Influencing Factors and Regional Differences of Carbon Emissions in Urban Agglomerations in the Middle and Lower Reaches of the Yellow River

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Abstract. Quality growth and eco-environmental protection have become the national development strategies, and the Yellow River Basin occupies an important position in China. Using the data from 2006 to 2017, this paper studies the relationship between economic growth and carbon emission, and proves the Environmental Kuznets Curve in urban agglomerations of the middle and lower reaches of the Yellow River. The paper proves the spillover effects of carbon emission and the influencing factors through using the SEM and SDM. Finally, we propose a coordinated reduction path of carbon emission based on different influencing factors such as quality growth, population, urbanization rate, industrial structure, technological progress, and energy structure.

Keywords: Urban Agglomerations · Carbon Emission · Economic Growth · SDM Model · STIRPAT Model

1 Introduction

The Yellow River Basin has an important position in China's ecosystem and economic development. Since eco-environmental protection and economic development became the national strategies, people have paid more attention on this area. The downstream of this river flows through the five provinces of Inner Mongolia, Shanxi, Shanxi, Henan, and Shandong. The GDP of the five provinces is about 2.97 trillion dollars in 2020, accounting for 18.63% of the national GDP. However, the air quality inspections of 168 key cities in 2020 show that 3/4 of the bottom 20 cities are located in the middle and lower reaches of the Yellow River. Therefore, it is imperative to protect the environment, reduce carbon emission and air pollution in this area. So this paper studies the influencing factors of carbon emissions of urban agglomerations in the middle and lower reaches of the Yellow River and the differences of the influencing factors of different cities, so that to provide suggestions and methods for reducing carbon emission of urban agglomerations collectively.

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2 Literature Review

2.1 Carbon Emission and Economic Growth

Most scholars used the Kuznets curve to study the relationship between carbon emission and economic growth, and concluded that economic growth and carbon emission present an inverted U-shaped relationship. Some scholars dealt with an empirical investigation using annual data over the period from 1970 to 2010 in Turkish, and the results validated the presence of environmental Kuznets curve (EKC) [6]. Others used the Pakistan's data from 1972 to 2013, showed that there is an environmental Kuznets curve in both the short-term and the long-term. The level of CO2 in the initial stage increases with the increase of income, this relationship may change from positive to negative after reaching a certain value of income [4]. Chinese scholars also have studied this issue. Chinese scholars used spatial analysis methods to conduct empirical analysis on the economic growth and environmental pollution of various provinces. The results showed that the relationship between environmental pollution and economic growth was an inverted U-shaped curve [2]. Others studied the question by focusing on the EKC theory, and the results found that whether the study was based on the total provinces or based on the division of eastern, central, and western regions, the relationship all match the EKC theory, which is the inverted U-shaped curve, but the turning points of different subjects were different [7].

2.2 Influencing Factors of Carbon Emission

Differences in carbon emissions are the main factors of reducing emissions in different regions. Factors such as the level of economic development, population size, technological development, and urbanization can lead to different carbon emissions of different cities. Regarding the research on the influencing factors of carbon emission, scholars used the STIRPAT model to analyze the situation of OECD countries and showed that per capita GDP, industrialization, population size, and urbanization are closely related to CO2 emission [5]. Some analyzed the influencing factors of CO2 emission in the residential sector in China and India, and pointed out that the main reason for the CO2 emission was the increase of per capita income, and the main reason for suppressing the increase was the decline of energy intensity [8]. And other scholars used the LMDI method and the improved STIRPAT model to study energy-related carbon emission in Kazakhstan. The results showed that the relationship between CO2 emission and economy followed a U-shaped curve. Carbon emission was related to population size, economic activities, energy intensity, and energy [3].

2.3 This Article

Previous scholars have not studied the differences in carbon emissions and influencing factors of the Yellow River Basin. This paper adds variables representing economic growth, that is the quadratic and tertiary terms of per capita GDP, into the STIRPAT model to analyze whether the relationship between economic growth and carbon emissions conforms to the Environmental Kuznets Curve (EKC). And this article uses the Spatial Dubin Model (SDM) to analyze the spatial spillover effects of carbon emission and influencing factors of urban agglomerations of the middle and lower reaches of the Yellow River, and compares the influencing factors of carbon emissions among different urban agglomerations. The third part of the article is the research method, the fourth part is the empirical analysis and result, the fifth part is the conclusion.

