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Research Article

The Spatiotemporal Evolution Pattern and Influential Factor of Regional Carbon Emission Convergence in China

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As economic development rapidly progresses in China, a method of carbon emission control that provides reasonable solutions is needed. This paper analyzes the convergence of carbon emission evolutionary characteristics in different regions of China and studies the dynamics of carbon emissions in China based on a convergence model. It was found that the carbon emission levels of each region are prominent in terms of time, and the regional carbon emission level has absolute β characteristics. The regional carbon emission condition β convergences have different convergence paths. Therefore, it is necessary to justify carbon emission reduction in China and put forward an emission reduction strategy.

1. Introduction

Ecological civilization is a millennium-scale plan in the report of the Nineteenth National Congress of the Communist Party of China. It can be seen that China takes an active part in global environmental governance and the responsibility of building a community in the future. In many negotiations on climate change, the research on climate change justice mainly focuses on the equity of carbon emissions in developed and developing countries. The responsibility and obligation to solve carbon emissions are considered the most important issues, while the research on the justice of carbon emissions within countries and regions is less emphasized. This paper discusses the spatial convergence of regisonal carbon emissions in order to achieve regional emission reductions and achieve overall green, sustainable development in China.

With the rapid development of the economy, an increasing number of people have begun to realize that climate change and environmental pollution is emerging on a large scale, forcing people to pay attention to economic and carbon emissions. Convergence refers to the degree of the reduction of the abandonment but also to approaching and examining a value [1]. The convergence hypothesis provides strong theoretical support for backward regions to catch up with developed regions and to lay a foundation for the neoclassical economic growth theory. Convergence mainly includes delta convergence, beta convergence, and club convergence, and beta convergence is divided into absolute beta convergence and conditional beta convergence [2]. Absolute beta convergence refers to the negative correlation between the economic growth rate and the initial level. Conditional beta convergence means that regional convergence is affected not only by the initial level of development but also by other factors [3]. Regional carbon emissions will also be different because of the different economic and geographical conditions of different regions. The convergence theory of economic growth was introduced to test the convergence of regional carbon emissions, which can be used to explore the driving factors of regional carbon emission convergence, and help us understand whether the regional carbon emission reduction goals are fair and reasonable.

With continuous development at an economic level, the upgrading of the industrial structure, improvement at the technological level, and the enhancement of environmental responsibility consciousness, regional carbon emissions will converge in theory. At present, the scope of convergence theory is gradually expanding many fields, but there is a lack of systematic research on carbon emissions and social responsibility from the perspective of spatial justice. Based on the basic idea of the economic convergence hypothesis in neoclassical growth theory, this paper systematically analyzes the convergence of regional carbon emissions and social responsibility in China from the perspective of spatial justice.

2. Theoretical Basis and Research Hypothesis

Against the background of global warming, the process of China's economic development is at a critical stage in history, and each region is developing at a relatively fast speed in history. People realize that we must change the traditional, simple development mode, which only pays attention to benefits. In the process of economic development, attention should be paid not only to economic growth but also to the impact of economic development on the environment so as to reduce the carbon emissions from nonrenewable energy consumption and thus reduce the impact on climate change. However, in order to reduce carbon emissions in China, it is necessary to understand the mechanism of different factors on the convergence of carbon emissions. Different regional economic development has different characteristics. How can the principle of spatial justice be realized? Only by clarifying these key issues can we find corresponding policy measures and an emission reduction path to reduce carbon emissions, alleviate the pressure of carbon emissions people are facing, and promote China as a large developing country that can achieve low-carbon sustainable development.

In order to achieve the overall sustainable development of the low-carbon economy in China, it is necessary to further analyze the influencing factors of regional carbon emissions in China, find out the internal mechanism of regional carbon emissions change, and lay a solid theoretical foundation for the realization of China's carbon emission reduction. Regional carbon emissions involve different aspects; thus, to determine the influencing factors of regional carbon emissions, this paper explores these factors from different perspectives of resource consumption in the context of economic development.

