doi: 10.36689/uhk/hed/2022-01-083

Non-linear Relationship Analyses about Urbanization, Economic Growth and Carbon Emissions in China Based on Semi-parametric Fixed Effects Model

Li WANG[1*], Qian XIE[1*] and Fei XUE[2]

[1] School of Economics and Management, Northwestern University, Xi'an, China; wlily218@126.com; wfs528591875@foxmail.com
[2] University of Chinese Academy of Social Sciences, Beijing, China; 201620145@stumail.nwu.edu.cn
* Corresponding author: wlily218@126.com; wfs528591875@foxmail.com

Abstract: At present, China is in a period of important historical opportunity to achieve the goal of "peak carbon and carbon neutral" and consolidate the achievements of poverty eradication. So, it is important to investigate the changes of carbon emissions in the process of economic development and urbanization to achieve high-quality development. Based on the Kuznets curve hypothesis, using the China's provincial panel data from 1997 to 2018, the semi-parametric fixed-effects model was applied to simultaneously explore the nonlinear relationship about the three and their regional differences. The results illustrate that the trajectory of carbon emissions presents an inverted U-shape in the past economic development and urbanization process at the national level. There are significant differences in carbon emission trajectories among regions. The carbon emission Kuznets curve exists in the economic growth and urbanization of the eastern region, while it does not exist in the other two regions. In addition, carbon emissions in western region show a monotonically decreasing pattern with the advancement of urbanization.

Keywords: economic growth; urbanization; carbon emission Kuznets curve; semi-parametric fixed effect model

JEL Classification: R11

1. Introduction

China's GDP has exceeded 100 trillion by 2020, and the urbanization rate has increased from 17.9% in 1978 to 60.6% in 2019. However, it cannot be ignored that China's rapid economic growth in the past was mainly based on the model of high energy consumption, high pollution and high emissions. In 2020 alone, China emits 30.15% of the world's carbon, a whopping 10.251 billion tons. In order to achieve the synergy between high-quality economic development and high-level ecological protection, in September 2020, Chinese Government announced that China will strive to achieve peak CO2 emissions by 2030 and carbon neutrality by 2060. How to transform the economic development model and scientifically control carbon emissions has become an urgent issue. Specifically, different regions in China are at different stages of economic development and urbanization, which may have varying effects on carbon emissions. This paper discusses the influence of economic growth and urbanization on carbon emissions at both the national and regional levels, which is critical for China to tailor carbon reduction plans to local conditions and precision.

Interaction between economic development and environmental quality has always been a hot issue of concern to economists. In the 1990s, Grossman and Krueger (1991) first proposed that environmental pollution will increase with the growth of income at low-income levels, and decrease with income increase at high income levels. Panayotou (1993) calls this "inverted U-shaped" form between income and environmental deterioration the Environmental Kuznets Curve (EKC). Since then, the existence of EKC curves between different pollutants has been discussed extensively. It is generally agreed that economic growth is one of the largest drivers of carbon emissions, but there is clear divergence on the pattern of environmental Kuznets curve for carbon emissions (CKC). Most of studies reveal that the CKC curve present an "inverted U-shaped" (Saboori, 2013), "N-shaped" (Martínez-Zarzoso & Bengochea-Morancho, 2004) or monotonically rising shape (Azomahoua & Vanc, 2006).

Early studies on CKC patterns in China used national time-series data at most, and the findings concluded that the CKC curve was not valid in China (Hu et al.,2013). In recent years, the analysis using panel data mostly support the existence of an inverted U-shaped CKC curve at the national level (Li et al., 2016), but there are obvious differences in the curve shape and its inflection point location at the regional level (Xu & Song, 2013). In addition, some scholars have questioned this conclusion (He et al., 2012; Deng, 2014).

Another important direction of research on the CKC curve is incorporating other factors that affect carbon emissions into the CKC hypothesis' research framework. The level of urbanization has become a key element influencing carbon emissions as the urbanization process continues to progress in China. Early studies suggested that there is a straightforward linear relationship. Liddle and Nelson (2010) discovered a positive relationship, Fan et al. (2006) believed that urbanization can curb carbon emissions. In subsequent studies, scholars discovered that there may be a more complex nonlinear relationship between them. Wang et al. (2015) used semi-parametric fixed effects models to study the relationship between them in OECD countries, suggesting an inverted U-shaped relationship. Using geographic data analysis methods, Xiao et al. (2021) investigated the association of economic growth, air pollution and urbanization in the Yangtze River Delta, finding that the relationship is "positive U-shaped".

