Spatial Heterogeneity of Regional Carbon Emissions and Its Driving Factors in China

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Abstract. Using Exploratory Spatial Analysis and Geographically Weighted Regression Model, this paper studies and analyses the global and local spatial self-correlation of regional carbon emissions in China from 1997 to 2017, as well as the spatial heterogeneity characteristics of driving factors. The results show that: (1) The impacts of economic development, energy consumption and population on regional carbon emissions in China are all positively correlated, but there are heterogeneity in the impact of different regions. (2) The proportion of the tertiary industry has a negative correlation with the regional carbon emissions in China. The impact of the industrial structure in the western region is significantly lower than that in the eastern and central regions. (3) The influence degree of the four driving factors on China's regional carbon emissions is: population> industrial structure> energy consumption> economic development.

1. Introduction

China's previous extensive economic development model, that is, the large use of fossil fuels in the process of industrialization, often brings serious ecological damage. Increased carbon emissions can lead to a series of extreme abnormal climate problems, such as ecosystem deterioration, sea level rise. China's carbon emissions continued to grow from 7373.4 million tons in 2008 to 9419.6 million tons in 2018, but grew by 2.2% in 2018, down from an average annual growth rate of 2.5% in 2008-2017. This shows that China's total carbon emissions are still high, but the effect of carbon reduction measures began to be highlighted.

Using low-carbon development to deal with the global climate change affecting human survival and development has become the consensus of all countries in the world, low-carbon economy is also an important direction of China's economic development, and Chinese government has begun to take all-round environmental protection measures. But what are the structural characteristics of China's regional carbon emissions? How much impact do economic development, energy consumption, population and industrial structure have on China's regional carbon emissions? These are important issues that need to be addressed urgently.

There are two main characteristics of this paper: first, in the aspect of sample selection, this paper uses Geographically Weighted Regression model to explore the spatial self-correlation characteristics of China's regional carbon emissions from 1997 to 2017, and deeply studies the spatial heterogeneity of the impact of four important carbon emission drivers, including economic development, energy consumption, total population and industrial structure. Secondly, this paper selects the sample data of
several landmark years for dynamic research, so it can more scientifically and accurately describe the spatial heterogeneity characteristics of China's regional carbon emission drivers.

2. Methodology and data selection

2.1. Exploratory Spatial Analysis

2.1.1. Global Spatial Self-correlation Test. The Moran's I index and its scatter plot (Moran, 1950) [1] can analyse whether variables are spatially concentrated and scientifically analyse the spatial effects and spatial self-correlations of economic phenomena, expressed as:

\[
    \text{Moran's I} = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (Y_i - \frac{1}{n} \sum_{i=1}^{n} Y_i) (Y_j - \frac{1}{n} \sum_{j=1}^{n} Y_j)}{\frac{1}{n} \sum_{i=1}^{n} (Y_i - \frac{1}{n} \sum_{i=1}^{n} Y_i)^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}}
\]

(1)

2.1.2. Local Spatial Self-correlation Test. In this paper, the local Moran's I index and LISA aggregation chart method proposed by Anselin (1995) [2] are used in most research literature to measure the spatial self-correlation of carbon emissions in China, expressed as:

\[
    I = \frac{\sum_{i=1}^{n} (Y_i - \frac{1}{n} \sum_{i=1}^{n} Y_i) \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} (Y_j - \frac{1}{n} \sum_{j=1}^{n} Y_j)}{\sum_{i=1}^{n} (Y_i - \frac{1}{n} \sum_{i=1}^{n} Y_i)^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}}
\]

(2)

2.2. Geographical Weighted Regression model

This paper uses the Geographical Weighted Regression model proposed by Brunsdon and Fotheringham (1996, 1999) [3, 4] to explore the heterogeneous characteristics of the drivers of carbon emissions in China in different spatial locations, expressed as:

\[
    Y_i = \beta_0 + \sum_{k=1}^{K} \beta_k (a_i, b_i) X_{ik} + \varepsilon_i
\]

(3)

2.3. Variable selection and data sources

In this paper, four explanatory variables, namely, economic development level, energy consumption, population total population and industrial structure, are selected to examine the spatial heterogeneity of its impact on China's regional carbon emissions. Among them, the regional carbon emissions data are derived from Shan et al. (2018, 2020) [5, 6], energy consumption data from Shahbaz et al. (2020) [7], and the GDP, population data and tertiary sectors as a share of GDP of each regional unit are derived from the relevant data in the China Statistical Yearbook published by the National Bureau of Statistics in previous years.
3. Empirical results

3.1. Global spatial dependence pattern of regional carbon emissions
The change curve of the Moran's I index for each year is shown in Figure 1. During the period 1997-2017, China's regional carbon emissions had a positive global self-correlation rather than a completely random distribution, with significant spatial dependence characteristics. China's regional carbon emissions have a global spatial concentration phenomenon, the overall difference is becoming increasingly significant, but this trend is weakening over time.

