitigate its CO₂ emissions.

The power industry is the main industry for greenhouse gas emission reduction. China's power industry also consumes the most energy and emits most of the CO₂ [4]. It bears the responsibility for 44.56% of total annual energy consumption and 48.79% of CO₂ emissions in 2014. According to [5], in order to achieve the target of carbon dioxide emissions, 1.7 billion tons of carbon dioxide emissions need to be cut down in the existing policy scenario by 2030. It was also reported that the development of renewable energy, nuclear power and natural gas power generation in the power generation industry would be the main emission reduction initiatives. The power industry might shoulder the responsibility of reducing the emissions of 840 million tons, accounting for more than half of all emission reductions. Therefore, investigating CO₂ emissions in China's power industry is of vital importance for relevant departments to develop energy-saving emission reduction policies.

Many researchers have made outstanding contributions in the field of the power industry's carbon emissions. Research on the internal relationship between the low carbon target and the electric power industry in the power industry has been studied. The results of Grubb's study show that the diversity of the power structure is consistent with the goal of low-carbon development in the power industry [6]. Strachan and Kannan [7] used the hybrid MARKAL-MACRO model to study the UK's problem of reducing carbon emissions, the results showing that in the long run, the goal of reducing carbon emissions by 60% in the UK is achievable. The impact of the implementation of renewable energy quota policy on power generation enterprises was analyzed from the aspects of power generation transaction rights, power system planning and reliability research of low-carbon power. The results show that there must be a certain proportion of renewable energy in energy consumption of power production [8-15]. The impact of low-carbon futures on carbon reduction in the power sector was studied by Soderhol et al. [16]. The results of Viebahn Peter et al. [17], Braun Marcel et al. [18] and Zhang Chi et al. [19] show that the EU countries can transfer their greenhouse gas emission reduction technologies and new energy power generation technologies to help developing countries achieve emission reduction targets. CCS (carbon capture and storage) and renewable energy technologies were studied by Torvanger Asbjorn and Meadowcroft James [20] based on economic models, and the lowest cost curves for alternatives were obtained. Then various policy recommendations to ensure the minimum cost of carbon reduction were put forward from an economic and political point of view. Studies of Nelson James et al. [21] have shown that the core of reducing carbon emissions is to achieve emissions reductions in the power sector. From the

perspective of low-carbon technology, Lampreia Joao et al. [22] designed a development program for Brazil to expand its power matrix and the overall energy sector. Siriwardena et al. [23] investigated the impacts of carbon emissions and energy taxes on Sri Lanka's power sector. Gale, Herzog and Braitsch [24] analyzed the impacts of financial capital and public policy on the application of carbon capture and carbon sequestration technology coal-fired power plants in U.S. The results of Giovanni, Emily and Richards, and Kenneth [25] show that using CCS technology to expand the power generation capacity of coal-fired power plants is an effective means of developing low-carbon power.

Though carbon emissions in the power industry have been widely discussed, there are three differences between the present research and previous studies. The first difference is that the existing literature has focused more on the national and provincial levels when it comes to carbon emissions, while the present paper used panel data of 30 provinces in China and focused on comparing the different effects of the factors influencing the electricity industry among China's provinces. Since China is a country with an area of 9.6 million km², with significant regional differences, it is of great significance for policy makers to take into account the differences among provinces so that the goal of carbon reduction can be achieved more effectively. In addition, linear models were adopted by most researchers to explore the relationship between CO₂ emissions and the influencing factors, while in this article, the quantile regression model, taking nonlinear relationship among variables into consideration, is applied to study the effectiveness of different impacting factors on CO₂ emissions in China's power industry. The last one is that authors often focus only on the average performance in many empirical analyses, while the quantile regression method also pays attention to the distribution of the tail, making the regression model more accurate and detailed.

Material and Methods

The Quantile Regression Approach

Koenker and Bassett [26] originally introduced the idea of quantile regression into economic analysis. The quantile regression method, which uses the weighted average absolute error as the objective function to estimate the regression coefficients, is different from the least squares estimation method. The dependent variables of different quantiles can be investigated by using the quantile regression method. In many empirical analyses, the authors often focus only on the average performance, but not on the distribution of the tail. The quantile regression both deepens the understanding of the traditional regression methods, and promotes the type and application of the regression model, making

the regression model more accurate and detailed when fitting the relevant statistical data. Therefore, it is increasingly widely used in various fields such as mathematics, economics, sociology, medical science, political science, and so on [27-31].

The following is the mathematical expression of the panel data models:

$$y_i = x_i' \beta_{\theta} + u_{\theta}, 0 < \theta < 1 \tag{1}$$

$$Quant_{\theta}(y_i | x_i) = x_i \beta_{\theta} \tag{2}$$

...where y denotes the explained variable, x is a vector of the explanatory variables, the random error term is explained by μ , and $Quant_{\theta}(y_i|x_i)$ means the θ th quantile of the dependent variable y.