By combing through the relevant research literature, we find there is still room for expanding the research on the relationships about economic growth, urbanization and carbon emissions as follows: First, from the perspective of data acquisition, most of the data used by scholars are calculated from the emission factors recommended by the IPCC, which undoubtedly leads to an overestimation of carbon emissions (Liu et al., 2015). Therefore, we will use the latest provincial carbon emissions dataset (1997-2018) calculated by Shan et al. (2017), measuring China's carbon emissions more scientifically. Second, most of the research methods in existing literature make strong assumptions on model setting, which may lead to large "setting errors". Therefore, we propose to use a semi-parametric fixed-effects model to investigate the nonlinear link about the three. Finally, in terms of research substance, most literature focus on the relationship between economic growth and carbon emissions, only a few papers studied the influence of urbanization on carbon emissions. The relationships about them are addressed in depth in this research. Further, the regional heterogeneity is investigated by the STIRPAT model.

2. Data and Methodology

2.1. Model Building

The STIRPAT model is extended from the IPAT model (Dietz, 1997) proposed by Ehrlich and Holdren (1972), inheriting the advantages of simple form of model setting and breaking the constraint of linear influence of each factor on environmental quality. We take the STIRPAT model as a theoretical framework to study the nonlinear relationship among carbon emissions, economic growth and urbanization, the benchmark model is of the following form:

$$I_i = aP_i^b A_i^c T_i^d \varepsilon_i \tag{1}$$

where i represents regions. The variable I_i denotes environmental impact, P_i denotes demographic factors, A_i denotes affluence factors, and T_i denotes technical factors. a, b, c, d respectively represent the estimated coefficients of the corresponding variables, ε is the error term. To further test the existence of the CKC curve between them, The STIRPAT model is extended to include quadratic components for economic growth and urbanization variables. Based on this, the equation (1) is deformed as:

$$LnCE_{it} = \alpha_0 + \beta_1 LnP_{it} + \beta_2 LnA_{it} + \beta_3 (LnA_{it})^2 + \beta_4 LnEI_{it} + \beta_5 US_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{2}$$

$$LnCE_{it} = \alpha_0 + \beta_1 LnP_{it} + \beta_2 LnA_{it} + \beta_3 LnEI_{it} + \beta_4 US_{it} + \beta_5 US_{it}^2 + \delta_t + \mu_i + \varepsilon_{it} \tag{3}$$

where i is region and t is year, CE_{it} is the carbon emissions of province i in year t; P_{it} is the population size, representing the demographic factor; A_{it} is the per capita GDP, representing the degree of wealth, IE_{it} is the energy consumption intensity, representing the technical level; US_{it} is the urbanization rate; δ and μ respectively represent the time fixed effect and the regional fixed effect, α_0 is a constant term, and ε is a error term.

Under the above framework, we first use the parametric panel fixed effects model to inspection whether there is an CKC curve between them. Then, the semi-parametric fixed effects model proposed by Baltagi and Li (2002) is used to further test whether there is a nonlinear relationship between them. The model is as follows:

$$LnCE_{it} = \alpha_0 + \beta_1 LnP_{it} + f(LnA_{it}) + \beta_2 LnEI_{it} + \beta_3 US_{it} + \delta_t + \mu_i + \varepsilon_{it} \tag{4}$$

$$LnCE_{it} = \alpha_0 + \beta_1 LnP_{it} + \beta_2 LnA_{it} + \beta_3 LnEI_{it} + f(US_{it}) + \delta_t + \mu_i + \varepsilon_{it} \tag{5}$$

where the function $f(\bullet)$ represents the non-parametric estimator. In order to eliminate the fixed effect of the above equation, differential processing is performed on both sides of the equation:

$$LnCE_{it} - LnCE_{it-1} = \beta_1 (LnP_{it} - LnP_{it-1}) + [f(LnA_{it}) - f(LnA_{it-1})] + \beta_2 (LnEI_{it} - LnEI_{it-1}) + \beta_3 (US_{it} - US_{it-1}) + \varepsilon_{it} - \varepsilon_{it-1} \tag{6}$$

$$LnCE_{it} - LnCE_{it-1} = \beta_1(LnP_{it} - LnP_{it-1}) + \beta_2(LnA_{it} - LnA_{it-1}) +$$
$$\beta_3(LnEI_{it} - LnEI_{it-1}) + [f(US_{it}) - f(US_{it-1})] + \varepsilon_{it} - \varepsilon_{it-1} \quad (7)$$