3 Method

3.1 Basic Model

Scholars proposed the STIRPAT model to study the random regression model of population, per capita wealth, and technology on the environment [1].

$$\mathrm{I} = \mathrm{a}\mathrm{P}^{\mathrm{b}}\mathrm{A}^{\mathrm{c}}\mathrm{T}^{\mathrm{d}}\mathrm{e} \tag{1}$$

I represents the impact on the environment, a is coefficient, P, A, T represent population, economy, and technology, and the indices b, c, and d can be estimated by the model, and e is the residual term. Take the natural logarithms on both sides of the formula to obtain the following equation:

$$\mathrm{LnI} = \mathrm{lna} + \mathrm{blnP} + \mathrm{clnA} + \mathrm{dlnT} + \mathrm{lne} \tag{2}$$

From the concept of elastic coefficient, the regression coefficient of the equation reflects the elastic relationship between explanatory variables and dependent variables. The STIRPAT model can be used to calculate the impact of population, economy, and technology changes on environmental changes. At the same time, technology can be decomposed and other factors that affect environmental can be added.

3.2 Variables

3.2.1 Dependent Variable

Carbon emission (C): Carbon emission is calculated from energy consumption, unit: 10,000 tons of carbon.

According to the method of the United Nations Intergovernmental Panel on Climate Change (IPCC), using the 17 kinds of terminal energy consumption data of Regional Energy Balance Table from Statistics Bureau of prefecture-level city, this article calculates carbon emission through converting the energy consumption into standard coal by conversion coefficient of standard coal and multiplying the standard coal with the carbon emission coefficient.

$$\mathrm{C} = \sum \mathrm{Cj} = \sum \mathrm{Eij} \times \mathrm{Fj} \times \mathrm{Pj} \tag{3}$$

Eij represents the energy consumption of the j energy in the i region, Fj represents the conversion coefficient standard coal of the j, the specific data come from “China Energy Statistics Yearbook 2018”, Pj represents the carbon emission coefficient of the j, the data from the “IPCC Guidelines for National Greenhouse Gas Emission Inventories”. The energy data in this article comes from the Statistical Yearbook of prefecture-level cities. The calculation of some missing data refers to the method of Zheng and Shan [9, 10]. The carbon emissions of cities are calculated based on the energy consumption data of the province, and then according to the percentage of the city’s GDP to calculate the carbon emission of the specific city.

Table 1. Explanatory variables. (Author's self-painting)

variables	unit	Meaning
Population size (P)	Ten thousand	Number of permanent residents in each region
Economic scale (pgdp)	Yuan	GDP per capita
Industrial Structure (IS)	%	Percentage of the secondary industry's GDP
Energy Consumption structure (ES)	%	Coal consumption as a percentage of total primary energy consumption
Technological Progress (EI)	Tons of standard coal per 10,000 yuan	Energy intensity (energy consumption per GDP)
Urbanization (U)	%	The proportion of urban population in total population

3.2.2 Explanatory Variables

According the present study and situation of carbon emission, this article uses six explanatory variables. Table 1 shows the explanatory variables.

3.2.3 The Source of the Data and Analysis Tool

This article selects the data of prefecture-level cities in five urban agglomerations from 2006 to 2017, spanning 11 years. The samples come from the "China Energy Statistical Yearbook" and the Bureau of Statistics of each city. The GDP data is the real GDP based on 2005. This article uses the stata16 to analyze the data and perform the empirical analysis.

3.3 Variables

Considering the actual situation, this paper analyze the elasticity coefficient of influencing factors and spatial spillover effects of carbon emission, and analyze the role of carbon emissions of neighboring regions. This paper constructs three econometric models of Spatial Lagged Model(SLM), Spatial Error Model(SEM) and Spatial Durbin Model(SDM):

$$\begin{aligned} \text{LnCit} = \rho \sum \text{WijlnCij} + \beta_0 + \beta_1\text{lnPGDPit} + \beta_2(\text{lnPGDPit})\hat{}2 + \beta_4(\text{lnPGDPit})\hat{}3 \\ + \beta_4\text{lnPit} + \beta_5\text{lnISit} + \beta_6\text{lnESit} + \beta_7\text{lnEIit} + \beta_8\text{lnUit} + \varepsilon\text{it} \end{aligned} \tag{4}$$

$$\begin{aligned} \text{LnCit} = \beta_1\text{lnPGDPit} + \beta_2(\text{lnPGDPit})\hat{}2 + \beta_3(\text{lnPGDPit})\hat{}3 \\ + \beta_4\text{lnPit} + \beta_5\text{lnISit} + \beta_6\text{lnESit} + \beta_7\text{lnEIit} + \beta_8\text{lnUit} + \varphi\text{it} \\ \varphi\text{ij} = \lambda \sum \text{Wij}\ \varphi\text{ij}\rho + \varepsilon\text{it} \end{aligned} \tag{5}$$