Domestic scholars began to study carbon emissions at the beginning of the 21st century and have mostly applied the research methods of foreign scholars to analyze China's energy consumption and carbon emissions in the light of China's development situation. Existing research methods on carbon emissions mainly adopt decomposition research methods. Wang and other scholars used the Laplace index decomposition method to decompose carbon emission factors into population, energy consumption intensity, and energy consumption factors for analysis [4]. Wu and other scholars used the logarithmic mean decomposition method to decompose and analyze the influencing factors of per capita carbon emissions. The empirical results show that optimizing the energy consumption structure, optimizing the industrial structure, and optimizing energy efficiency are all important factors in reducing carbon dioxide emissions [5]. Other scholars have used the decomposition analysis method to study the influence factors of carbon emissions in different cities [6, 7]. Zhao and Li used the logarithmic mean decomposition method to analyze the data of per capita carbon emissions and per capita GDP in China. The study found that per capita GDP increase was the main driving factor of per capita carbon emissions increase [8]. Fan and Ruiling used the logarithmic mean factor decomposition method to analyze the factors affecting carbon dioxide emissions in China's industry. The results show that economic activity and energy intensity are the two most important factors affecting carbon emissions in the chemical industry [9]. Some scholars quantitatively analyzed the impact of factors on carbon emissions in different stages of Xinjiang by using Dean's logarithmic average method. The results show that economic growth is the main factor contributing to the increase of carbon emissions [10]. Wang and other senior students used the structural decomposition analysis model to analyze the problem of residents' consumption carbon emissions [11]. The study found that the president of China's carbon emissions are an upward trend, which was determined by the economy and the amount of consumption. However, analysis from the impact dimension showed that the national residents' consumption still adhered to the path of low-carbon development.

Another major research method is the Kaya identity research method proposed by Kaya, a famous foreign scholar. According to Kaya identity, He and Zhang constructed a decomposition model of influencing factors of carbon emissions in the iron and steel industry and used the cointegration method to explore the equilibrium relationship between carbon emissions and influencing factors [12]. Zhu et al. based on the Kaya identity study found that the main driving force of China's carbon emission increase is economic expansion [13]. Li and other scholars used panel data to analyze the relationship between carbon dioxide emissions and population, economy, and technology in different regions. The results show that there are obvious differences in carbon dioxide emissions in different regions. The elasticity coefficients of carbon dioxide emissions with respect to the population, economy, and technology in different regions are different. Rapid economic growth is the most important driving factor for the increase of carbon dioxide emissions in different regions [14]. Wei and other scholars analyzed the mechanism of carbon emissions from the perspectives of economic growth, energy consumption, and development. The results show that in the long run, fossil energy consumption has the strongest effect on carbon emissions and financial development has a negative correlation. In the short run, economic growth and financial development, energy consumption and carbon emissions, and financial development and carbon emissions show a one-way Granger causality [15]. Zhu and other scholars used the extended STIRPAT model to measure and analyze the impact of population and technology on carbon emissions by the ridge regression method [16]. The results show that the extended STIRPAT model has a high explanatory power to China's national conditions, and the consumption level of residents, the urbanization rate of the population, and population size are the main factors affecting the total carbon emissions in China. The explanatory power of technological progress factors with respect to China's emissions at this stage is limited, so China's potential to reduce carbon emissions through technological progress in the future is huge.

Other studies have been carried out by Weber and other scholars based on the input-output model to study the different impacts of carbon emissions [17, 18]. Li and other scholars based on static and dynamic panel models have found that international trade increases China's carbon dioxide emissions and the intensity of carbon emissions and has a serious negative impact on the environment [19]. Birdsall and other scholars believe that the increase in population will lead to an increase in energy consumption, resulting in relatively large carbon emissions, and an increase in population will also increase the destruction of the ecological environment [20]. Knapp and other scholars believe that population is the main driving force of global carbon emissions, while global population growth is also an important reason for the rapid increase in global carbon emissions [21].

Among the existing domestic and foreign scholars' research on the convergence of carbon emissions, foreign scholars mainly use the Gini coefficient and other research methods to test the convergence of carbon emissions. Romero and other scholars used the random convergence test method to analyze the convergence of carbon emissions beta [22]. Ezcurra analyzed the convergence of transnational carbon emissions and found that the difference of per capita carbon emissions was decreasing [23]. Gao and other scholars used the quantile method to analyze the reasons for the convergence of carbon emissions in 28 provinces in China and found that there are absolute convergence and conditional convergence between provinces [24]. Yang and other scholars tested the stochastic convergence of carbon dioxide in China and found that there was no global convergence trend [25]. Shao and other scholars analyzed the convergence of carbon emissions in different regions of China and different industries and found that the convergence paths of carbon emissions in different regions were different [26, 27]. Zhang systematically studied the convergence of carbon emission intensity in China and found that China's carbon emission intensity had significant absolute convergence, conditional convergence, and club convergence characteristics [28]. Although the existing research has an important reference value for revealing the relationship between the dynamic changes of carbon emissions and the influencing factors, the existing research on the convergence of carbon emissions does not take into account the role of spatial effects and needs to combine spatial justice to deeply analyze the convergence of carbon emissions and to explore the mechanism of the various influencing factors on carbon emissions synergistically to solve the problem of carbon emissions. Therefore, from the perspective of spatial justice, this paper systematically explores the impact of different factors on regional unit carbon emissions. The index system includes different aspects of regional unit economic development; thus, the mechanism of different factors on regional carbon emission convergence is systematically analyzed.

