Influence factors and forecast of carbon emission in China: structure adjustment for emission peak

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Abstract. This paper introduced Principal Component Analysis and Multivariate Linear Regression Model to verify long-term balance relationships between Carbon Emissions and the impact factors. The integrated model of improved PCA and multivariate regression analysis model is attainable to figure out the pattern of carbon emission sources. Main empirical results indicate that among all selected variables, the role of energy consumption scale was largest. GDP and Population follow and also have significant impacts on carbon emission. Industrialization rate and fossil fuel proportion, which is the indicator of reflecting the economic structure and energy structure, have a higher importance than the factor of urbanization rate and the dweller consumption level of urban areas. In this way, some suggestions are put forward for government to achieve the peak of carbon emissions.

1. Introduction
The control of greenhouse gas emission is one of the most important policy orientations for improving the coordinated and balanced growth of economy with the environment in China. With the rapid economic development in China, it has undergone very fast increase of energy consumption since 21 century, whose increase rate leaps into the front ranks of the world. Compared with other Brics countries, the carbon emission of our country have increased very fast, where will influence the cooperation of Brics countries in climate negotiation. With the background of increasing pressures on climate change action and accomplishing the goal of building a moderately prosperous society in all aspects, how to achieve the low-carbon and energy-efficient pathway is the challenge faced by Chinese Government. Therefore, it is very significant and meaningful to analyse impact factors of carbon emission and forecast the total carbon emission and its intensity to understand the possible peak of emissions.

Many scholars have done numerous researches about this issue. Some apply qualitative analysis to discuss the impact factors of carbon emission. From the side of per capita carbon emission and the increase trend of annual emission, Zhang et al (2016) analyses the huge challenge faced by China, and then give some policy proposals for coping with climate change [1]. Similar research could be found in He et al (2004) [2]. From the point of quantitative analysis, Index decomposition method and multi-factor regression analysis are the common methods. From the aspects of research content, these studies can be divided into the following part: demography [3-4], the economic perspective [5-6], energy [7-8].
Various literatures above have done some positive and helpful researches about the issue, but it also reminds the following shortages. Firstly, large parts of those researches adopt factor decomposition method. This method takes numerous factors into account as well as for the difficulty of forecast. Secondly, other studies analyse this issue merely from one or two aspect, and rarely consider the impact of structure change. At last, the researches hardly take the multi-collinearity into account so that there are some uncertainties about the result.

This present study chooses eight major factors from three aspects (demography, economy, energy), then applies ADF unit root test for the data. After the test, this model gives differential treatment for non-stationary time series and employs the PCA method for standardized data. Then, all principal components are inputted for Multivariate Linear Regression Model and the T-test is made for choosing the variables. The difference of our study is to choose eight factors from three sides which not only contain aggregate indicators but also have the structure and technical index. Other uniqueness is that the improved PCA method can eliminate multi-collinearity and obtain higher accuracy results.

The remaining of this paper is organized as follows: the methodology, as well as the data adopted in the study is explained in Section 2; Section 3 denotes the analysis and discussion of the results. Policy suggestion and the conclusion are portrayed in Section 4.

2. Methodologies

The current research adopts the improved PCR model to make certain of the relations between carbon emission and impact factors with regression analysis. The theory of PCA (Principal Component Analysis) is that if large part of total variance (as 80%~90%) can be interpreted by the preceding m principal component, the original p variables can be replaced by the preceding m principal component. It is widely used in energy and environmental policy research [9-10]. However, this PCA model selects its principal component only between its independent variables, and does not consider the relation between principal component and dependent variable, which may cause the less representativeness of the dependent variable and the bad remove of the discarded components.

In allusion to this instance, this current work improves the basic PCA, and selects eight factors: population (X1); Population urbanization rate (X2); urban consumption level(X3); GDP (X4); industrialization rate (X5); intensity of energy consumption (X6); energy consumption (X7); proportion of fossil fuel (X8). The details for the improved PCR model are demonstrated as the following step:

(1) Data processing and PCR model: do ADF unit root test for all data \( X_{32,8} = (x_1, x_2, \cdots, x_8) \), then make difference equation for non-stationary time series, apply PCA method for standardized data, pick up all principal components (\( F_j \in \mathbb{R}^{32}, j = 1, 2, \cdots, 8 \)) for Multivariate Linear Regression Model with the dependent variable of carbon emission where ids different from traditional PCA model.