$$
\begin{aligned}
\mathrm{LnCit} = {} & \rho \sum \mathrm{WijlnCit} + \beta_0 + \beta_1 \mathrm{lnPGDPit} + \beta_2 (\mathrm{lnPGDPit})\hat{}2 + \beta_3 (\mathrm{lnPGDPit})\hat{}3 \\
& + \beta_4 \mathrm{lnP(it)} + \beta_5 \mathrm{lnISit} + \beta_6 \mathrm{lnESit} + \beta_7 \mathrm{lnEIit} + \beta_8 \mathrm{lnUit} \\
& + \alpha_1 \Sigma \mathrm{WijlnPGDPit} + \alpha_2 \Sigma \mathrm{Wij(lnPGDPit)}\hat{}2 + \alpha_3 \Sigma \mathrm{Wij(lnPGDPit)}\hat{}3 \\
& + \alpha_4 \Sigma \mathrm{WijlnPit} + \alpha_5 \Sigma \mathrm{WijlnISij} + \alpha_6 \Sigma \mathrm{WijlnESij} + \alpha_7 \Sigma \mathrm{WijlnEIij} \\
& + \alpha_8 \Sigma \mathrm{WijlnUij} + \varepsilon \mathrm{i} \qquad (6)
\end{aligned}
$$

4 Empirical Results and Discussion

4.1 Spatial Effect Test of Carbon Emission

This article uses Moran 'I to conduct an autocorrelation test to analyze whether there is a spatial effect on the carbon emissions of urban agglomerations. The results shown in Table 3 indicate that there is a regional correlation in the carbon emissions of urban agglomerations in the middle and lower reaches of the Yellow River. Through analyzing the data, the spatial autocorrelation of carbon emission changes over time, which shows a trend of increasing at the beginning and then decreasing. It shows that the carbon emission level of a region is affected by the carbon emissions of the adjacent regions, as well as the economic development, population size, technology, industrial structure, urbanization rate and other factors of the surrounding area. Therefore, it is necessary to select a spatial measurement model to study different effects of factors on carbon emissions.

4.2 Spillover Effect of Influencing Factors of Carbon Emission

4.2.1 Descriptive Statistics

Table 4 shows the descriptive statistics of explanatory variables. According to the method of the United Nations Intergovernmental Panel on.

4.2.2 SEM and SDM

Using Eqs. (5) and (6), the SEM and SDM are used to analyse the influencing factors of carbon emissions in prefecture level cities of urban agglomerations in the middle and lower reaches of the Yellow River. The results are shown in Table 5.

From Table 2, it can be seen that industrial structure, energy intensity, and energy structure have significant positive effects on carbon emission in the region. The proportion of the secondary industry increases 1%, carbon emission increases 0.737%. The energy consumption of per unit of GDP increases 1%, the percentage point of carbon emission increases 0.41%. The coal consumption increases 1%, carbon emission increases 0.2%. But the effect of the economy on the growth of carbon emission was not significant.

The results of the individual fixed effect of SEM show that industrial structure, energy intensity, and energy structure have significant positive effects on carbon emission. The proportion of secondary industriy increases 1%, carbon emission increases 0.659%. The

Table 2. Result of spatial analysis. (Author's self-painting)