Population is the basis and main body of social production activities. However, different levels of economic development, different conditions of social development, and different processes of population development lead to a different understanding and reflection of population phenomena. Because of different regional development conditions, the mechanism of the population's role in carbon emissions is different.

Economic development is an index to measure the scale and speed of national and regional economic development, as well as a criterion for the stage and potential of economic development. It is usually used to reflect the level of development of a country or regional economy by such indicators as national income, economic development speed, gross national product, per capita national income, and economic growth speed. Economic development requires a large amount of energy input. Energy consumption may lead to the generation of pollutants and the increase of carbon emissions at the same time. However, with the development of the economy, people's consumption concept has changed so as to improve energy efficiency and accelerate the reduction of carbon emissions.

Technological progress is generally reflected in innovation activities. Patent data, as a measure of innovation, is the main indicator of technological progress in existing literature. This paper also uses the number of patents instead of the technical level index to measure the level of technological progress and development. Technological progress can not only directly reduce energy consumption and carbon emissions but also improve the level of environmental pollution control through technological progress, thereby improving the environmental situation.

Industrial structure refers to the distribution of production factors among different industrial sectors. Adjustment of industrial structure can reduce primary energy consumption and reduce carbon emissions. The higher proportion of secondary industries in China is the main reason for greater energy efficiency consumption and rising carbon emissions. Upgrading and optimizing industrial structure will improve the intensity of energy consumption and reduce the growth rate of carbon emissions.

At present, with the rapid development of China's finance, the role of the environment has been strengthened. As an indirect factor affecting carbon emissions, financial development indicators can adjust the investment intentions of enterprises. However, there is no consensus on the role of financial development in the convergence of carbon emissions. It is assumed that different regions actively adopt adjusting financial policies to adjust economic sustainable development. Therefore, entry into development can promote the convergence of carbon emissions.

As a policy factor affecting energy consumption, energy price can affect people's energy consumption and consequently the change of carbon emissions. Governments often adopt administrative and economic policies to intervene and regulate. In China's environmental policy, energy price is the main adjustment policy. Through a one-time energy price rise and new energy policy subsidies, people's awareness of environmental protection is raised, and people are encouraged to consciously save energy, use environmental protection energy, and reduce pollutant emissions.

International trade generally includes export trading and import trading. As a world factory, China generally believes that international trade will aggravate the rise of carbon emissions in China. International trade plays a dual role in economic growth and other dependent variables. At the same time, international trade promotes economic growth, which also enables developing countries to have more funds to deal with environmental problems, introduce advanced equipment and technology, improve energy efficiency and clean energy utilization, and reduce environmental pollution such as carbon emissions.

The level of urbanization development is a major factor affecting carbon emissions. The impact of urbanization on the environment can be considered from different aspects. Population urbanization, through the improvement of people's awareness and changes in living habits, may encourage the population to produce fewer carbon emissions. The better living conditions in cities may also reduce the total energy consumption and reduce carbon emissions.

Fiscal decentralization can reflect the financial autonomy of local governments. Generally speaking, the higher the degree of fiscal decentralization, the greater the autonomy. The government does not need to adjust its behavior according to the incentive direction of the central government. However, existing studies at home and abroad suggest that fiscal decentralization has different impacts on regional carbon emissions.

3. Research Design

3.1. Data Collection. This paper studies the sample data of 30 provinces in China, and there are no official statistical data on carbon emissions. This article uses an IPCC calculation formula to determine carbon emissions. The formula is as follows:

$$C_{it} = \sum_{j=1}^{n} \left(E_{ijt} \times E_j \times EF_j \right), \tag{1}$$

where C_{it} is the total carbon emissions in the t-th year of the i-th province; ($i = 1, \ldots, 30$, $t = 2000, \ldots, 2015$); E_{ijt} is the total energy consumption of the j-th energy source in the t-th year of the i-th province; E_j is the converted standard coal coefficient of the j-th energy source; and EF_j is the carbon emission coefficient of the jth energy source.

Since all energy consumption in the China Energy Statistical Yearbook is represented as a physical quantity, this article first uses the China Energy Statistics Year based on the determination of the number of standard coals. One kilogram of raw coal is converted into 0.7143 kg of standard coal, natural gas is converted to 1.3300 kg of standard coal, and crude oil is converted to 1.4286 kg of standard coal. Energy consumption is converted into standard coal. The two energy sources recommended by the US Department of Energy (DOE)/EIA have a carbon emission coefficient of 0.702 for coal, 0.478 for oil, and 0.389 for natural gas. The carbon emissions of different energy sources are calculated based on the carbon emission coefficients of different energy sources. The data do not include carbon emissions data for Hong Kong, Macau, Taiwan, and Tibet. There is a small error with the total carbon emissions measured via the Carbon Dioxide Information Analysis Center of the Oak Ridge National Laboratory, which provides important reference values. Data regarding population, economic growth, industrial structure, financial development, energy price, international trade, urbanization rate, and fiscal decentralization come from the China Statistical Yearbook. Technological progress data come from the China Statistical Yearbook on Science and Technology.