The θ th quantile regression estimators is the solution of the following formula:

$$\min \sum_{y_i \geq x_i' \beta} \theta |y_i - x_i' \beta| + \sum_{y_i < x_i' \beta} (1 - \theta) |y_i - x_i' \beta| \tag{3}$$

The above equation can be solved by linear programming. We can set different values of θ in order to get different quantile regression results.

Since the quantile regression is used to estimate the parameters by minimizing the sum of the absolute values of the weighted residuals, it has the following advantages:

- 1) There are no assumptions in quantile regression on the distribution of random error terms. Since the distribution can be any probability distribution, the whole model has a strong robustness.
- 2) The quantile regression is a regression of all the quantiles and is therefore resistant to the anomalies in the data.
- 3) Unlike ordinary least squares regression, the quantile regression has a monotonic invariance for the dependent variable.
- 4) The parameters estimated using quantile regression have progressive superiority under the large sample theory.

Model Details

The IPAT identity is often used to study the influences of the different forces driving environmental pollution:

$$I = P \cdot A \cdot T \tag{4}$$

...where I represents the emission level of a pollutant, P denotes the size of the population, A represents a country's affluence and T is technological progress.

The STIRPAT model was constructed based on the IPAT model [32], and the model can be expressed as follows:

$$I_t = aP_t^b A_t^c T_t^d \xi_t \tag{5}$$

...where a represents the intercept term, P, A and T are the same as in Eq. (4); b, c and d represent the elasticities of environmental impacts with respect to P, A and T respectively; ξ_t is the random disturbance; and subscript t means the time as it is an annual data analysis.

In order to avoid the possibility of heteroscedasticity, every variable is transformed into a logarithmic form, and Eq. (5) can be written as below:

$$LI_t = La + b(LP_t) + c(LA_t) + d(LT_t) + \xi_t \tag{6}$$

Eq. (6) can be expressed in the following way to analyze the effects of CO₂ emissions drivers in China's power industry:

$$LCO_{2t} = La + b(LPOP_t) + c(LGDP_t) + d(LENE_t) + \xi_t \tag{7}$$

...where CO₂ is carbon dioxide emissions of the 30 provinces, POP indicates population size, and GDP represents economic growth and is measured in real gross domestic product per capita of 1990 constant yuan. ENE represents energy efficiency and is calculated by dividing GDP by energy use.

To further the study of the CO₂ emission's drivers in China's power industry, the formula was expanded by adding URB (urbanization level, calculated with urban population / total population), IND (industrialization level, calculated by industrial added value / GDP) and PGS (power generation structure, calculated by thermal power generation / total power generation) to the model. Firstly, the city is the center of population, transportation, construction and industry. The urbanization level increased from 36.22% in 2010 to 54.77% in 2014. An increasing urban population needs large amounts of power resources and will undoubtedly result in the increase of CO₂ emissions. Therefore, it is essential to introduce URB into the model. Secondly, China is still at the stage of industrial development. The long operation of numerous large machines is bound to consume a lot of power. It is definitely the proportion of the industry that has a significant positive impact on CO₂ emissions in China's power industry. So, IND is added into the model. Thirdly, China is a country dominated by thermal power, and thermal power needs to consume large amounts of coal, leading to an increase in carbon emissions. So the power generation structure has become an important factor affecting the carbon industry in the power industry. Accordingly, the PGS is also involved in the model.

The definitions of the variables are shown in Table 1.

Table 1. Definition of relevant variables.

| Variable | Definition | Unit |
|-----------------|----------------------------|--------------------|
| CO ₂ | CO ₂ emissions | 10,000 tons |
| GDP | Per capita GDP | yuan |
| ENE | Energy efficiency | Tce per ton output |
| URB | Urbanization level | Percent |
| IND | Industrialization level | Percent |
| POP | Total population | 10,000 people |
| PGS | Power generation structure | Percent |

Data Processing

Data includes annual observations on CO₂ emissions, industrialization level, power generation structure, energy efficiency, urbanization level and per capita GDP for 30 provinces from 2000 to 2014. They were all collected from the China Statistical Yearbook (2001-2015) and the provincial statistical yearbooks (2001-2015). Energy efficiency is obtained by dividing its output by electricity consumption. Industrialization level is the proportion of the industry. Urbanization level means the proportion of the urban population. Power generation structure refers to the scale of thermal power generation. The statistical descriptions of the variables are provided in Table 2.

This part analyzes the dynamic changes of the related variables. As Fig. 1 shows, CO₂ emissions have been growing rapidly since 2001 with an annual increasing rate of 8.9%. Energy efficiency also has a rapid growth rate thanks to the advance of modern science and technology. GDP's annual growth rate is 9.3%, which grew from 7816.3 yuan in 2000 to 26979.3 yuan in 2014. IND Shows the overall trend of increasing first and then decreasing, and the highest point appeared in 2006 (42.21%). PGS shows a fluctuating state, and after 2009 it shows an overall downward trend. POP has an overall upward trend with the annual 0.5%. URB also has a continuous rising trend, reaching 54.78% in 2014.