Baltagi and Li (2002) use the function sequence $p^k(LnA_{it}, LnA_{it-1})$ and $p^k(US_{it}, US_{it-1})$ to approximately replace $[f(LnA_{it} - LnA_{it-1})]$ and $[f(US_{it} - US_{it-1})]$. $p^k(LnA_{it}, LnA_{it-1})$ and $p^k(US_{it}, US_{it-1})$ are the first k terms of the function series $[p^1(LnA_{it}, LnA_{it-1}), p^2(LnA_{it}, LnA_{it-1}), \cdots]$ and $[p^1(US_{it}, US_{it-1}), p^2(US_{it}, US_{it-1}), \cdots]$. The value of intercept α_i can be calculated after the β_i in equations (6) and (7) are estimated. We can obtain:

$$\hat{\mu}_{it} = LnCE_{it} - \hat{\beta}_1 LnP_{it} - \hat{\beta}_2 LnEI_{it} - \hat{\beta}_1 US_{it} - \hat{\alpha}_i = f(LnA_{it}) + \varepsilon_{it} \quad (8)$$

$$\hat{\mu}_{it} = LnCE_{it} - \hat{\beta}_1 LnP_{it} - \hat{\beta}_2 LnEI_{it} - \hat{\beta}_1 LnA_{it} - \hat{\alpha}_i = f(US_{it}) + \varepsilon_{it} \quad (9)$$

Finally, local linear regression is used to estimate $f(\bullet)$. What needs to be pointed out is that, drawing on the research of the existing literature, this paper chooses $k = 4$ for regression in the empirical analysis.

2.2. Variable and Data

We control the influence of demographic factors and technological factors on carbon emissions according to the STIRPAT model. The detailed variable settings are shown in Table 1.

1. Carbon emissions (LnEC). Because official data is limited, Shan et al. (2017) estimated the total carbon emissions of all provinces except Tibet and Taiwan based on the default emission factors provided by IPCC. So, we use their estimation results as the Carbon emissions data.
2. The degree of economic development (LnA). As is usual practice in the current research, using the logarithmic value of per capita GDP measures the amount of economic progress. Per capita GDP is adjusted to a constant price based on 1997 to exclude the effects of pricing factors.
3. Urbanization rate (US). The fraction of urban residents in each region's resident population is used to assess population urbanization. We use the findings of Chen and Zhou (2005) to repair and augment the urbanization data from 1997 to 2000 by the S-shaped logistic curve method.
4. Other variables. (1) Population factor (LnP). The logarithm of the permanent population in each region is used to express the population size. (2) Technical factors (LnEI). The logarithm of energy consumption intensity (the ratio of total energy consumption to real GDP) is used to measure the level of technology.
5. Data Sources. The initial sample is panel data from 1997 to 2018 of 30 China's provinces (municipalities and autonomous areas). Taking into account the missing data, Tibet is excluded from the sample. The original data were obtained from the China Statistical Yearbook, China Energy Statistical Yearbook, CEIC database and China Carbon Emissions Database (CEADs) in previous years. Descriptive statistics of the main variables are presented in Table 2.

Table 1. The detailed variables settings

Variable	Meaning	Formula
LnEC	Log value of carbon emissions	Ln (carbon emissions)
LnA	Log value of real GDP per capita	Ln (real GDP per capita)
US	Urbanization level	(urban permanent residents/ the permanent residents) ×100
LnP	Log value of permanent population	Ln (permanent population)
LnEI	Log value of energy consumption intensity	Ln (total energy consumption/real GDP)

Table 2. Descriptive statistics of main variables

Variable	Observations	Mean	SE	Minimum	Maximum
LnEC	660	5.076	0.881	1.974	6.816
LnA	660	9.683	0.794	7.712	11.506
LnA^2	660	94.395	15.369	59.472	132.398
LnP	660	8.149	0.764	6.207	9.337
LnEI	660	0.328	0.528	-0.740	1.648
US	660	49.029	15.889	21.530	89.610
US^2	660	2,655.875	1,764.793	463.541	8,029.952

3. Estimation Results

3.1. Benchmark Analysis

The regression results between economic growth and carbon emissions are shown in models (1) and (2) in Table 3. The results of Model (1) indicate that the coefficients of energy consumption intensity and population size are both significantly positive at the level of 1%. Specifically, carbon emissions will increase by 0.995% and 0.629% respectively with each 1% increase in population size and energy consumption intensity. The coefficient of urbanization is not significant at the level of 10%. In addition, the coefficient of economic growth and its quadratic terms are significant at 1% level, which implies an inverted U-shaped CKC relationship between the two.