(2) Model cycling: based on the result, make T-test for selecting the variables and use PCR again for the reminded variables (\( F_{i1}, F_{i2}, \cdots, F_{ir}, r \leq 8 \))

(3) End condition: repeat the step again until all reminded variables pass the T test, and then get the regression equation as described in Equation 1. Because the principal components (as described in Equation 1 for \( \tilde{F}_1, \tilde{F}_2, \cdots, \tilde{F}_s \)) are linear combination of all independent variables (\( x_1, x_2, \cdots, x_8 \)), we can get the final equation (Equation 2) for the primary variables through matrix transformation.

\[
\bar{Y} = \alpha_1 \tilde{F}_1 + \alpha_2 \tilde{F}_2 + \cdots + \alpha_s \tilde{F}_s ; \quad s \leq 8
\]  
\[\hat{Y} = \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_8 x_8 \]

In above steps, ADF unit root test is used for the variables to avoid "Spurious Regression" phenomenon. Based on the result of ADF test, difference equation process has been taken for non-stationary time series. At the same time, each regression coefficient of principal components and T test value is independent with other principal components. If T test values of several components are non-significant, they could be deleted at the same time. In a word, this method is to extract components
with the explanation effect more efficiently, and to establish regression model on the condition of multi-collinearity between the independent variables.

Data as population, economy, and energy are taken from China Statistical Yearbooks 2015 [11], and partly from China Energy Statistical Yearbook 2000-2015. Consumption level and GDP are calculated by 1978 constant price. Carbon emission data is from the CDIAC of US Department of Energy. GDP reflects economy situations, national capabilities and development level of a country, and rapid growth of GDP is companied with enormous energy consumption as well as fast carbon emissions rising. Carbon dioxide from Fossil fuel burning is the main cause of global warming, energy consumption and carbon dioxide emissions are closely related. In the model, the rate of fossil fuel, industrialization and urban level reflect energy structure, economic structure, and the industrialization and urbanization process in China. What’ more, energy consumption intensity represents energy efficiency of economic activities, which has been selected as a technical index too.

3. Result analysis and discussion

3.1. Major parameters for Carbon Emission

First of all, ADF unit root test is used for 8 factors. And the result will decide whether equation without constant and time tendency can be chosen. With the data sources about the 8 factors between 1978-2014, ADF unit root test is used for one order differential and two order differential, the result shows that population, GDP, Energy Consumption and carbon emission are unstable.

After the first-order difference for the non-stationary time series, the next step is applying PCA method for standardized data. In terms of the results for the principal components, contribution rate of the former four principal components exceed 1%, and for the cumulative percent 99%. With the further analysis, it can be seen that the component C1 has an altitudinal positive correlation with population, population urbanization rate, energy consumption, and that the component C2 is close related with industrialization rate, carbon emission intensity. The initial PCR model will choose the former four components for the next analysis. However, based on the improved method, we select the foregoing five components, which represent the necessity of improvement. Table 1 is the regression parameters of PCR model and Equation 3 is the regression equation of the improved PCR. The data of 2015 and 2016 is to test whether the regression model is solid for the forecast.

| Variables | Partial Regression Coefficient | Standard Deviation | T-value | Significance level | Tolerance | Var Inflation |
|-----------|--------------------------------|--------------------|---------|--------------------|-----------|---------------|
| Constant  | 0.000                          | 0.016              | 0.019   | 0.985              | --        | --            |
| C1        | 0.152                          | 0.003              | 53.825  | 0.000              | 0.931     | 1.074         |
| C2        | 0.108                          | 0.014              | 7.796   | 0.000              | 0.979     | 1.003         |
| C3        | 0.632                          | 0.064              | 9.935   | 0.000              | 0.806     | 1.241         |
| C4        | 0.944                          | 0.142              | 6.670   | 0.000              | 0.912     | 1.097         |
| C5        | -1.406                         | 0.141              | -9.995  | 0.000              | 0.725     | 1.379         |