Table 2. Statistical description of the variables.

| Variable | Unit | Mean | Std. dev. | Min | Max |
|-----------------|-----------------|----------|-----------|---------|----------|
| CO ₂ | 10,000 tons | 8941.06 | 7757.78 | 246.05 | 37394.38 |
| GDP | Yuan | 16607.84 | 11226.85 | 2742.07 | 73260.32 |
| ENE | Tce per percent | 9.22 | 3.82 | 1.92 | 22.76 |
| URB | Percent | 48.35 | 15.29 | 23.30 | 89.60 |
| IND | Percent | 39.43 | 7.97 | 13.37 | 53.04 |
| POP | 10,000 people | 4380.36 | 2696.99 | 517.00 | 10724.00 |
| PGS | Percent | 78.33 | 22.116 | 15.35 | 100.00 |

Results and Discussion

Result of Unit Root Tests

Usually, the time series analysis requires a stable sequence so that there is no existence of stochastic trend or accurate trend. However, the majority of the sequences might be not stationary, which may possibly result in biased analysis.

The unit root test is used to test whether the variables have unit roots, therefore helps to test the smoothness of the sequences. However, the panel unit root tests have significant differences. Since the efficiency of unit root tests of time series is not high, many experts have come up with various ways to overcome this difficulty. In this paper, taking China's specific national conditions into account, we chose the Im-Pesaran-Skin, Fisher-ADF and Fisher-PP approaches to identify whether the data is stationary.

Table 3 presents the test results of the different variables. It indicate that none of the original time series above is a stationary sequence. To address this issue, the first-order difference method is applied to change the sequence into a stationary one. Test results of the first-order differential form are also shown in Table 3. Results in Table 3 indicate that all the transformed variables can reject the null hypothesis at different significance levels. This provides us with strong evidence to accept the conclusion that the first-order difference sequences are stationary.

Relationship between Independent and Dependent Variables

In order to more intuitively present the relationship between the independent variable and the dependent variables, we use the scatter plot to visualize this content. Based on the panel data for 30 provinces, six scatter plots between CO₂ emissions and ENE, GDP, POP, PGS, IND and URB were obtained in Fig. 2, which shows a number of significant relationships between carbon emissions and its drivers. This gives us sufficient evidence to believe that the following quantile regression might be feasible and effective.

