The Impact of Logistics Agglomeration on the Regional Heterogeneity of Carbon Emissions in Henan Province

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Abstract. Based on the panel data of 18 cities in Henan Province from 2011 to 2022, this paper constructs a multiple regression model to reveal the nonlinear relationship and spatial heterogeneity between logistics industry agglomeration and carbon emissions. The results show that: (1) there is a U-shaped relationship between the two areas, with the inflection point LQ=0.87, (2) the U-shaped trend is significant in high-level areas (β_2=0.051**), and the agglomeration in low-level areas continuously inhibits carbon emissions (β_1=-0.072***). (3) The spatial spillover effect is significant (ρ=0.132***), and core cities such as Zhengzhou have a radiative impact on the surrounding areas. Based on this, differentiated low-carbon transformation countermeasures are proposed, which provides an empirical basis for regional logistics planning.

Keywords: logistics agglomeration; carbon emissions; Fixed-effect model

1 Introduction

Under the "dual carbon" goal, the logistics industry, as a high-energy-consuming industry, is facing pressure to reduce emissions [1], and policy-driven industrial agglomeration may exacerbate the complexity of carbon emissions [2]. There are controversies in existing studies on agglomeration and environmental effects: the positive effect emphasizes the reduction of marginal emissions by economies of scale [3] ~ [4], the negative effect focuses on pollution caused by crowding [5], and the nonlinear theory (such as inverted U-shaped) further expands the cognitive boundaries [6]. However, the existing literature mostly focuses on the manufacturing industry, and the carbon emission mechanism of the logistics industry is not clear, especially the lack of spatial interaction effect and regional heterogeneity analysis.

However, there is still a gap in the research on carbon emissions in the logistics industry, especially the lack of region-specific analysis. This paper focuses on Henan Province and uses multiple regression and spatial panel models to reveal the "U" shaped relationship and regional heterogeneity between logistics industry agglomeration and carbon emissions. To fill the gap in the empirical evidence of carbon emissions in the logistics industry, the conclusions of this study can help coordinate the goals of

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industrial intensification and low-carbonization and empower the ecological protection strategy of the Yellow River Basin.

2 Research Methods

2.1 Model Building

Establishing a Fixed-Effect Model:

$$CEI_{it} = c + \beta_1 LQ_{it} + \beta_2 LQ_{it}^2 + \beta_3 X_{it} + u_i + v_t + e_{it} \quad (1)$$

Among them, CEI is the carbon emission intensity of the logistics industry, $LQ$is the location entropy of the logistics industry, X is the control variable, and the $U_i$and $V_t$are fixed effects of individual and time, respectively.

Spatial Durbin Model (SDM): To capture the spatial spillover effect, the spatial lag term and the spatial interaction term are introduced:

$$CEL_{it} = \rho WCEL_{it} + \beta_1 LQ_{it} + \beta_2 LQ_{it}^2 + \theta_1 WLQ_{it} + \theta_2 WLQ_{it}^2 + \beta_3 X_{it} + u_i + v_t + \epsilon_{it} \quad (2)$$

In the formula, W is the spatial weight matrix, which is constructed based on the dual dimensions of geographical distance and economic distance: the geographic distance matrix: the Euclidean distance is calculated by the latitude and longitude of the administrative center of each prefecture-level city by using the inverse distance weight method; Economic distance matrix: The reciprocal of the difference in GDP per capita is used as the weight, i.e., $W_{ij} = 1/|GDP_i - GDP_j|$. The spatial autocorrelation test showed that there was a significant spatial dependence on the carbon emissions of the logistics industry in Henan Province (I=0.217, p<0.01), which verified the necessity of the spatial model.

2.2 Indicator Selection and Data Sources

Core explanatory variable: Agglomeration level of the logistics industry. This paper selects the location entropy coefficient to calculate the agglomeration degree of the logistics industry in Henan Province. Location entropy can be used to analyze the level of industrial specialization. By analyzing the degree of industrial agglomeration in different regions, the position of the industrial agglomeration situation in that region in the country can be determined:

$$CEI = \sum_{i=1}^{n} CEI_i = \sum_{i=1}^{n} E_i \times NCV_i \times CEF_i \times COF_i \quad (3)$$

$$LQ_{it} = \frac{e_{it} / E_{it}}{n_t / N_t} \quad (4)$$

Control variable:(1) level of economic development (GDP), (2) intensity of government intervention (GI), and (3) transportation infrastructure (TIRS).