	SEM			SDM		
	Ind	Time	both	ind	time	Both
	c	c	c	c	c	c
Main						
pgdp	−0.685	−9.187***	−1.013	−1.253	−8.312***	−0.463
	(1.001)	(1.795)	(1.000)	(0.942)	(1.885)	(0.943)
pgdp2	0.0388	0.871***	0.0750	0.0796	0.761***	0.0103
	(0.113)	(0.201)	(0.113)	(0.107)	(0.211)	(0.107)
pgdp3	0.000187	−0.0250***	−0.00114	−0.000258	−0.0205**	0.00137
	(0.00416)	(0.00733)	(0.00416)	(0.00397)	(0.00772)	(0.00398)
p	0.385	0.682***	0.392	0.370	0.721***	0.334
	(0.211)	(0.0399)	(0.211)	(0.208)	(0.0366)	(0.209)
is	0.737***	0.220	0.726***	0.659***	0.300**	0.716***
	(0.0889)	(0.118)	(0.0903)	(0.0875)	(0.114)	(0.0866)
u	0.0351	−0.139***	0.0183	0.0330	−0.170***	0.0201
	(0.0244)	(0.0185)	(0.0246)	(0.0211)	(0.0178)	(0.0220)
ei	0.405***	0.754***	0.447***	0.280***	0.862***	0.440***
	(0.0629)	(0.0595)	(0.0647)	(0.0618)	(0.0574)	(0.0625)
es	0.204***	0.0917**	0.185***	0.206***	0.239***	0.201***
	(0.0236)	(0.0303)	(0.0239)	(0.0227)	(0.0299)	(0.0230)
Spatial	0.715***	0.128*	0.608***	0.781***	0.350***	0.621***
rho	(0.0259)	(0.0581)	(0.0342)	(0.0234)	(0.0561)	(0.0332)
LogL	294.1968	−420.0429	304.8703	271.5875	−482.0060	308.6521
Variance	0.0210***	0.204***	0.0208***	0.0215***	0.239***	0.0211***
sigma2	(0.00119)	(0.0111)	(0.00117)	(0.00123)	(0.0132)	(0.00119)
N	672	672	672	672	672	672
R2	0.3981	0.642	0.688	0.382	0.542	0.279
adj. R2	0.3934	0.631	0.667	0.370	0.532	0 .265

a. resource: China Energy Statistical Yearbook.

energy consumption per unit of GDP increases 1%, carbon emission increases 0.28%. The coal consumption increases 1%, carbon emission increases 0.21%. Urbanization has a negative effect on the increase of carbon emission in the region, but it is not significant. In addition, while studying the impact of economic growth on carbon emission, this article adds the tertiary terms of per capita GDP. The results show that $\beta 1 < 0$, $\beta 2 > 0$, $\beta 3 < 0$, which is consistent with Inverted N-shaped curve, but it is not significant.

Table 3. Moran's I (Author's self-painting)

Year	Moran's I	P	Year	Moran's I	P
2017	0.3094	0.001	2011	0.3955	0.001
2016	0.391	0.001	2010	0.3331	0.001
2015	0.2958	0.001	2009	0.3676	0.001
2014	0.3812	0.001	2008	0.3405	0.001
2013	0.3851	0.001	2007	0.33261	0.001
2012	0.4021	0.001	2006	0.3089	0.001
2006–2012	0.3414	0.001			

a. resource: China Energy Statistical Yearbook.

Table 4. Descriptive statistics (Author's self–painting)

Variable	Obs	Mean	Std.Dev.	Min	Max
city	684	29	16.46	1	57
lnyear	684	2012	3.455	2006	2017
lnlc	684	5.991	0.762	3.729	8.174
lnpgdp	684	10.20	0.933	5.595	12.28
npgdp2	684	105.0	17.95	31.31	150.8
lnpgdp3	684	1088	266.5	175.2	1852
lnp	684	6.004	0.590	4.209	6.935
lnis	684	3.921	0.231	2.964	4.392
lnu	684	4.062	1.079	1.979	8.618
lnei	684	0.252	0.440	−0.978	1.435
lnes	684	4.315	0.656	−0.248	8.689

a. resource: Statistical Yearbooks of each city.

The empirical results in Table 4 also show that the Spatial rho values of the individual fixed effect of SDM and SEM are 0.715 and 0.718, both of which pass the significance test, 0.1% indicating that the carbon emissions of different prefecture-level cities will affect the carbon emissions of neighboring regions. Therefore, the analysis results of SDM show that the industrial structure, energy intensity, and energy structure of the regions have significant negative effects on the growth of carbon emissions in neighboring cities, and the industrial structure has a great positive effect on carbon emission in neighboring areas. The population and the urbanization rate have positive effects, but the they are not significant. The impact of economic growth on carbon emissions in neighboring regions has the same trend as the impact on carbon emission in original region, but the result is also not significant. The empirical results show that the carbon emissions and influencing factors of neighboring prefecture-level cities have obvious

Table 5. Result of SEM (Author's self-painting)

	Ind	Time	both
Wx			
pgdp	−1.290	−1.940	−3.716
	(1.834)	(3.933)	(1.919)
pgdp2	0.178	0.280	0.440*
	(0.201)	(0.433)	(0.211)
pgdp3	−0.00784	−0.0128	−0.0171*
	(0.00725)	(0.0156)	(0.00761)
p	0.353	−0.409***	0.449
	(0.419)	(0.0878)	(0.440)
is	−0.768***	−0.409	−0.691***
	(0.131)	(0.232)	(0.163)
u	0.00198	0.148***	−0.0237
	(0.0294)	(0.0425)	(0.0299)
ei	−0.417***	−0.130	−0.155
	(0.0806)	(0.137)	(0.117)
es	−0.197***	−9.187***	−0.245***
	(0.0533)	(1.795)	(0.0551)

a. resource: Statistical Yearbooks of each city.

spatial spillovers. The influencing factors of a region and neighboring regions affect the carbon emissions of a certain region collectively. So the spatial spillover effect has a great role on reducing the carbon emission in the future study.