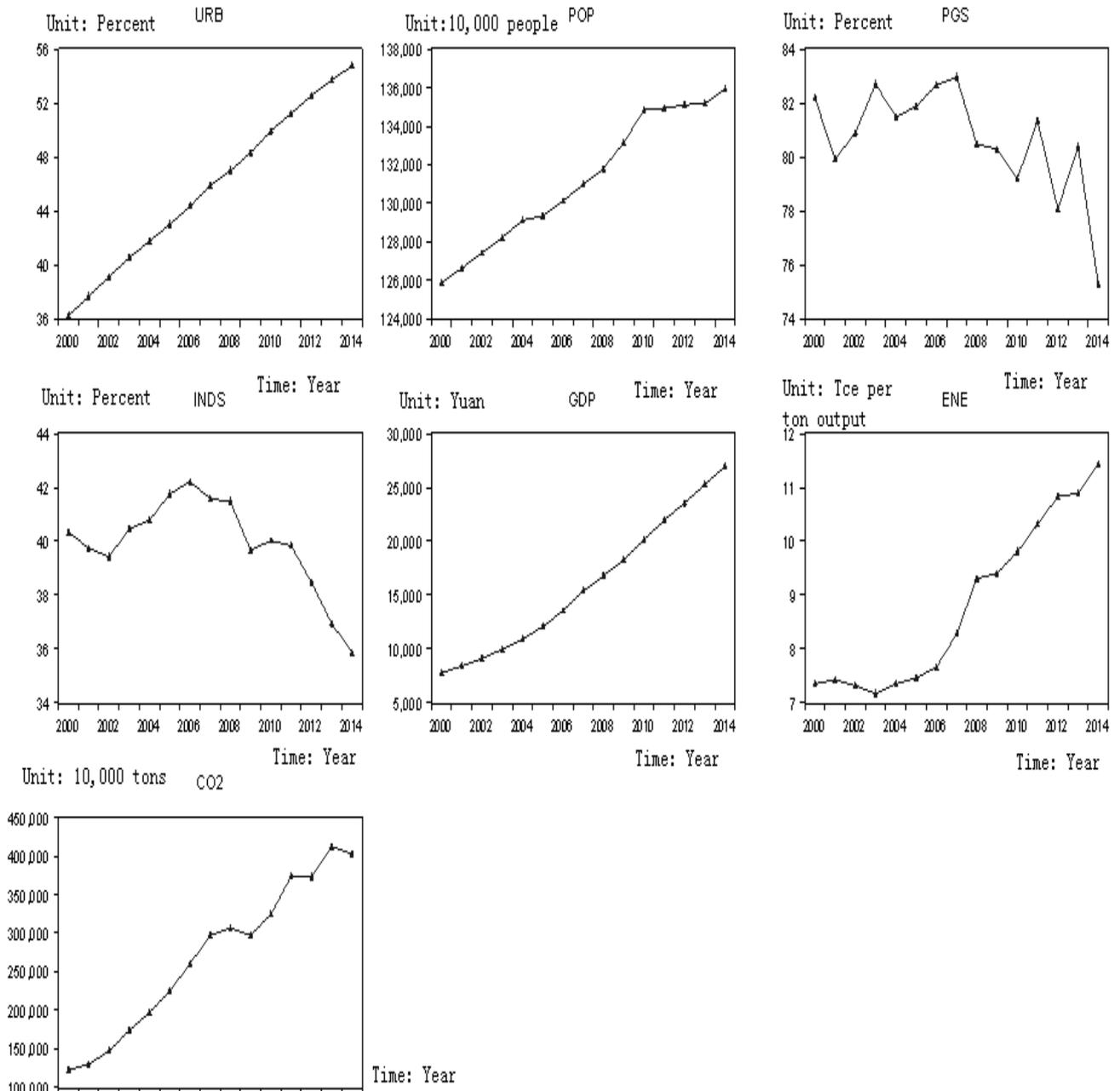


Fig. 1. Trends of variables over 2000-2014.

Results of Quantile Regression

Because there are such significant differences in the levels of carbon emissions among 30 provinces, it is difficult to take into account the situation of each province in different quantiles. Therefore, this paper selected five representative quantiles and divided the carbon level into six levels (as shown in Table 4), to analyze the impact differences of the drivers at different emission levels. From Table 5 and Fig. 3 we can find the regression results. As the table shows, every dependent variable is statistically significant at the confidence level of 10% or higher.

The impacts of GDP on CO₂ emissions present a U-shaped trend from quantile provinces in group 1 to

quantile provinces in group 6. This might be because of the investment in fixed assets and export trade. In the first place, public infrastructure and other fixed assets will consume a lot of reinforced concrete, and will require a lot of power resources to ensure the operation of the projects. This will lead to a large number of carbon dioxide emissions. Investment of fixed assets in the quantile provinces of group 6 is twice or more than that of other quantile provinces. Therefore, the impact of economic growth in these provinces is more pronounced. In addition, China's export products such as clothing are mostly high-energy consuming products. In the production process, the operation of the large-scale machine will definitely consume a lot of human resources and power resources, and then the CO₂

Table 3. Results of unit root tests.

| | Series | Fisher ADF | | Fisher PP | | IPS | |
|------------------|-----------------|----------------------|--------------------------------|----------------------|--------------------------------|----------------------|--------------------------------|
| | | Individual intercept | Individual intercept and trend | Individual intercept | Individual intercept and trend | Individual intercept | Individual intercept and trend |
| Level | GDP | 139.058 | 12.5587 | 609.85 | 47.5607 | -6.3765 | 2.50583 |
| | URB | 32.1757 | 114.555 | 116.331 | 69.6169*** | 2.90124 | -0.28715 |
| | IND | 63.0822 | 16.3584 | 101.144 | 66.2146 | -1.28738 | 3.02324 |
| | ENE | 46.6818 | 73.3179 | 85.0108** | 165.310 | 0.52521 | -1.17663 |
| | PGS | 30.6611 | 48.9389 | 118.222 | 127.500 | 1.48096** | -0.34139 |
| | POP | 37.5805*** | 21.9003 | 12.7709 | 37.9766 | 4.92997 | 3.67997 |
| | CO ₂ | 81.5470 | 24.5026 | 146.064 | 108.121* | -2.12810 | 1.14816 |
| First difference | GDP | 16.2709*** | 37.4558*** | 29.9265*** | 251.219** | 1.96572*** | -0.09237*** |
| | URB | 117.436*** | 48.0402*** | 175.513*** | 176.035*** | -1.08932** | 1.60686*** |
| | IND | 20.7139*** | 39.2868*** | 118.055* | 182.967*** | 2.23075*** | 0.57368*** |
| | ENE | 65.5589*** | 15.6398*** | 266.624*** | 221.286*** | -1.31149* | 1.78273*** |
| | PGS | 66.6338*** | 62.2199*** | 336.621*** | 311.354*** | -1.20156*** | -0.42237*** |
| | POP | 29.8361*** | 61.0377*** | 170.609*** | 171.488*** | 3.17680*** | 0.76935*** |
| | CO ₂ | 32.9569*** | 58.7794*** | 222.285*** | 219.239*** | 0.69248*** | -0.14222* |

Note: Lags are all selected automatically by AIC and SC standard.

* P<0.1; ** P<0.05; *** P<0.01

emissions will increase. The export volume in quantile provinces of group 6 is much higher than that in other provinces, so the impact of economic factors is stronger than other provinces.