![Figure 1. Global Moran's I Index of China's Regional Carbon Emissions, 1997-2017](image)

3.2. Local spatial dependence pattern of regional carbon emissions
In order to further explore the specific structure and interrelationship of its local spatial dependence, this paper selects four representative key points in the global spatial dependence pattern, 1997, 2005, 2010 and 2017, and studies the local spatial dependence pattern of China's regional carbon emissions. Since 1997, the distribution of carbon emissions in China has a very significant spatial heterogeneous change and non-equilibrium development of the spatial dependence pattern.

3.2.1. Spatial heterogeneity of carbon emission drivers in China. The result of a Geographic Weighted Regression is shown in Table 1. As can be seen from Table 1, the geographical weighted regression model has a high degree of interpretation of Carbon Emissions in China, the adjusted $R^2$ has reached more than 80%, and the residual square sum is relatively small, which indicates that the overall fit of the Geographic Weighted Regression model is better.

|                | 1997  | 2005  | 2010  | 2017  |
|----------------|-------|-------|-------|-------|
| Optimal bandwidth | 24.363 | 19.302 | 74.363 | 22.976 |
| AIC            | 44.543 | 36.751 | 37.749 | 41.045 |
| RSS            | 0.205  | 0.344  | 0.414  | 0.199  |
| $R^2$         | 0.887  | 0.883  | 0.882  | 0.892  |
| Adjusted $R^2$ | 0.811  | 0.857  | 0.839  | 0.856  |
3.2.2. Spatial differences in the impact of economic development. From the point of view of economic development, from 1997 to 2010, the impact of economic development on China's regional carbon emissions are positive, that is, during this period of time the rapid development of the national economy accompanied by the increase in carbon emissions, is a "extensive growth mode." Among them, the region with the greatest sensitivity to carbon emission impact of economic development is Xinjiang Uygur Autonomous Region, which shows a decreasing trend to the east, and the carbon emissions in northeast China are the least sensitive to economic development.

3.2.3. Spatial differences in the impact of energy consumption. From the point of view of energy consumption, the impact of this variable on China's regional carbon emissions is positively correlated in all years, indicating that higher energy consumption will lead to an increase in carbon emissions, in line with common sense. In addition, it reflects that China's energy consumption is still dominated by fossil fuels, and that, although clean energy is growing rapidly, it still accounts for less of actual consumption. Regional carbon emissions are less sensitive to changes in energy consumption in remote areas such as northwest and southwest China, and are gradually increasing along the southeast.

3.2.4. Spatial differences in the impact of total population. The impact of total population on China's regional carbon emissions is positively correlated in all years, mainly because population growth means an increase in consumption and material production, which naturally contributes to an increase in carbon emissions. The regions with large population impact on carbon emissions are mainly concentrated in southwest and northwest China, and show a decreasing trend to the east. Northwest and other places have a small population base, difficult to form a scale effect, and the average education level of the population is low.

3.2.5. Spatial differences in the impact of industrial structure. As for the impact of industrial structure on China's regional carbon emissions, the relationship between the proportion of tertiary industry and regional carbon emissions is negatively correlated, that is, the increase of tertiary industry in GDP will lead to the reduction of regional carbon emissions. The three northeastern provinces and north China are the regions with higher influence, showing a decreasing trend to the west, mainly because the western region needs to vigorously develop industrialization when carrying out large-scale development, the whole process of energy use is low, resulting in a large amount of carbon emissions.

4. Conclusion
Using the Exploratory Spatial Analysis and Geographical Weighted Regression model, this paper explores and analyzes the global and regional dependence pattern of China's regional carbon emissions and the spatial heterogeneity of the four drivers from 1997 to 2017. The main conclusions obtained are the following:

First, from a global perspective, during 1997-2017, China's regional carbon emissions have a positive global self-correlation, and the overall difference is becoming increasingly significant, but this trend is weakening over time. From the local point of view, East China and Northwest China have the most significant local spatial correlation. Among them, the high value high value region is decreasing, while the low value low value region is increasing, which shows that the implementation effect of carbon emission reduction measures in some regions is more significant.

Second, economic development and population have a positive impact on carbon emissions in most regions of China. The regions with greater impact are concentrated in the southwest and northwest regions, and the trend is gradually decreasing to the East. However, in North China and Northeast China, the impact of economic development on regional carbon emissions shows a negative correlation.

Third, from the perspective of energy consumption, although its impact on China's regional carbon emissions is also positive, the remote areas such as northwest and southwest are less affected areas, and gradually increase along the southeast direction. China's energy consumption is dominated by fossil fuels, and the proportion of clean energy in the actual consumption is still small. At the same time,
energy utilization technology is constantly improving, and the gradual improvement of new energy technology promotes the continuous optimization of energy consumption structure.

Fourth, from the perspective of industrial structure, the relationship between the proportion of tertiary industry and regional carbon emissions is negative. The three provinces of Northeast China and North China are the regions with higher degree of impact, and the impact of industrial structure in the western region is significantly lower than that in the eastern and central regions. The growth rate of the tertiary industry is slowing down, and industrial investment is still the first choice for economic development in most regions.

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