The estimation results of Model (2) reveal the coefficients of the semi-parametric fixed-effects model remain significantly positive at the levels of 5% and 1% for population size and energy consumption intensity. The coefficients of urbanization are not significant, and their size and direction of the estimated coefficients have changed. Specifically, in the semi-parametric model, the coefficient of population size is larger, the coefficient of energy intensity is less than that of parametric model. Besides, the left panel of Figure 1 provides a proof that the fitted curves reveal gradually flatten. In summary, both models prove the existence of CKC curves between economic growth and carbon emissions.

The effects of urbanization on carbon emissions are shown by Models (3) and (4) in Table 3. The coefficients of population size, energy intensity, and economic growth do not change significantly by compared the outcomes of different model. However, the coefficients of the quadratic term of urbanization is significantly negative in the 10% level, indicating a non-linear relationship between the two. As reported in the right panel of

Figure 1, a semi-parametric fit of urbanization and carbon emissions demonstrates a clear inverted U-shape, and the former has a restraining effect on the latter when the urbanization rate exceeds 70%. The results indicate an inverted U-shaped CKC relationship between the two.

Table 3. Estimated of the impact of economic growth and urbanization on carbon emissions

	Economic growth	**Economic growth**	**Urbanization**	**Urbanization**
	Models (1)	**Models (2)**	**Models (3)**	**Models (4)**
c	-12.5995***		-9.1275***	
	(1.7103)		(1.2698)	
LnA	1.5462***		0.9709***	0.7256***
	(0.1830)		(0.0596)	(0.2175)
LnA^2	-0.0293***			
	(0.0084)			
LnP	0.6292***	0.8101**	0.5284***	0.6697**
	(0.1024)	(0.3423)	(0.1046)	(0.3393)
LnEI	0.9952***	0.4638***	1.0062***	0.4746***
	(0.0299)	(0.0577)	(0.0302)	(0.0571)
US	-0.0005	0.0041	0.0050	
	(0.0015)	(0.0046)	(0.0032)	
US^2			-0.0001*	
			(0.0000)	
Time fixed effect	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes
Observations	660	630	660	630
R^2	0.9731	0.5434	0.9727	0.5469

Note: (1) Standard errors are in parentheses; (2) ***, **, * represent the significance level of 1%, 5%, and 10% respectively.