The effects of URB on the CO₂ emissions in quantile provinces of group 1 and quantile provinces of group 6 are more significant than those in the quantile provinces of groups 2-5. The reason can be summarized in the following three points:

- 1) The increase in urban population will first bring a lot of housing demand. Real estate developers will invest a lot of money to meet the housing needs, and therefore will consume a lot of building materials. The large use of manufacturing products will undoubtedly increase CO₂ emissions.
- 2) The process of urbanization not only promotes the development of public transport, but also leads to the increase of motor vehicles, and this might be due to the city's fast pace of life and work. The large use of motor vehicles and electric vehicles consumes a lot of fossil fuels and electrical resources, thereby increasing CO₂ emissions.
- 3) Thanks to the improvement in living standards, people in cities have more recreational activities, so the electricity consumption in cities will be much higher than in the countryside. This also results in increased CO₂ emissions in urban areas. According to statistics, real estate investment, motor vehicle ownership and residential electricity consumption in the quantile provinces of group 6 are much more than

Table 4. Provincial distribution in term of total CO₂ emissions.

| Group | Quantile | Provinces |
|---------|--|---|
| Group 1 | The lower 10 th quantile group | Beijing Hainan Qinghai |
| Group 2 | The 10 th - 25 th quantile group | Chongqing Guangxi Ningxia Tianjin Xinjiang Yunnan |
| Group 3 | The 25 th - 50 th quantile group | Fujian Gansu Hunan Jiangxi Jilin Sichuan |
| Group 4 | The 50 th - 75 th quantile group | Anhui Guizhou Heilongjiang Hubei Shanghai Shanxi1 |
| Group 5 | The 75 th - 90 th quantile group | Hebei Henan Liaoning Shanxi2 Zhejiang Neimenggu |
| Group 6 | The upper 90 th quantile group | Guangdong Jiangsu Shandong |

Notes: China's 30 provinces are divided into six grades using the statistics grouping method.