The data in this paper are from the Henan Statistical Yearbook from 2011 to 2022, and the missing data are supplemented by interpolation method and mean method. The descriptive statistics of the variables are shown in Table 1:

Table 1. Descriptive statistics

variable	Variable Code	Sample Size	Mean	Standard Deviation	Minimum	Maximum
Carbon emissions	*CEI*	216	30.34	14.57	7.40	75.15
Agglomeration level	*LQ*	216	0.60	0.28	0.11	1.83
level of economic development	*GDP*	216	4.451	1.928	1.294	10.45
Intensity of government intervention	*GI*	216	0.15	0.04	0.04	0.23
Transport infrastructure	*TIRS*	216	14.00	8.82	2.22	40.24

3 Empirical Analysis

3.1 Temporal Variation Characteristics

From 2011 to 2022, the carbon emission intensity of Henan Province decreased, and the agglomeration level of the logistics industry increased (Figure 1).

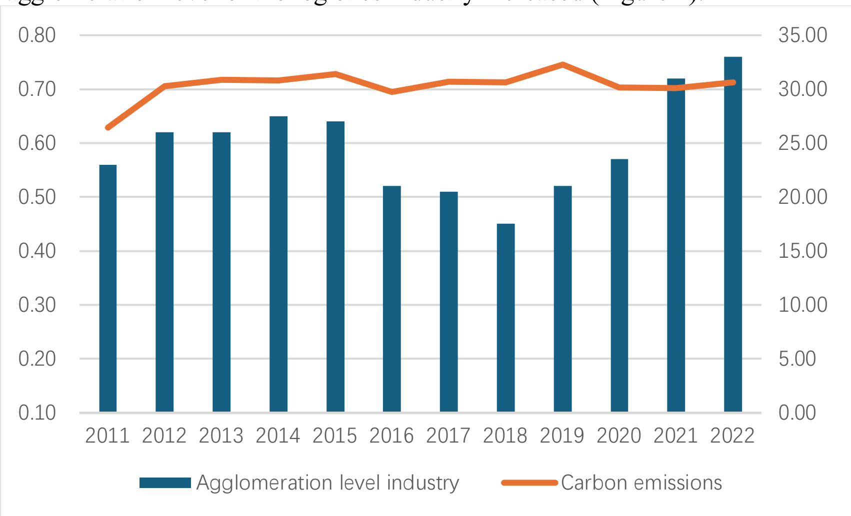

Fig. 1. Average carbon emissions and agglomeration level of the logistics industry

3.2 Correlation Analysis

Figure 2 shows a "U" shaped trend between LQ and CEI. Further verify its statistical significance by following these steps: The quadratic coefficient test: the LQ^2 coefficient in model (1) is 0.051 ($p<0.01$), indicating that there is a U-shaped inflection point. Inflection point calculation: obtained from $\partial CEI/\partial LQ=0$ to $-LQ*=-\beta 1/(2\beta 2)=0.87$, and the sub-sample robustness test showed that the quadratic term was significant ($p<0.01$) in the high-level area and only the one-time term was significant in the low-level area (Table 2), which supported the heterogeneous U-shaped relationship.