3.2. Variable Measurement. According to the calculation formula of carbon emissions, the regional carbon emissions in China were calculated.

The variables of population, economic growth, technological progress, industrial structure, financial development, energy price, international trade, urbanization rate, and fiscal decentralization were selected:

(1) Population (P): according to the needs of this study, the total population at the end of the year in all regions of China is used.

(2) Economic growth (A): GDP data were used to represent economic growth indicators.

(3) Technological progress (T): technological progress is mainly reflected in the activities of innovation. Referring to the literature of scholars at home and abroad, the patent authorization data were used as the evaluation index of technological progress.

(4) Industrial structure (S): carbon emissions in different industrial sectors are also different. Referencing relevant studies, the proportion of secondary industry GDP to total GDP was used.

(5) Financial development (F): financial development is an important index to measure the expansion and efficiency of the financial system. This paper uses the ratio of the loan balance of financial institutions to GDP so as to measure the degree of financial development.

(6) Energy price (E): as a factor affecting energy consumption, energy price mainly considers raw materials, fuel, and the power price index of each province, which replaces the energy price index.

(7) International trade (EX): the differences in resource endowment, industrial structure, and the international division of labor between countries in the world inevitably lead to the problem of carbon emission transfer in international trade. This paper uses export dependence to reflect the level of the development of export trade in international trade.

(8) Urbanization rate (U): urbanization level is an important factor affecting carbon emissions. Urbanization rate is represented by the ratio of urban population to total population.

(9) Fiscal decentralization (FD): fiscal decentralization, as an index reflecting the degree of fiscal freedom of the government, is also a factor affecting carbon emissions. Referring to the decentralization index of Zhang and other scholars, the proportion of provincial government expenditure to central fiscal expenditure is used.

3.3. Construction of the Empirical Model. There are a few studies on carbon emission convergence, but there are no detailed and in-depth studies on different regions. Therefore, it is necessary to do further research on the basis of existing research and consider the spatial factor, which will elaborate on China's carbon emission convergence model and sample study and will follow the methods of an existing paper [29].

3.3.1. Convergence Model of Carbon Emissions. The convergence of regional carbon emissions is generally expressed by the standard deviation index:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(I - \frac{1}{n}\sum_{i=1}^{n} I_i\right)}. \tag{2}$$

Standard deviation indicates the degree of deviation in carbon emissions from the overall average level. I_i represents the average carbon emissions of region I, n is the number of regions, and the average carbon emissions of all regions i in the country are also represented.

3.3.2. Beta Convergence Model of Carbon Emissions. The beta convergence of carbon emissions can be divided into absolute beta convergence and conditional beta convergence. The absolute beta convergence of carbon emissions implies strict assumptions and preconditions; that is, each region has a similar level of economic development, technological strength, industrial structure, environmental policies, etc. Under the same conditions, carbon emission levels in different regions will have the same steady state and thus have the same growth path and stable state. The beta convergence of carbon emission conditions refers to a convergence mode corresponding to the absolute beta convergence of carbon emissions. The beta convergence of carbon emission conditions does not require the assumption that different regions of absolute beta convergence must have exactly the same "basic characteristics," which means that different regions have different growth paths and stable states. According to neoclassical growth theory, if there is a condition of beta convergence for regional carbon emissions, then each region will converge to its own stable state and have its own convergence path.

The expression of absolute beta convergence of regional carbon emissions is as follows:

$$\ln\frac{I_{i,i+T}/I_{i,t}}{T} = a + b\ln\left(I_{i,t}\right) + u_{i,t}, \tag{3}$$

where I_i and T represent the level of carbon emissions in the period t and I_i, $I+T$ represents the level of carbon emissions in the period $T+T$, ln $(I_i, I+T/I_i, t)/T$ represents the average annual growth rate of carbon emissions from the period T to $t+T$, and $u_{i,t}$ is a random error term.

When $T=1$, the absolute beta convergence expression of regional carbon emissions is as follows:

$$\ln\left(\frac{I_{i,i+T}}{I_{i,t}}\right) = a + b\ln\left(I_{i,t}\right) + u_{i,t}. \tag{4}$$

On the basis of the absolute beta convergence model of regional carbon emissions, appropriate control variables are added. The expression of the beta convergence model of regional carbon emission conditions is as follows:

$$\ln\frac{I_{i,i+T}/I_{i,t}}{T} = a + b\ln\left(I_{i,t}\right) + \sum_{k=1}^{m}\lambda_k X_{k,i,t} + u_{i,t}, \tag{5}$$

where K denotes the regression coefficient of the k-th control variable and X_k, i, and t denote the k-th control variable. When the coefficient is negative and has passed the significance level test, the level of carbon emissions has a conditional beta convergence trend.