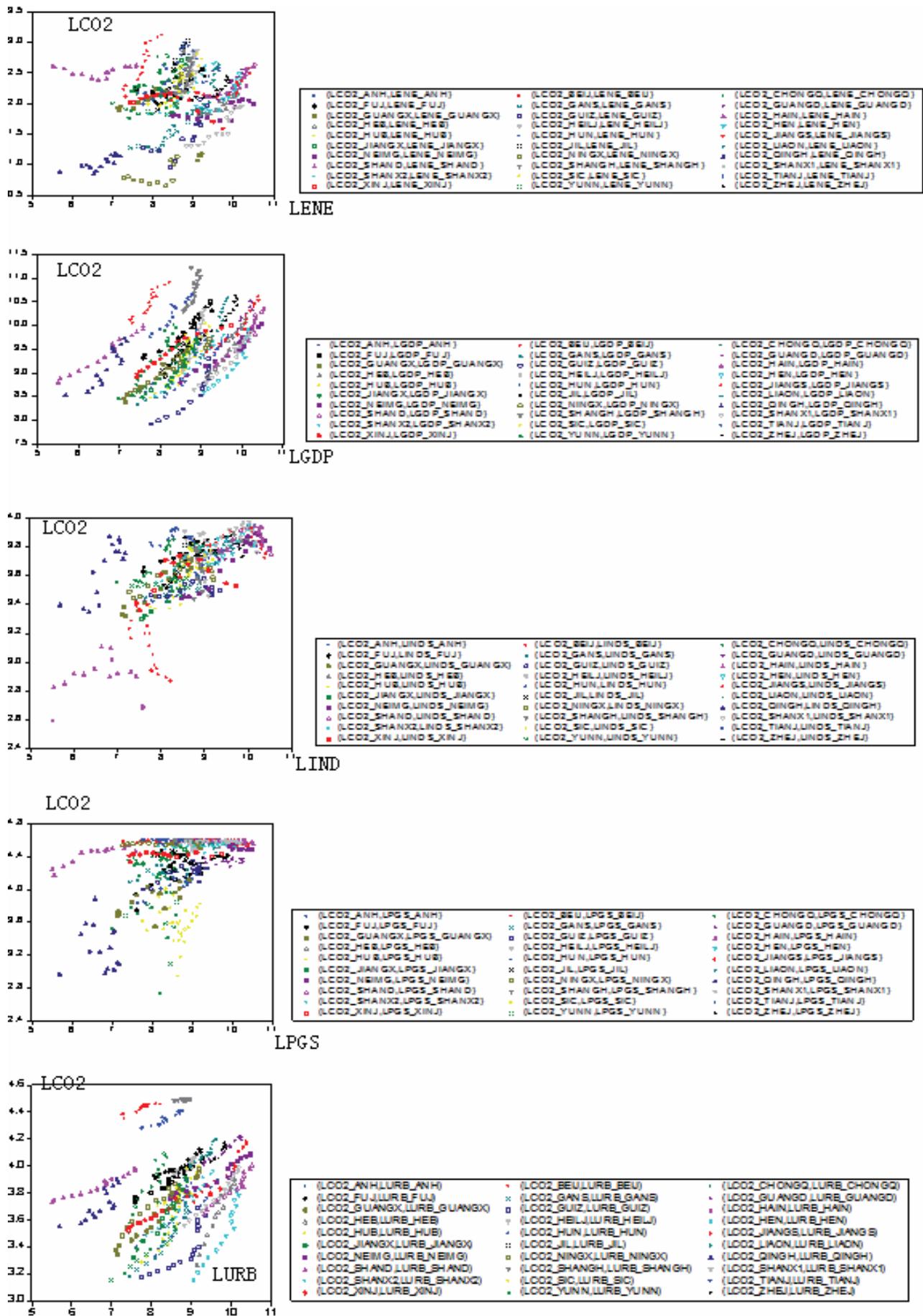


Fig. 2. Relationship between CO₂ emissions and its driving factors.

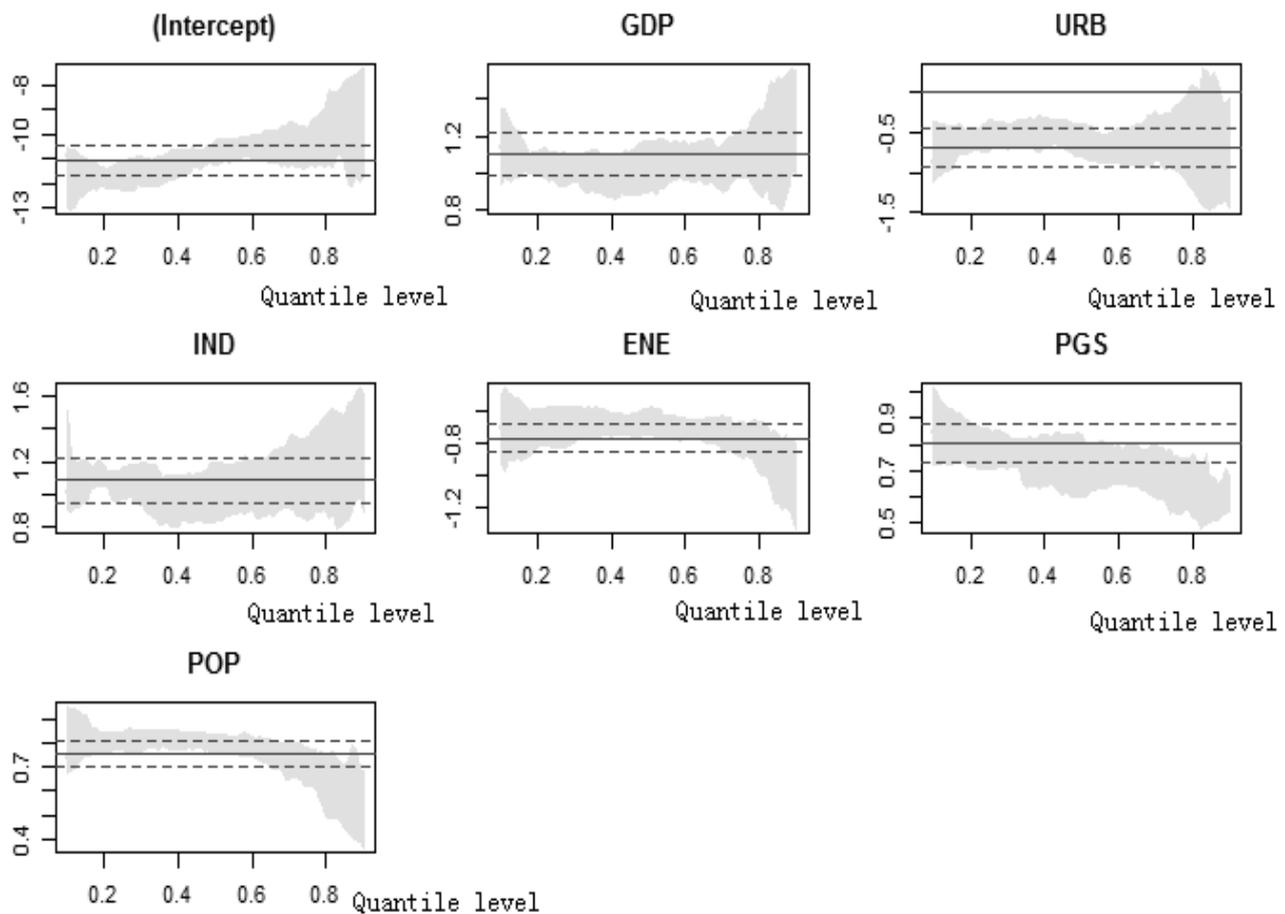


Fig. 3. Quantile regression results.

other provinces. Thus, the impact of urbanization on CO₂ emissions in the quantile provinces of group 6 is more significant.