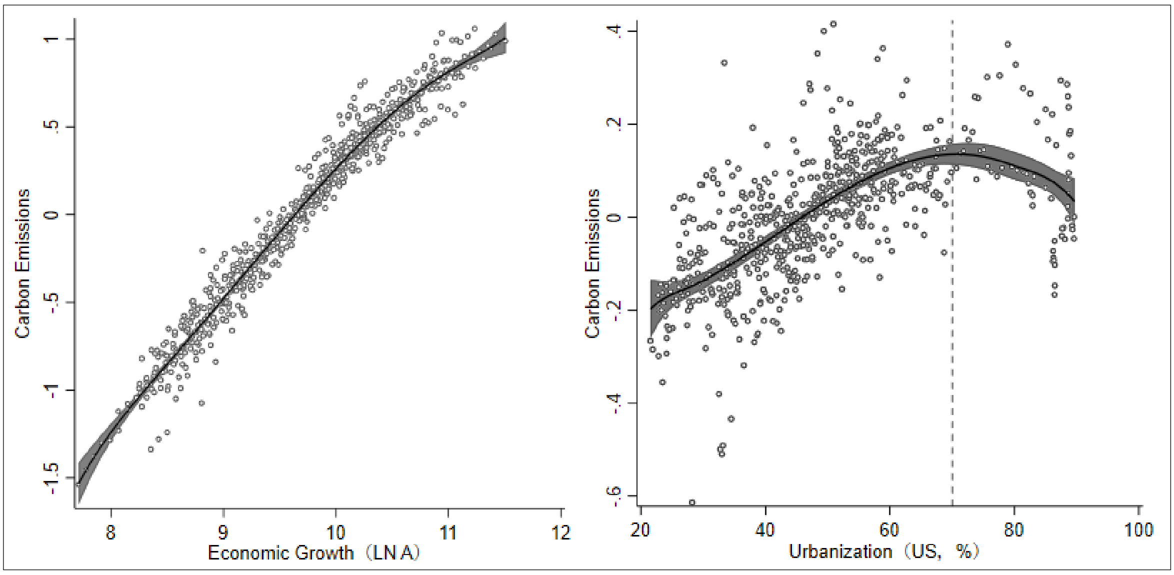

Figure 1. Semi-parametric fit plots of carbon emissions and economic growth (left), urbanization (right)

Note: The points in the figure are the estimated partial residuals of carbon emissions; the curve represents the fitted values of the adjusted effects of other explanatory variables in the model, and the shaded part represents the 95% confidence interval.

3.2. Spatial Heterogeneity

Considering the difference of industrial development and policy strength in different regions, sample is divided into three parts: eastern, central and western regions. We want to know whether there is spatial heterogeneity about the nonlinear relationship. When the sub-regional study was conducted, the panel type changed from short panel to long panel, and the three groups of models were tested to select the appropriate estimation method, the results are shown in Table 4.

The problems of groupwise heteroscedasticity, autocorrelation within panel and contemporaneous correlation present significantly in all regions, and autocorrelation within panel also presents in the eastern and central regions. Therefore, the comprehensive FGLS method is estimated for the eastern and western regions, and the PCSE method is estimated for the central region.

Table 4. Long panel model correlation test

	Groupwise heteroscedasticity			Autocorrelation within panel			Contemporaneous Correlation		
	Eastern	Central	Western	Eastern	Central	Western	Eastern	Central	Western
Economic Growth	224.96***	52.68***	591.09***	21.89***	1.81	3.91*	124.30***	48.76***	118.66***
Urbanization	252.42***	56.95***	574.38***	28.95***	1.89	3.92*	127.46***	58.73***	125.70***

Table 5. The impact of economic growth on carbon emissions: spatial heterogeneity

	Eastern		Central		Western	
	Models（1）	Models（2）	Models（3）	Models（4）	Models（5）	Models（6）
c	-12.9030***		-22.3742***		-22.0082***	
	(3.6824)		(3.7581)		(3.8172)	
LnA	2.0987***		3.2658***		1.8656***	
	(0.4503)		(0.8504)		(0.4447)	
LnA^2	-0.0576***		-0.1249***		-0.0454**	
	(0.0187)		(0.0457)		(0.0203)	
LnP	0.2004	0.8910*	0.9716***	0.7817	1.7874***	0.5035
	(0.1776)	(0.5017)	(0.2130)	(0.7434)	(0.2414)	(1.0210)
LnEI	0.7060***	0.2734**	0.7569***	0.7120***	0.7201***	0.4609***
	(0.0569)	(0.1064)	(0.0728)	(0.1247)	(0.0491)	(0.1084)
US	0.0031*	0.0071	-0.0065*	0.0190*	-0.0146***	-0.0127
	(0.0016)	(0.0058)	(0.0037)	(0.0097)	(0.0038)	(0.0140)
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	242	231	176	168	242	231
Adjusted R^2	-	0.6524	0.9899	0.6761	-	0.5109

Note: (1) Standard errors are in parentheses; (2) ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively.

Table 5 lists the impact of regional economic growth on carbon emissions. There is a significant positive impact from the population size in the central and western regions, but not in the eastern region. Urbanization has a significant negative impact in the western region but a positive impact in the eastern and central regions. The coefficients of energy consumption intensity do not differ significantly among regions. Overall, the estimation results indicate the presence of significant regional heterogeneity. The coefficients of economic growth and its quadratic term are significant in all three regions, suggesting the existence of the CKC curve in all regions.