Note: C1, C2, C3, C4, C5 are the principal components that passed T-test in the improved PCR analysis. T-value comes from hypothesis testing for the null hypothesis of Partial Regression Coefficient.

\[ \hat{Y} = 0.152C_1 + 0.632C_2 -1.406C_3 +0.108C_4 + 0.944C_5 \]  \tag{3}

Adjusted \( R^2 \) and the T-value of each component are represented in the above table. The equation above can be converted into a new equation (as described in Equation 4) about the original variables.

The \( t \) represents the corresponding year. \( Y \) is instead of carbon emission.

\[ \Delta Y' = 1.9596 \Delta x_1 + 0.0333 \Delta x_2 + 0.2521 \Delta x_3 + 1.9802 \Delta x_4 + 0.7335 \Delta x_5 + 0.1470 \Delta x_6 + 2.5563 \Delta x_7 + 0.2689 \Delta x_8 \]  \tag{4}

Population, urbanization rate and the dweller consumption level of urban areas were selected as three demography factors. It was found that their interpreted proportion of carbon emissions increment, according to their influence coefficient, was ordered as follows: population (1.9596), the dweller
consumption level of urban areas (0.2520), urbanization rate (0.0333). Among those three observed variables, the population scale has been efficiently controlled since 1978 when the basic state policies of family planning were brought into effect. Nonetheless, the population scale in China will be expanded over the next ten years, and the total population, continue to inertia increase. In 2009, the State Family Planning Commission predicted that the population of China would reach a peak in 2033, and the population scale would keep around at 1.5 billion. From the demography point of view, the urban consumption level is the secondary effect factors of carbon emissions. Our country is currently in a period which has the need urgently to enhance the per capita income level, and the GNI (gross national income) per capita is comparably at the bottom of the world.

3.2. Analysis of economic factors on carbon emissions
GDP, industrialization rate and carbon emission intensity was selected as economic factors. It was considered that their interpreted proportion of carbon emissions increment was ordered as follows: GDP (1.9802), the industrialization rate (0.7335), carbon emission intensity (0.1470). According to the present situation for our economy, industrialization, informatization, urbanization, marketization and globalization was in-depth developed. This stage needs infrastructure construction and demands for energy-guzzling raw materials are robust, which will also lead to huge fossil fuels consumption.

The analysis results showed that, under the condition that other factors remain unchanged, when the GDP increment change every one percentage point, the carbon emissions based on energy consumption would change 1.9802% to the same direction. Furthermore, interpreted proportion of carbon emissions increment to industrialization rate is 0.7335. Except for total energy consumption, GDP and total population, industrialization rate is the biggest effect factor of carbon emission. Industrial departments mostly belong to energy-intensive industries, as well as carbon intensive industry. In the export trade structure, the export of energy intensive products is large.

3.3. Analysis of energy factors on carbon emissions
The total energy consumption and fossil fuel proportion were selected as two representative energy factors. The results of model indicated that, under the condition that other factors remain unchanged, when the energy consumption increment change every one percentage point, the carbon emissions based on energy consumption would change 2.5563% to the same direction. This data is smaller than the carbon emission coefficient (3.76%) of china’s energy consumption given by other studies. The reason may be that the former article simply studied the single regression analysis between energy consumption and carbon emissions, and the T-test value is very close to the critical level. Moreover, the goodness-of-fit of the model reach to 0.993, which indicate the reliability of the results.

Fossil fuel proportion is considered as the indicator of energy structure, and its interpreted proportion of carbon emissions increment is 0.2689. An increase of proportion in the total energy consumption would certainly have an impact on carbon emissions. New energy industry has undergone a rapid deployment in recent years. However, the increasing rate of new energy consumption is equals to or a little bit lower than the increasing rate of fossil fuel, which directly weakened the impact of new energy development on carbon emissions action.