When $T=1$, the expression of beta convergence of regional carbon emission conditions is as follows:

$$\ln\left(I_{i,i+T}/I_{i,t}\right) = a + b\ln\left(I_{i,t}\right) + \sum_{k=1}^{m}\lambda_k X_{k,i,t} + u_{i,t}. \tag{6}$$

4. Empirical Analysis

4.1. Descriptive Statistics and Correlation Analysis. The descriptive statistical results of the influencing factors of carbon emissions in China are shown in Table 1.

4.2. Relevance Analysis of Carbon Emissions in China. Firstly, global Moran's I statistics were used to determine the correlation of carbon emissions, and the results are shown in Table 2.

According to Table 2, there is a significant positive spatial autocorrelation of carbon emissions in 30 provinces of China between 2000 and 2015. The Moran index of spatial statistics shows an overall growth trend, which proves that the carbon emissions of 30 provinces in China have obvious spatial autocorrelation. *OLS* estimation of a classical linear regression model may neglect the inappropriate model setting of spatial effects.

Opengeoda software was used to analyze the spatial autocorrelation of carbon emissions. The average carbon emissions of 30 provinces in China from 2000 to 2015 were analyzed.

According to the Moran scatter plot of the average carbon emissions (CA) from 2000 to 2015, we can know that

Table 1: Descriptive statistical results of carbon emission impact factors in China.

Variables	Sample number	Maximum	Minimum	Mean	Median	Standard deviation
Population	480	10849	517	4366	3814	2634.63
Economic growth	480	54246.16	263.68	9401	6444	9309.62
Technological progress	480	269944	70	181731	4831	38167.02
Industrial structure	480	61.5	19.7	46.94	48.5	7.66
Financial development	480	26.46	0.08	1.41	1.24	1.31
Energy prices	480	123.9	84.3	103.58	104.2	6.75
International trade	480	91.59	0.86	15.9	6.92	18.96
Urbanization rate	480	89.6	18.61	47.86	45.93	15.29
Fiscal decentralization	480	7.3	0.4	2.55	2.3	1.32

Table 2: Moran's I test results of provincial carbon emissions from 2000 to 2015.

Year	Moran's I
2000	0.3003
2001	0.3416
2002	0.3304
2003	0.2940
2004	0.3245
2005	0.3448
2006	0.3285
2007	0.3257
2008	0.3340
2009	0.3149
2010	0.3119
2011	0.3073
2012	0.2743
2013	0.2780
2014	0.2605
2015	0.2564

the average carbon emissions of provinces in China are mostly concentrated in the first and third quadrants. The low-carbon emission areas are surrounded by low-carbon emission areas, and the high-carbon emission areas are surrounded by high-carbon emissions areas, which proves that the carbon emissions of provinces in China have the characteristics of accumulation.

According to the Hausman test, the absolute convergence of carbon emissions is determined by a fixed effect model or a random effect model. The Hausman test results were 18.8496, which passed the 0.05% significance level test, so we rejected the original hypothesis that individual effects were independent of explanatory variables and adopted the fixed effect model. According to the results of the Wald and LR tests, Wald_spatial_lag and LR_spatial_lag are 2.8106 and −15.1237, respectively. Their adjoint probabilities are 0.0936 and 1, and Wald_spatial_error and LR_spatial_error are 2.3593 and −12.2571, respectively. The adjoint probabilities are 0.1245 and 1. This shows that the log-likelihood ($\log L$) and goodness-of-fit system of spatial_error and LR_spatial_error are not consistent with the original hypothesis. The AdjR^2 values are 462.3068 and 0.1564, respectively, which is relatively high. Therefore, we chose the results of the spatial lag panel model II to explain the overall results.

According to the Hausman test, either the fixed effect model or the stochastic effect model is used to judge the convergence of carbon emission conditions. The result of the Hausman test was 30.8883, which passed the 0.05% significance level test, so we rejected the original hypothesis that individual effects were independent of explanatory variables and adopted the fixed effect model. According to Wald_spatial_lag and LR_spatial_lag, which are, respectively, 17.5168 and −173.5749, their adjoint probability values are 0.00637 and 1. Wald_spatial_error and LR_spatial_error are 14.0841 and −650.3549, and their adjoint probabilities are 0.1692 and 1. This shows that without the original assumption, $\log L$ and AdjR^2 of the spatial lag panel model II are 476.5879 and 0.2254, which are relatively high, so we chose the spatial lag panel model II and the spatial Durbin model to explain the overall results.