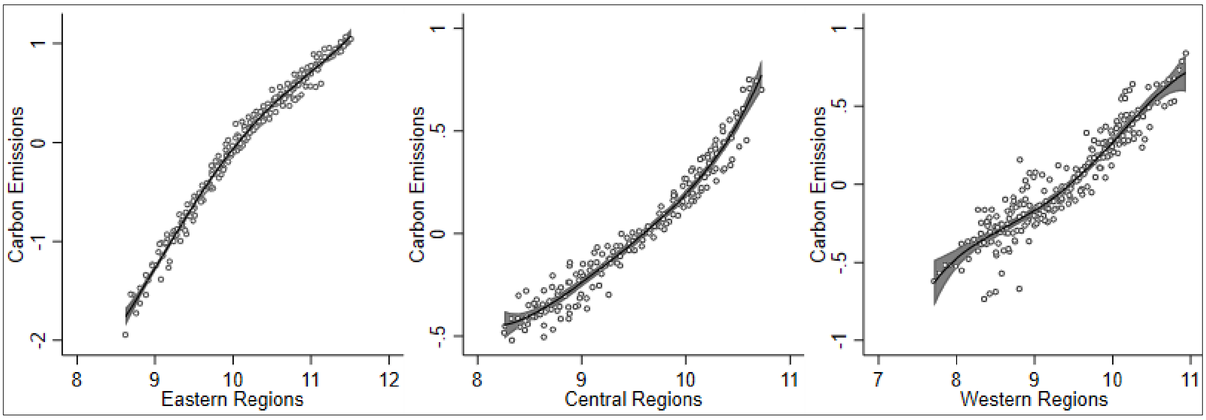

Figure 2. The impact of economic growth on carbon emissions: spatial heterogeneity

Note: The points in the figure are the estimated partial residuals of carbon emissions; the curve represents the fitted values of the adjusted effects of other explanatory variables in the model, and the 95% confidence interval is shaded.

We plotted semi-parametric fits of carbon emissions and economic growth for three regions, as shown in Figure 2. Figure 2 illustrates that the curve in the eastern region tends to flatten, meaning that it is close to the turning point of the CKC curve. While the economic growth in the western and central regions is still some way from reaching the turning point, remaining the cost of high pollution and high emissions.

Table 6 compares the regression results of the effect of urbanization on carbon emissions by regions. We can see, the effects of population size and energy consumption intensity are similar to the regression results in Table 5. The coefficients of urbanization and its quadratic term are significant and consistent with the CKC hypothesis in the eastern and central regions, indicating existence of the CKC curve between the two.

The semi-parametric fitting results as shown in Figure 3 provides a proof existing a clear inverted U-shaped relationship between carbon emissions and urbanization in the eastern region, but not the other two regions. In the eastern, taking the urbanization rate of 69% as the boundary, carbon emissions increase along with the urbanization rate before reaching the boundary. Conversely, it decreases. In the central region, differed significantly from those of the parametric regression, the right part of the curve is steeper than the left part, illustrating that the carbon emissions increase with the accelerated urbanization process. In western region, the fitted curve presents a decreasing trend and the right side is steeper than the left side, implying that carbon emissions decrease with the improvement of urbanization.

Specially, carbon emissions decrease faster when the urbanization rate over 55%, the reason may be that the urbanization process in western region realizes the spatial agglomeration of population, capital and technology generating economies of scale.

Table 6. The impact of urbanization on carbon emissions: spatial heterogeneity

	Eastern		Central		Western	
	Model（1）	**Model（2）**	**Model（3）**	**Model（4）**	**Model（5）**	**Model（6）**
c	-10.0278***		-14.6927***		-21.4582***	
	(0.9545)		(2.2814)		(3.4599)	
LnA	1.0804***	0.8904***	0.9200***	0.5362	1.1461***	0.5866
	(0.0584)	(0.3199)	(0.0996)	(0.4408)	(0.1230)	(0.4817)
LnP	0.3978***	0.6297	1.2975***	0.8491	2.0137***	1.1340
	(0.0809)	(0.5021)	(0.2074)	(0.7012)	(0.3087)	(0.9670)
LnEI	0.7291***	0.3073***	0.7712***	0.6812***	0.7386***	0.4596***
	(0.0521)	(0.1069)	(0.0768)	(0.1153)	(0.0497)	(0.1046)
US	0.0127***		0.0192***		0.0094	
	(0.0045)		(0.0052)		(0.0110)	
US^2	-0.0001**		-0.0003***		-0.0003**	
	(0.0000)		(0.0001)		(0.0001)	
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Regional fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	242	231	176	168	242	231
Adjusted R^2		0.6473	0.9900	0.6781		0.5183

Note: (1) Standard errors are in parentheses; (2) ***, **, and * indicate significance levels of 1%, 5%, and 10%.