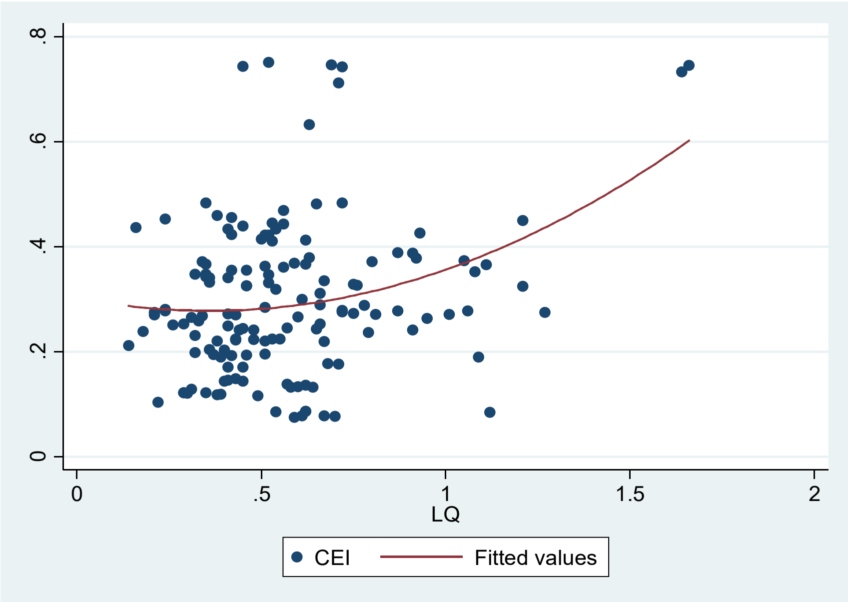

Fig. 2. Scatter plot and fitting trend line of LQ and CEI

3.3 Heterogeneity Analysis

Taking the median per capita GDP in 2022 (45,000 yuan/person) to divide the sample, the regression results are shown in Table 2:

High-level areas: the quadratic term coefficient is 0.051 ($p<0.01$), and the accumulation after the U-shaped inflection point pushes up carbon emissions; Low-level areas: the primary term coefficient is -0.072 ($P<0.01$), and the agglomeration continues to inhibit carbon emissions. Spatial spillover effect: The SDM model (2) shows that the spatial lag term coefficient $\rho=0.132$ ($p<0.01$), indicating that there is a positive interaction between the carbon emissions of neighboring cities, and high-agglomeration cities such as Zhengzhou have a significant radiation effect on the surrounding areas.

Table 2. Heterogeneous regression results

variable	Level	Low
LQ^2	0.051***	0.005
	(4.29)	(0.26)
LQ	-0.089***	-0.072***
	(-4.28)	(-4.48)
GDP	0.045	0.025
	(1.37)	(0.56)
GI	0.431*	0.711***
	(2.33)	(6.22)
TIRS	-0.120	-0.036
	(-0.49)	(-0.63)
_cons	0.237***	0.196***
	(5.46)	(12.25)
N	96.000	120.000
r2	0.327	0.484
r2_a	0.269	0.449

4 Conclusions and Countermeasures

4.1 Conclusions

Based on theoretical research, this paper analyzed the panel data of 18 prefecture-level cities in Henan Province from 2010 to 2022 using statistical analysis software. Meanwhile, an empirical analysis was conducted on the relationship between the agglomeration of the logistics industry and the carbon emissions of the logistics industry in Henan Province through a multiple regression model, and the following conclusions were drawn:

First, based on the calculation results of the location entropy index, it can be concluded that: The agglomeration level of the logistics industry in Henan Province is not high. Secondly, based on the overall regression results, it can be concluded that there is a "U" -shaped relationship between the agglomeration of the logistics industry and the carbon emissions of the logistics industry in Henan Province.

Thirdly, according to the heterogeneity regression analysis: The impact of logistics industry agglomeration in Henan Province on logistics industry carbon emissions shows regional heterogeneity: In regions with a higher level of economic development, there is a "U" -shaped relationship between logistics industry agglomeration and logistics industry carbon emissions, while in regions with a lower level of economic development, logistics industry agglomeration can reduce carbon emissions.

Fourth, in terms of control variables, the level of economic development and government intervention can increase carbon emissions, but the impact of transportation infrastructure on carbon emissions is not significant.

4.2 Countermeasures

(1) Enhance the quality of logistics industry agglomeration: Promote the transformation from extensive growth to intensive growth and strictly control high energy consumption and high pollution projects. Increase investment in research and development of energy conservation and emission reduction technologies, encourage cooperation among industry, academia and research institutions, and introduce and optimize advanced foreign technologies. Build core logistics industrial clusters, promote the concept of green logistics, develop multimodal transport and new energy vehicles, and drive the logistics industry towards low-carbon development.

(2) Strengthen regional differentiated management and enterprise division of labor and collaboration: Formulate differentiated policies based on the characteristics of different regions. High-demand regions should develop high-end logistics services (such as cold chain logistics and smart logistics), ecologically fragile areas should increase environmental protection investment, and central and western regions should strengthen infrastructure construction. Enterprises, in accordance with their division of labor and collaboration, reduce resource waste and lower carbon emissions.

(3) Optimize the logistics industrial structure and give full play to the collaborative role of the market and the government: Use green financial tools to support the green development of logistics enterprises and encourage investment in green technologies. The government has introduced energy conservation and emission reduction policies, promoted industrial transformation and upgrading, increased subsidies for new energy vehicles and green warehousing facilities, and facilitated the low-carbon transformation of the energy structure.

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