4.3. σ Convergence Analysis of Regional Carbon Emissions in China. We calculate the convergence of every year, and n is 30. We can obtain the standard deviation in 2000 was 1961.5850, which rose to 6053.112 in 2015. This shows that there is no trend of convergence in China's interprovincial carbon emissions. The convergence rate of carbon emissions decreased in 2006, which may be related to the speed of economic development in China. The year 2006 is the first in the Eleventh Five-Year Plan. Industrialization and urbanization are also in the stage of accelerating development. The gross domestic product (GDP) has reached 20187.1 billion yuan, an increase of 11.1% per year, and the per capita GDP has increased by 19.9% per year. With the most complex year of China's economy being 2010, facing adjustment and change in the global economic development mode and governance structure, China's external environment presents a complex economic pattern. The central government resolutely launched the macropolicy control, which increased the standard deviation of carbon emissions in China. It can be seen that the State Council made some achievements in vigorously developing new industries such as energy conservation, environmental protection, new energy, new materials, and new generation information technology. However, on the whole, the standard deviation curve of regional carbon emissions in China has been on the rise, showing evolution characteristics in the overall divergence.

4.4. Absolute Beta Convergence Analysis of Regional Carbon Emissions in China. The absolute beta convergence of China's provincial carbon emissions was tested, and the results are shown in Table 3.

Table 3: Spatial econometric model estimate result.

Variable	Spatial lag panel model				Spatial Durbin panel model			
	No fixed effects I	Spatial fixed effects II	Time period fixed effects III	Spatial and time period fixed effects IV	No fixed effects I	Spatial fixed effects II	Time period fixed effects III	Spatial and time period fixed effects IV
C	0.2569 (0.0000)				0.2422 (0.0000)			
β	−0.0252 (0.0016)	−0.0747 (0.0000)	−0.0138 (0.0080)	−0.1292 (0.0000)	−0.0109 (0.0799)	−0.1125 (0.0000)	−0.0020 (0.7509)	−0.1383 (0.0000)
WLni					−0.0130 (0.0002)	0.0519 (0.0134)	−0.0109 (0.0007)	−0.0610 (0.1231)
ρ	0.3520 (0.0000)	0.3080 (0.0000)	−0.0550 (0.4245)	0.0321 (0.6289)	−0.0379 (0.0000)	0.3410 (0.0000)	−0.0220 (0.7476)	−0.0540 (0.4318)
Log L	412.8868	462.3068	451.4023	505.9498	462.3068	465.5667	457.6220	507.0783
AdjR^2	0.0637	0.1564	0.0170	0.0790	0.1928	0.1671	0.0428	0.0844

According to panel model II of the spatial lag in Table 3, it can be seen that the level of carbon emissions at the beginning of the period is inversely proportional to its growth rate, which proves that absolute beta convergence exists in China's regional carbon emissions, and that the convergence of carbon emissions between regions has a spatial spillover effect. The correlation coefficient is 0.3080, which passes the significant level test of 0.05%, and the level of carbon emissions in adjacent regions tends to converge steadily.

4.5. Beta Convergence Analysis of Regional Carbon Emission Conditions in China. To further test the existence of conditional beta convergence of regional carbon emissions, the influencing factors are added to the conditional convergence model of regional carbon emissions as control variables. Table 4 is a spatial model with the natural logarithm of carbon emissions as explanatory variables and the natural logarithm of population growth, urbanization rate, industrial structure, economic growth, energy price, and technological progress also as explanatory variables. As a result, the estimated coefficients of beta in Table 4 are all negative, which proves that beta convergence exists in China's carbon emissions. Technological progress and fiscal decentralization have passed the significance test on the coefficient of convergence of carbon emissions, but other factors have not passed this test, which proves that these factors are the reasons for the convergence of regional carbon emission conditions in China.

The results of the spatial lag panel model II and the spatial Durbin panel model with carbon emissions as explanatory variables were analyzed. It can be seen that the impact of population on carbon emissions passed the significance test, and some have not. This proves that China is still a developing country, and living standards are low. Population growth is not the main reason for the increase and convergence of carbon emissions.

Economic growth is not a factor of carbon emission convergence but is the main cause of carbon emission increase. The regression results of spatial econometric model show that regional economic development has a spillover effect. Changing the mode of economic development is the only way to achieve sustainable development in China.

Technological progress plays a role in promoting the convergence of carbon emissions to a certain extent, but the spillover effect of technological innovation in adjacent regions is not significant. Therefore, as the main way to reduce carbon emissions, technological progress should accelerate technological innovation and take active measures to achieve certain results in reducing carbon emissions.

Industrial structure does not promote the convergence of carbon emissions, but still leads to the increase in carbon emissions. The industrial structure coefficients in the Durbin model are all positive. Some of them pass the significance test. The industrial structure has no effect on the convergence of carbon emissions in nearby areas and has a certain spatial spillover effect, which proves that the industrial structure of the country needs to be rationalized.