The influences of IND on CO₂ emissions in China's power industry increases continuously from the quantile provinces of group 1 to the quantile provinces of group 6. This provides us with sufficient evidence to believe that the greater the amount of carbon emissions in the city, the greater the level of industrial response. As

we all know, the industrial sector plays a vital role in energy consumption, and the expansion of industrial scale consumes a lot of fossil energy. Differences in the size of the industry will inevitably lead to differences in carbon emissions. Since the industrial output is increasing from quantile provinces of group 1 to the quantile provinces of group 6, the role of industrialization is getting stronger at the level of carbon emissions.

Table 5. Estimation results: Quantile regression model and liner fixed effects model during 2000-2014.

| Variables | Quantile regressions | | | | | OLS |
|-----------|------------------------|------------------------|------------------------|------------------------|------------------------|------------|
| | 10 th quant | 30 th quant | 50 th quant | 70 th quant | 90 th quant | |
| Intercept | -10.886 | -11.610*** | -10.875*** | -10.763*** | -8.935*** | -11.072*** |
| POP | 0.739*** | 0.822*** | 0.803*** | 0.742*** | 0.532*** | 0.755*** |
| GDP | 1.134*** | 1.010** | 1.077*** | 1.071*** | 1.165*** | 1.099*** |
| ENE | -0.670*** | -0.664*** | -0.694*** | -0.759*** | -1.008* | -0.765*** |
| URB | -0.890*** | -0.497*** | -0.683*** | -0.586*** | -0.510*** | -0.685*** |
| IND | 1.013*** | 1.067*** | 1.018*** | 1.165*** | 1.115*** | 1.086*** |
| PGS | 0.845*** | 0.760*** | 0.728*** | 0.685*** | 0.638*** | 0.806** |
| R-square | 0.784 | 0.759 | 0.773 | 0.785 | 0.816 | 0.871 |

***Significance at 1% level; **Significance at 5% level ; *Significance at 10% level

The effect of ENE on carbon emissions is gradually increasing from quantile provinces of group 1 to quantile provinces of group 6. And the impact reaches strongest in the quantile provinces of group 6. This indicates that technological progress has more significant impacts on the quantile provinces of group 6 than other provinces. This may be due to the differences in R & D investment and educational input. The research and development, improvement and application of energy-saving emission reduction technology and clean energy technology are more dependent on highly educated people. As a result, the impact of energy efficiency on carbon emissions is more pronounced in the quantile provinces of group 6.

The last finding is the impact of PGS continuing to decline from the quantile provinces of group 1 to the quantile provinces of group 6. This is contrary to the empirical results of Xu and Lin [33]. In China, the proportion of thermal power generation has an absolute advantage compared to other power generation modes. Since the energy consumption of thermal power generation is dominated by high-polluting coal, this will bring a lot of carbon emissions to the power industry. Since the differences in the structure of the power generation structures are not obvious in each quantile province, and the interaction with other factors, the power generation structure has a relatively small impact on CO₂ emissions in provinces with large carbon emissions.

Conclusions

Panel data of 30 provinces in China from 2000 to 2014 were used to investigate the carbon emissions of China's power industry. First of all, factors influencing carbon emissions of the power industry are divided into six aspects: economic growth (GDP), urbanization level (URB), industrialization level (IND), energy efficiency (ENE), power generation structure (PGS), and population size (POP). Then we use the quantile regression method to analyze the different impacts of these six factors on the carbon footprints of the power industry. The results show: (1) the impact of economic growth is most significant in the upper 90th quantile provinces; (2) urbanization level in the lower 10th and the upper 90th quantile provinces play a more significant role than in quantile provinces 10-30, 30-50, 50-70 and 70-90; (3) the impact of the industrialization level is getting more and more significant from the lower 10th to the upper 90th quantile provinces; (4) the impact of energy efficiency on carbon emissions has a similar upward trend; and (5) ... while the effect of power generation on carbon emissions has an opposite trend. It is decreasing from the lower 10th to the upper 90th quantile provinces, which might be attributed to the interaction of various factors.

These empirical results might be crucial for policy makers in 30 provinces of China. Based on their own circumstances, different quantile provinces can

formulate policies to control their own CO₂ emissions, and the following policy recommendations might be helpful.

First, the quantile provinces of group 6 should pay attention to the development of low-carbon economy (low-carbon production, low-carbon consumption and low-carbon services), because the impact of economic growth on the quantile provinces of group 6 is more significant than that on other provinces. Therefore, the development of the low-carbon economy in these provinces will be more efficient. It is really unwise to develop the economy at the expense of the environment. The governments in these provinces should take the road of sustainable development and realize the economic transformation to actively respond to the call of the state. We must promote the sustained and healthy development of the economy in accordance with the working attitudes of steady progress.