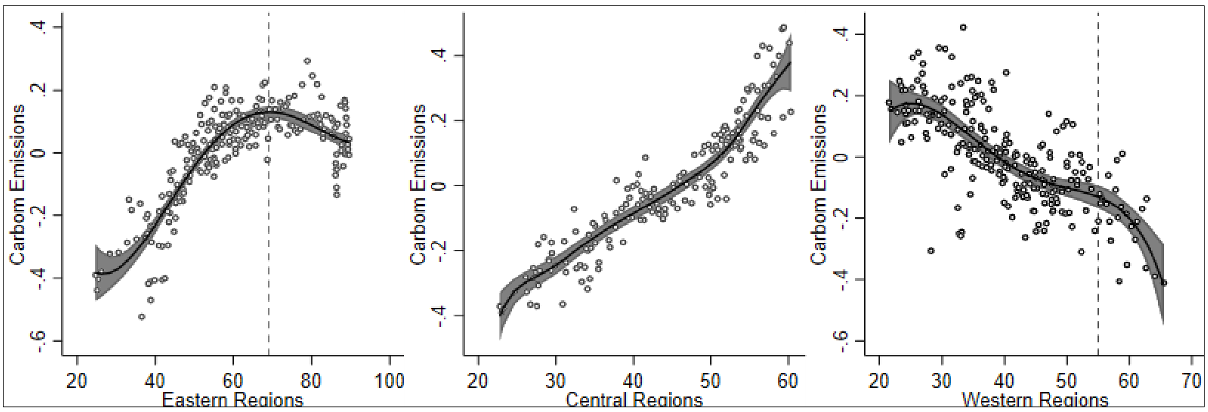

Figure 3. The impact of urbanization on carbon emissions: spatial heterogeneity

Note: The points in the figure are the estimated partial residuals of carbon emissions; the curves represent the fitted values of the adjusted effects of other explanatory variables in the model, and the 95% confidence interval is shaded.

4. **Conclusions**

Based on the carbon emission Kuznets curve hypothesis, this paper empirically investigates the nonlinear relationship about carbon emissions and economic growth, urbanization, using a semi-parametric fixed-effects model under the framework of the STIRPAT model by using the China's provincial panel data from 1997 to 2018. The results illustrate that the relationship about urbanization, economic growth and carbon emissions present an obvious U-shape at the national level, and carbon emissions decline with the rise of urbanization level when the urbanization rate crosses 70%. The regional level presents obvious heterogeneity. In addition, carbon emissions are also influenced by the size of the population and the intensity of energy consumption.

Based on the research results, we put forward some policy recommendations:

Firstly, with formulating and coordinating carbon emission reduction policies, it is essential to comprehensively consider the characteristics of different regions' economic development, resource endowments, and emission reduction potentials. The eastern region is near the inflection point of the CKC curve, meaning that it may be the first to realize the "decoupling" development of economic growth and carbon emission. Therefore, the eastern region might be treated with high standards and requirements to play a leading role. Conversely, the curves of the central and western regions maintain a monotonically rising trend, illustrating that they are still in the mid-stage of industrialization. Therefore, green low-carbon technologies should be actively developed and utilized to improve energy utilization efficiency, promoting the ecological civilization construction.

Secondly, we must practice the concept of green development with advancing the process of urbanization. The results of the study reveal that the scale effect on population, industry, technology and capital agglomeration have achieved roughly in the eastern region. Therefore, the eastern region should actively play the guiding function to promote the urbanization level of small and medium-sized cities crossing the inflection point. The central region should focus on the transformation and upgrading of resource-based cities and urban ecological management, increasing ecological environmental protection in the process of urbanization. The western region should continue to accelerate the new urbanization, improve infrastructure and enhance environmental management to improve the ecological carrying capacity of cities.

Conflict of interest: none

References

Azomahoua, T., & Vanc, L. P. N. (2006). Economic development and CO2 emissions: A nonparametric panel approach. *Journal of Public Economics*, *90*(6),1347–1363. https://doi.org/10.1016/j.jpubeco.2005.09.005

Baltagi, B. H., & Li, D. (2002). Series Estimation of Partially Linear Panel Data Models with Fixed Effects. *Annals of Economics and finance*, *3*(1), 103–116.