3.4. Forecast of carbon emission and Policy Suggestion
Based on the results above, it is observed that the influence of these factors can be ranked as follows: energy consumption; GDP; population; industrialization rate; proportion of fossil fuel; urban consumption level; intensity of energy consumption; Population urbanization rate. On the basis of the 13th Five Year Plan and the Annual Outlook of CEEP-BIT 2016, this paper gives three scenarios. With the scenarios and Equation 4, medium-term trends of carbon emissions are simulated in Figure 1.

From the chart, it can be implied that apart from the weak decrease of carbon intensity, our country’s carbon emission will increase rapidly in the future and the difference in social development plan will result in different carbon peak at different times. This trend will require the social system to
understand the risk of climate change on society, economy and environment and hold the ability to adapt to future climate change [12, 13].

![Figure 1. Forecast of Carbon Emission in China (2015-2040)](image)

4. Conclusions and policy suggestions

This research employed the improved PCA and Multivariate Linear Regression Model to investigate the impact factors of carbon emission. The following results were obtained:

(1) Among all influence factors of carbon emission, energy consumption, GDP and population are ranked as the first three factors. It follows that reasonable control of energy consumption and the growth rate of GDP have a vital role in achieving the goal of carbon emission reduction. In term of population, considering that the present “two-child policy” is indeterminate and the room for adjusting the population base and structure is limited. The emission reduction strategy in the future is the balance point of the growth of GDP, energy consumption and carbon emissions.

(2) Among the selected structure factors, economic structure has a higher influence than energy and population structure. This means that adjusting the economic structure by developing the less energy-intensive service industry not merely is the need of development but also play a significant role in emission reduction. From the view of energy structure, promoting the new energy development to increase the share of non-fossil fuels are very meaningful for reduction of carbon emission.

(3) Improvement of household consumption level can promote the rise of carbon emission. However, due to the low consumption level of our country, how to improve the living standard as well as make low-carbon lifestyle popular is a problem of vital importance. From the three aspects of the state, enterprise, individual, the encouragement and guidance of low-carbon development, production, and lifestyle can be the appropriate solution for our future development.

The results and forecast analysis could offer the following important enlightenment.

(1) Long-term plan for carbon emission reduction should consider the total carbon emissions and carbon emissions intensity together. As the second largest economy in the world, China’s carbon emissions just reflect the emissions characteristics of big country. Meanwhile, scenario analysis suggests that high emissions scenarios will lead to double the amount of carbon emissions, also failed to realize the proposed emission reduction goals. Consequently, in the near future, a close attention should be paid to the carbon emissions control. And the improvement of living standards and economic development should decouple from energy use by energy transition.

(2) Energy-saving environmentally and friendly lifestyle should be advocated, and energy saving potential in areas of public consumption needs to excavate. The 2016 national economic and social development in China statistical bulletin showed that, our country’s rural and urban per capita net income rose to 12363 and 33616RMB, a real increase of 8.2% and 7.8% from the previous year [14]. The results indicate that the raise of urban consumption level will promote carbon emissions growth.
The reasons may lie in that with the improvement of living standards, the lifestyle such as the pursuit of high quality life and purchase of cars, promote the consumption of high-carbon production. The improvement of people's living standards is certain, but the lifestyle could be changed.

(3) Rational control of energy consumption, promoting energy structure cleaner and decarbonated, the promotion of new energy development are the directions of energy structure adjustment. As the biggest energy producers, the fact that energy consumption was to be doubled will not only increase the environment burden, but pose pressures on International Negotiation. In addition, there are shortages for new energy development in the areas of independent innovation capability. Consequently, the independent innovation ability of new energy sector should be improved.

The considered factors in this paper are appropriate to research their impacts on carbon emission. The improvement is that industrialization rate could be replaced by export trade structure, which may better reflect the direction of economic structure adjustment. Also, this work only discusses the impact factors of carbon emission and the influence of climate change on the society will be the next work.

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