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4.2.3 Analysis of Differences in Influencing Factors of Carbon Emission

Taking five urban agglomerations in the middle and lower reaches of the Yellow River as the research objects, this article studies the influencing factors and differences of carbon emissions of different urban agglomerations. Since the number of prefecture-level cities in urban agglomerations is small, using spatial weight matrix will cause measurement errors. This chapter adopts ordinary panel econometric model to analyze the influencing factors. The results are in the Table 6.

In the analysis of the impact of economic growth on carbon emission, the results of the Zhongyuan, Taiyuan, and Guanzhong Plain urban agglomerations are similar. When the primary term is included individually, per capita GDP has a significant positive impact on carbon emission. After adding the secondary term, the Environmental Kuznets Curve is inverted “U"-shaped curve. When the tertiary term is added, it conforms to the inverted “N"-shaped curve. By calculating the turning point and per capita GDP data, it can be seen that the per capita GDP data of the five urban agglomerations lie between the two turning points, where the carbon emission increases with the growth of economy. But it is close to the second turning point, which means that it will show a downward trend in carbon emission in the future.

The population has a significant positive effect on the Zhongyuan, Hubao Eyu and Taiyuan urban agglomerations, but the effect is not significant on the Shandong Peninsula and Guanzhong Plain urban agglomerations. The industrial structure has a significant positive effect on the Guanzhong Plain and Taiyuan urban agglomeration. Urbanization has different effects on carbon emissions in different regions. It has a significant negative effect on the Zhongyuan urban agglomeration, but has not a significant negative effect on the Shandong Peninsula urban agglomeration, and has a significant positive effect on the Taiyuan urban and the Hubao Eyu urban agglomeration. The positive effect of urbanization on Hubao Eyu urban agglomeration is not significant. Energy consumption per unit of GDP has a significant positive effect on carbon emission, but it has not a significant effect on the Guanzhong Plain urban agglomeration. The energy structure has a significant positive effect on the carbon emissions of the Zhongyuan, Shandong Peninsula and Guanzhong Plain urban agglomerations.

5 Conclusion

The study finds that the relationship between economic growth and carbon emission in the middle and lower reaches of the Yellow River shows an inverted N-shaped curve. The carbon emission of per capita GDP of the five urban agglomerations are all between two turning points, that means the carbon emissions locate on the rising stage where the emission increases with the increase of per capita GDP. It is close to the second turning point, which means that urban agglomerations should coordinate the relationship between economy and carbon emission to let the GDP beyond the second turning point, so that to reach the stage where carbon emission reducing with economic growth. The results of spatial panel analysis show that the carbon emissions of prefecture-level cities and influencing factors of carbon emission present spatial spillover effects. The influencing factors of different urban agglomerations are different. In areas with high carbon emission intensity, the industrial structure has a more significant impact on carbon emission. The urbanization rate, technological progress and energy structure have different effects on different urban agglomerations.

Through the analysis of the differences in carbon emissions and influencing factors of urban agglomerations, it is possible to propose some paths to reduce carbon emission, the methods can be based on different influencing factors such as economic growth, population and urbanization rate, industrial structure, technological progress, and energy structure. The Shandong Peninsula urban agglomeration and the Hubao Eyu urban agglomeration with high per capita GDP should use technology to promote sustainable economic development. The Zhongyuan urban agglomeration, Taiyuan urban agglomeration and Guanzhong Plain urban agglomeration should transform their economic development models to achieve economic sustainability. They also should develop low-carbon, energy-saving and emission reduction technologies, and coordinate the relationship between economic growth and carbon emission in the development process in the future. The upstream urban agglomerations should improve population quality through attracting high-quality talents, and actively implementing talent introduction strategies to promote effective use of resources. The urban agglomerations should optimize industrial structure, eliminate outdated production capacity, develop high-tech industries, and accelerate economic strategic adjustments. The urban agglomerations of the lower Yellow River should optimize the energy structure and develop new energy sources. There are resource-dependent cities in the upstream urban agglomeration, so the cities of these urban agglomerations should reduce high-energy-consuming industries during the development.

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