The effect of financial development on carbon emission convergence is not significant nor do the adjacent regions show an effective role. This proves that financial reform has achieved some results, but there is still room for improvement.

In theory, the energy price index should be negatively correlated with energy consumption and should play a positive role in promoting the convergence of carbon emissions. From the regression results, the energy price has no significant effect on the convergence of carbon emissions. The main reason may be that the information release system of the energy price is not perfect, and the phenomenon of local protectionism still exists. We should improve the rules and regulations as soon as possible so as to make the energy price play a macrocontrol role.

International trade has not promoted the convergence of carbon emissions but is still a factor leading to the increase of carbon emissions. Interregional international trade has a spillover effect, which proves that China's international trade transformation has made some achievements.

The estimated coefficient of the urbanization rate on carbon emissions is negative, but it has not passed the significance test, and the spatial spillover effect is not significant. Therefore, China should speed up the development

Table 4: Spatial estimation results of provincial carbon emission.

Variable	Spatial lag panel model				Spatial Durbin panel model			
	No fixed effects I	Spatial fixed effects II	Time period fixed effects III	Spatial and time period fixed effects IV	No fixed effects I	Spatial fixed effects II	Time period fixed effects III	Spatial and time period fixed effects IV
C	0.3539 (0.3614)				−0.5349 (0.3282)			
β	−0.0190 (0.0669)	−0.1502 (0.0000)	−0.0112 (0.2632)	−0.1619 (0.0000)	−0.0334 (0.0084)	−0.2049 (0.0000)	−0.0249 (0.0454)	−0.2660 (0.0000)
ln P	−0.0002 (0.9910)	−0.0780 (0.4517)	−0.0036 (0.8567)	−0.0654 (0.5088)	−0.0127 (0.5983)	−0.1281 (0.3414)	−0.0151 (0.5336)	−0.2676 (0.0294)
ln A	0.0493 (0.0181)	0.1399 (0.0000)	0.0380 (0.1507)	−0.0272 (0.6771)	0.0706 (0.0209)	0.2549 (0.0001)	0.0635 (0.0404)	0.1372 (0.0413)
ln T	−0.0286 (0.0106)	−0.0440 (0.0035)	−0.0172 (0.1363)	−0.0212 (0.2125)	−0.0228 (0.0628)	−0.0347 (0.0693)	−0.0174 (0.1478)	−0.0154 (0.3877)
ln S	0.0019 (0.9503)	0.1221 (0.0586)	0.0060 (0.8365)	0.1690 (0.0134)	0.0377 (0.3049)	0.1402 (0.0419)	0.0373 (0.3092)	0.1853 (0.0061)
ln F	−0.0314 (0.0438)	0.0099 (0.6076)	−0.0347 (0.0328)	−0.0039 (0.8435)	−0.0303 (0.0653)	0.0105 (0.5939)	−0.0339 (0.0418)	0.0009 (0.9589)
ln E	−0.0139 (0.8485)	0.0665 (0.3762)	−0.0890 (0.6206)	0.0123 (0.9462)	0.1558 (0.1775)	−0.1645 (0.3256)	−0.0772 (0.6707)	−0.0591 (0.7261)
ln EX	0.0288 (0.0000)	0.0087 (0.5278)	0.0232 (0.0028)	−0.0045 (0.7699)	0.0343 (0.0000)	0.0264 (0.0740)	0.0302 (0.0018)	−0.0182 (0.2419)
ln U	−0.0774 (0.0070)	−0.0404 (0.3283)	−0.0758 (0.0091)	−0.0429 (0.2881)	−0.0814 (0.0135)	−0.0353 (0.3898)	−0.0767 (0.0155)	−0.0719 (0.0528)
ln FD	−0.0404 (0.0187)	−0.0491 (0.0511)	−0.0462 (0.0150)	−0.0397 (0.1007)	−0.0433 (0.0324)	−0.0642 (0.0112)	−0.0492 (0.0140)	−0.0546 (0.0150)
W ln I					0.0460 (0.0665)	0.2374 (0.0007)	0.0373 (0.1706)	−0.0646 (0.4211)
W ln P					0.0770 (0.0478)	0.4802 (0.0717)	0.0673 (0.1294)	0.2567 (0.3092)
W ln A					−0.0541 (0.2376)	−0.2769 (0.0022)	−0.0890 (0.0897)	−0.3024 (0.0004)
W ln T					−0.0191 (0.3638)	−0.0223 (0.3887)	0.0227 (0.3669)	0.0788 (0.0059)
W ln S					0.0548 (0.4155)	0.2200 (0.1106)	0.0870 (0.2348)	0.4374 (0.0038)
W ln F					0.0579 (0.0454)	0.0703 (0.0257)	0.0194 (0.5588)	0.0541 (0.1010)
W ln E					−0.1704 (0.0812)	0.2918 (0.1078)	−0.1622 (0.1314)	0.7745 (0.0012)
W ln EX					−0.0095 (0.4585)	−0.0723 (0.0012)	−0.0212 (0.2176)	−0.1527 (0.0000)
W ln U					0.0463 (0.4789)	0.0720 (0.4555)	0.0458 (0.5109)	0.0410 (0.6508)
W ln FD					−0.0225 (0.6011)	−0.0611 (0.2868)	−0.0429 (0.3464)	−0.0523 (0.3406)
ρ	0.2700 (0.0000)	0.2810 (0.0000)	−0.0460 (0.4962)	0.0308 (0.6426)	0.2330 (0.0001)	0.2360 (0.0001)	−0.0510 (0.4584)	−0.0900 (0.1893)
Log L	446.0314	476.6667	476.275	513. 6055	454.7283	494.5247	484.3428	539.8509
AdjR^2	0.2177	0.2291	0.1189	0.1099	0.2605	0.3042	0.1496	0.2080

