Research on the Impact of Urban Agglomeration Spatial Structure on the Innovation Capacity of the New Energy Vehicle Industry

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Abstract. As a new productive force, new energy vehicles have the characteristics of high technology, high efficiency, and high quality, which are in line with the advanced productive state of the new development concept. The spatial structure is related to whether the innovative elements of the new energy vehicle industry can be effectively organized, allocated, and produced within the city. This article takes the Beijing Tianjin Hebei Urban Agglomeration, Yangtze River Delta Urban Agglomeration, Chengdu Chongqing Urban Agglomeration, and Pearl River Delta Urban Agglomeration as research objects. Based on fused corrected DMSP/OLS and NPP-VIIRS night light data, it examines the impact of spatial structure on the innovation capacity of the new energy vehicle industry, and explores the transfer of innovation capacity within urban agglomerations, and predicts possible future development paths.

Keywords: new energy vehicles; innovation capability; spatial structure; influence factor; state transition.

1. Introduction

As a technology-driven industry, the development of new energy vehicles is inextricably linked to technological innovation. Existing research on the innovation capabilities within the new energy vehicle industry primarily addresses technological characteristics, innovation entities, and social environments. Urban agglomerations, as a highly concentrated form of economic spatial organization, are replacing traditional industrial development patterns that focus on geographic scales such as municipal and provincial areas. They have become pivotal spaces for gathering technological talent, driving innovative growth, establishing emerging technological hubs, and promoting the advancement of new energy vehicles. While the existing literature provides a certain level of academic insight for this paper, there is a lack of scholars who have integrated urban spatial structures with the innovation capabilities of the new energy vehicle industry within the same analytical framework. Therefore, this paper conducts a heterogeneity analysis to explore how urban spatial structures influence the innovation capabilities of the new energy vehicle industry under varying degrees of topography, within different urban agglomerations, and across different levels of economic development. This research aims to enrich the discourse in the relevant fields and aspires to offer new perspectives for regional strategic planning in the new energy vehicle industry, identifying suitable areas for development to enhance the industry's innovation capabilities.

2. Research Design

2.1 Model Construction

This paper aims to explore the impact of urban agglomeration spatial structure on the innovation capabilities of the new energy vehicle industry. To achieve this, a baseline regression model is constructed as follows:

$$innovx_{ijt} = \alpha_0 + \alpha_1 stru_{i,j,t} + \alpha_2 X_{i,j,} + \mu_i + \gamma_j + \theta_t + \varepsilon_{ijt} \tag{1}$$

Where i denotes the section unit of a single city level, j denotes the the section unit of the city level; t denotes the year. "Innov" denotes the dependent variable; "Stru" denotes the primary independent variable; and "X" denotes the control variables. The symbols μ and γ indicate individual fixed effects that do not vary over time; θ indicates time fixed effects that do not change across individuals. ε denotes the random error term. To mitigate heteroscedasticity, logarithmic transformations have been applied to certain indicators. In order to address heteroscedasticity, a logarithmic transformation was implemented on specific indicators.

To further explore the nonlinear relationship , this paper references scholar Hansen's methodology for grouping and estimating model parameters. This approach minimizes the sum of squared residuals to establish a threshold value and test the significance of this threshold using the "bootstrapping method" [37]. Considering the research content of this article and the nature of the variables., the model is constructed as follows:

$$\begin{aligned} innov_{it} &= \mu_i + \alpha_1 Control_{it} + \beta_1 stru_{it} D(lngdp_{it} \quad \eta_1) + \\ &\beta_2 stru_{it} D(\eta_1 < lngdp_{it} \quad \eta_2) + \\ &\cdots + \beta_n stru_{it} D(\eta_{n-1} < lngdp_{it} \quad \eta_n) + \beta_{n+1} stru_{it} D(lngdp_{it} > \eta_n) + \mu_{it} \end{aligned} \tag{2}$$

Where innov denotes the dependent variable; stru denotes the core explanatory variable; i and t denotes the ith city and the tth year ; η_1、$\eta_2 \cdots\cdots \eta_n$ denotes the threshold values at different levels; $Control_{it}$ deonotes other control variables; $lngdp_{it}$ denotes threshold variable; μ_{it} denotes random perturbation term.