Second, the quantile provinces of group 1 and the quantile provinces of group 6 must focus on improving the quality of urbanization. On the one hand, the prosperity of the real estate industry in urban area leads to high consumption of steel cement and electricity. Thus, first of all the relevant departments are supposed to encourage real estate developers and builders to use low-carbon and environmentally friendly building materials. Then the authorities guide them to choose more power-efficient machinery and equipment in order to reduce electricity consumption. On the other hand, the popularity of motor vehicles in urban life has become an irresistible trend. So it is necessary to encourage people to choose cars with lower emissions. In addition, people should be encouraged to use public transportation more. Nowadays, China is vigorously promoting the development of shared bicycles – a typical low-carbon travel mode. By 2016, the number of users sharing bicycles reached 18.86 million in China, which has far exceeded expectations. Thus, government should continue to call for more people to use shared bicycles in order to achieve low-carbon travel. Both low-carbon building materials and low-carbon vehicles require the government to increase investments in higher education and scientific research, in order to promote the progress of energy-saving and emission reduction technologies.

Third, the quantile provinces of group 6 must further optimize the industrial structure. In 2016, total electricity consumption of four energy-intensive sectors, including chemical, building materials, steel and non-ferrous industries reached as high as 42.7%. The impact of the industrialization level on carbon emissions from the quantile provinces of group 1 and the quantile provinces of group 6 is becoming more and more significant. Guangdong, Jiangsu and Shandong provinces are not only China's three largest industrial provinces, but also three provinces with the largest carbon emissions in the power industry. So it is imperative to focus on improving the industrial structure of the three provinces. In the first place, the governments in these provinces should formulate

policies to limit the development of heavy industry (such as equipment manufacturing, electronics and electrical machinery industry), and encourage the development of light industry (such as food and textile industry). In the second place, it is of vital importance to increase the investment funds to encourage technological innovation and improve the status of high energy consumption in the industrial sector. In addition, the development of the tertiary industry has a vital significance in achieving the optimization and upgrading of industrial structure. Since carbon emissions in tertiary industries (financial, computer services and software, etc.) are far less than that in secondary industry, increasing the proportion of tertiary industry has far-reaching significance for reducing carbon emissions.

Fourth, all quantile provinces should strive to improve energy efficiency, because it is a key factor in limiting carbon emissions.

The progress of energy saving and emission reduction technology is the most effective way to improve energy efficiency. China's 13th Five-Year Plan for Energy Development set the goal in terms of energy efficiency: by 2020, energy consumption per unit of gross domestic product (GDP) would drop 15% compared with that in 2015. To improve the energy efficiency of the power industry, first we must improve the efficiency of coal combustion. Achieving complete combustion of fuel and collection of waste gas to achieve secondary combustion are both effective ways to improve the utilization of coal. The second is to promote the progress of clean energy technology. The government should attach great importance to the cultivation of talents in related institutions (environmental protection, etc.), because they would become experts or leaders in this field.

Fifth, all the quantile provinces should not only strive to improve the efficiency of thermal power generation to reduce carbon emissions resulting from thermal power generation, but also increase the proportion of new energy generation to optimize the power generation structure. In China, the proportion of thermal power generation remains above 70%. So thermal power generation has an absolute advantage compared to the other power generation mode, and the differences among the quantile provinces in the power generation structure are not obvious. On the one hand, for improving the efficiency of thermal power generation: according to the Annual Report on China's Power Industry in 2017, in 2016 the standard coal consumption of power supply of 6,000 kilowatts and above in the country was 312 grams. While in China's 13th Five-Year Plan for Energy Development, it is proposed that by 2020, the average coal-to-electricity coal consumption will drop below 310 grams of standard coal per kWh in energy system efficiency. This requires acceleration in the R&D of advanced and practical technologies, such as ultra-supercritical coal-fired power generation technology, IGCC (integrated gasification combined cycle), CCS and so on, but on the other hand, encouraging the development of renewable energy power generation.

According to Fig. 1, the proportion of thermal power generation remains above 70%. And in 2016, thermal power accounted for 72%, followed by hydropower 20%, wind power 4%, nuclear power 3% and solar power 1%. According to Fig. 3, the influence coefficient of PGS is around 0.8. In terms of both proportion and influence, thermal power is still dominating the development of power generation. In 2015, China's power generation consumed 1793.184 million tons of coal, 2.655 million tons of oil, 0.125 million tons of crude, 0.224 million tons of diesel and 0.315 million tons of fuel oil. Although the proportion of coal-fired power generation has dropped, it is still as high as 65%. In order to improve the proportion of new energy power generation, for enterprises that introduce new energy power generation technology, the government can give some subsidies and income tax relief according to the specific circumstances. In addition, taking regional differences into consideration is of vital importance. Based on the geographical advantages, we can encourage the western region (Gansu, Ningxia, Xinjiang, etc.) to increase the proportion of wind power, and suggest that the eastern coastal areas (Hainan, Guangdong, Fujian, etc.) develop nuclear power, and advocate for the Yangtze River Basin (Qinghai, Guizhou, Hubei, etc.) to develop hydro power.

Conflict of Interest

The authors declare no conflict of interest.

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