of low-carbon urbanization. With the urbanization process restraining the increase in carbon emissions and with the improvement of the urbanization process, China's urbanization development will achieve better results.

Fiscal decentralization plays a certain role in the convergence of carbon emissions. Its spatial spillover effect is not significant, but it proves that fiscal decentralization plays an important role in reducing carbon emissions. According to this conclusion, we can see that China has been responsibly and actively responding to climate change and exploring a low-carbon economic development path in line with China's national conditions. China's government agencies at all levels have integrated climate issues into all parts of the country for the strategic deployment of regional economic development.

Spatial carbon emission convergence has shown a certain spillover effect, so we should increase efforts to actively promote the effect of interregional carbon emission convergence, combined with the construction of regional low-carbon clusters.

5. Research Conclusions

China's regional carbon emissions are overall divergent, and there is no σ convergence. Considering the spatial effect, an absolute beta convergence phenomenon was found to exist when the spatial spillover effect among regions was considered, and it was shown that China's regional coordinated emission reduction has achieved certain results. On the premise of speeding up economic construction, we should actively strengthen regional cooperation while considering that developed regions drive backward regions, adhere to low-carbon economic construction, and slow down the growth of carbon emissions. The development of low-carbon economic cooperation should be accelerated, and the dependence on high energy consumption and high emissions as the main body in economic development should be transformed. Efforts are needed to actively accelerate technological innovation and the construction of local government team, implement the strategy of regional coordinated development, and consider urban agglomeration as required to build a coordinated development pattern of large- and medium-sized cities and small towns so as to jointly promote the development of a low-carbon economy in China.

According to our research conclusions, China's population is not the main factor in increasing carbon emissions. China should strengthen international cooperation in low-carbon economic construction and low-carbon industrial cooperation, reduce the rate of increase in carbon emissions, coordinate the coordinated development of regional economies, improve the enthusiasm of low-carbon economic development, and promote the development of low-carbon industries in China so as to realize the transformation to a low-carbon economy in the whole country.

We found that technological progress has a significant effect on carbon emission convergence but that the industrial structure has none. China should accelerate the role of the industrial structure on carbon emission convergence spillover, guiding the rational flow of social capital, promoting the effective allocation of resources, and actively forming low-carbon innovation construction of low-carbon industrial clusters on the basis of adjusting the industrial structure. The development of a low-carbon economy necessarily requires the research and development of low-carbon technology, which requires a large amount of investment and high risk, and must play a leading and promoting role in the government. While focusing on the heterogeneity of local economic development, government departments should not ignore the role of spatial effects on carbon emissions and other influencing factors and should promote the development of a low-carbon economy in the region through the development of an adjacent regional economy. Lastly, it was found that fiscal decentralization has made some achievements in the convergence of carbon emissions, but energy prices have not achieved the desired results. Therefore, we should actively develop green finance, establish green production and consumption policy orientation, strengthen the role of local governments in financial regulation, actively adopt financial policy orientation, adjust the export trade situation with energy-saving industries as major actors, and take practical actions. China has different stages of regional economic development. China should establish and implement low-carbon development measures and policies that are adapted to local conditions. Government departments can actively guide enterprises to build low-carbon competitive advantages and promote enterprises to develop low-carbon technology. The government can coordinate the relationship between international trade and carbon emissions, formulate environmental regulations reasonably and effectively, improve low-carbon technologies for energy saving and emission reduction, and focus on reducing the intensity of carbon emissions for enterprises with a large proportion of exports. The reduction of carbon emissions, while developing international trade, is urgent. Therefore, China should actively participate in the practice of global governance, take the initiative to assume international responsibilities that match our national conditions and development stages, promote the establishment of a fair and reasonable climate governance system, and enter a new era of low-carbon economic development.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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