Chen, Y. G, & Zhou, Z. X. (2005). The stage division of urbanization logistic process and its spatial interpretation--a revision and development of Northam curve. *Economic Geography, 6*, 817–822.

Deng, X. L., Yang, Z. M., & Wu, Y. G. (2014). Do carbon emissions and economic development obey an inverted U-curve relationship--a reinterpretation of the environmental Kuznets curve hypothesis. *Finance and Trade Economics*, 2, 19–29.

Dietz, T., & Rosa, E. A. (1997). Effects of Population and Affluence on CO2 Emissions. *Proceedings of the National Academy of Sciences of the United States of America, 94*(1), 175–179. https://doi.org/10.1073/pnas.94.1.175

Ehrlich, P. R., & Holdren, J. P. (1972). *A Bulletin Dialogue on "The Closing Circle," Critique*. Bulletin of the Atomic Scientists.

Fan, Y., Liu, L. C., Wu, G., & Wei, I.-M. Analyzing impact factors of CO2, emissions using the STIRPAT model. *Environmental Impact Assessment Review*, *26*(4), 377–395. https://doi.org/10.1016/j.eiar.2005.11.007

Grossman, G. M., & Krueger, A. B. (1991). Environmental Impacts of a North American Free Trade Agreement. *Social Science Electronic Publishing, 8*(2), 223–250. https://doi.org/10.3386/w3914

He, X. G., & Zhang, Y. H. (2012). Factors influencing industrial carbon emissions and CKC restructuring effect in China: An empirical study of dynamic panel data by industry based on STIRPAT model. *China Industrial Economics*, *1*, 26–35.

Hu, Z. Y., Liu, Y. W., & Tang, L. W. (2013). Study on the Kuznets curve of carbon emissions in the context of low carbon economy. *Statistical Research, 30*(2), 73–79. https://doi.org/10.19343/j.cnki.11-1302/c.2013.02.010

Li, T., Wang, Y., & Zhao, D. (2016). Environmental Kuznets Curve in China: New evidence from dynamic panel analysis. *Energy Policy*, *91*(2), 138–147. https://doi.org/10.1016/j.enpol.2016.01.002

Liddle, B., & Nelson, D. R. (2010). Age-structure, urbanization, and climate change in developed countries: revisiting STIRPAT for disaggregated population and consumption-related environmental impacts. *Mpra Paper*, *31*(5), 317–343.

Liu, Z., Guan, D., Wei, W., et al. (2015). Reduced carbon emission estimates from fossil fuel combustion and cement production in China. *Nature*, *524*(7565), 335–338. https://doi.org/10.1038/nature14677

Martínez-Zarzoso, I., & Bengochea-Morancho, A. (2004). Pooled mean group estimation of an environmental Kuznets curve for CO2. *Economics Letters*, *82*(1), 121–126. https://doi.org/10.1016/j.econlet.2003.07.008

Panayotou, T. (1993). Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development. *ILO Working Papers* (992927783402676). International Labour Organization.

Saboori, B., & Sulaiman, J. (2013). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. *Energy Policy*, *60*(5), 892–905. https://doi.org/10.1016/j.enpol.2013.05.099

Shan, Y., Guan, D., Zheng, H., et al. (2018). China CO2 emission accounts 1997-2015. *Scientific Data*, *5*, 170201. https://doi.org/10.1038/sdata.2017.201

Wang, Y., Zhang, X., Kubota, J., et al. (2015). A semi-parametric panel data analysis on the urbanization-carbon emissions nexus for OECD countries. *Renewable & Sustainable Energy Reviews, 48*, 704–709. https://doi.org/10.1016/j.rser.2015.04.046

Xiao, Y. H., Hou, L. L., & Mao, Y. Y. (2021). Economic growth, urbanization and air pollution: An empirical study based on the Yangtze River Delta urban agglomeration. *Shanghai Economic Research*, *9*, 57–69.

Xu, G. Y, & Song, D. Y. (2013). An empirical study on the environmental Kuznets curve of carbon emissions in China--based on provincial panel data. *Chinese Journal of Population Resources and Environment*, *9*(3), *66–76*. https://doi.org/10.1080/10042857.2011.10685040