2.2 Variable Declaration

In light of the data accessibility and drawing upon scholarly research, this paper quantifies the innovation capacity of the new energy vehicle sector within urban clusters by examining the volume of patent applications for new energy vehicles in urban locales. This paper adopts the measurement approach established by Meijers & Burger and utilizes the rank-size methodology to evaluate the spatial structure index across four prominent urban agglomerations, as elaborated below:

$$lnP_i = C - qlnR_i \tag{3}$$

Where P_i denotes the mean of the nighttime light data for the ith city; R_i denotes the ranking of the i-th city's nighttime light data mean; C denotes a constant term; q denotes the regression coefficient. As the value of q diminishes, the internal spatial configuration of urban agglomerations increasingly adopts a polycentric model; conversely, an increase in q corresponds to a trend towards a monocentric structure. To address challenges associated with the endogeneity of statistical research data, this paper utilizes a spatial structure index derived from the harmonized and calibrated DMSP/OLS and NPP/VIIRS nighttime light datasets as the principal explanatory variable. To mitigate the impact of external factors, this research incorporates urban common characteristic variables as control variables, detailed as follows:

Table 1. Index selection

Variable	Index	Symbol	Variable Declaration
Explained variable	Innovation ability of new energy automobile industry	innov	ln(Number of patents granted for new energy vehicles in the region)
Explanatory variable	Space structure	stru	Logarithm of average value of lighting brightness in the region/Logarithm of ranking of urban lighting brightness in the region.
Control	Popularization of new	nev	ln(Number of new energy vehicles in the region)

variable	energy vehicles		
	Innovation level of urban agglomeration	patent	ln(Number of patents granted in the region)
	Level of economic development	gdp	ln(Gross domestic product in the region)
	Openness	eop	Proportion of total import and export volume to GDP in the region
	government intervention	gov	Proportion of government revenue and expenditure to GDP
	human resources	hum	The number of college students accounts for the total population
	Urban agglomeration scale	siz	ln(Total population of municipal districts)
	Higher education level	ns	Ln(Number of colleges and universities)
	infrastructure	Infra	ln(Internet users)

3. Demonstration Analysis

3.1 Benchmark Regression

This paper utilizes panel data from four major urban agglomerations between 2017 and 2021. Table 2 presents the baseline regression results concerning the impact of spatial structure on the innovative capacity of the new energy vehicle industry. When no control variables are included, the coefficient indicating the influence of spatial structure on the innovative capacity of the new energy vehicle industry is significantly negative at the 1% level, suggesting that a monocentric spatial structure within the region may adversely affect the innovative capacity of the new energy vehicle sector. Building upon this, control variables are incorporated, alongside the implementation of time fixed effects.

Table 2. The result of Benchmark regression

innov	(1)	(2)	(3)
stru	-0.428*** (0.092)	-0.028** (0.012)	-0.024** (0.012)
Urban fixed effect	Y	N	Y
Fixed year effect	Y	Y	Y
Sample size	325	325	325
R2	0.365	0.363	0.275

Note: *p<0.1, **p<0.05, ***p<0.01; the values in parentheses represent robust standard errors. Unless otherwise specified, the following table is consistent with this note.

According to the results presented in column (3), the coefficient indicating the influence of spatial structure on the innovation capacity of the new energy vehicle industry is -0.024, and it is statistically significant at the 5% level. As the coefficient of urban agglomeration spatial structure increases, the respective urban agglomeration tends to adopt a single-center structure; conversely, as the spatial structure coefficient decreases, it leans towards a multi-center structure. This suggests that, at the present stage, a decentralized configuration is more conducive to the development of innovation capabilities within the new energy vehicle industry, a point well-supported by evidence from the Yangtze River Delta urban agglomeration. The new energy vehicle sector began to experience rapid growth in 2020, with its penetration rate initially increasing at a slow pace. This growth necessitates not only that central cities leverage their agglomeration effects for theoretical research innovations at high-density spatial scales but also that sub-central regions engage in innovative practical verification at lower-density spatial scales.

3.2 Heterogeneity of Topographical Gradients

The previous research demonstrates that a multicentric spatial configuration can significantly enhance the innovation capabilities within the new energy vehicle sector. Nonetheless, some researchers argue that effective innovation research and development requires a robust agglomeration effect. This paper examines the heterogeneous impacts influenced by regional topographical characteristics, quantifying the median of the standard deviation of slopes for 65 cities spanning the years 2017 to 2021, referred to as median_iv. This median serves as a criterion for categorizing urban cluster samples. When iv is less than or equal to median_iv, it is assigned a value of 1; if not, it is assigned a value of 0. The findings, illustrated in Table 5, indicate that a standard deviation of slopes beneath the median correlates negatively with the innovation capabilities of the new energy vehicle sector at a 10% statistical significance threshold. Conversely, a standard deviation that exceeds the median reveals a significant positive correlation. Notably, utilizing Handan as a reference point, a multicentric spatial framework is more beneficial for enhancing the innovation capabilities within the new energy vehicle industry when the standard deviation of slopes is under 8.50. However, when this standard deviation surpasses 8.50, a monocentric spatial structure significantly supports the innovation process.

Table 3. Heterogeneity Analysis

variable	iv<=median_iv	iv>=median_iv
stru	-1.091* (0.516)	1.169*** (0.421)
Control variable	Y	Y
Urban fixation	Y	Y
Fixed time	Y	Y
Adj R-squared	0.899	0.950

3.3 Heterogeneity of Development Level

The spatial configuration plays a crucial role in shaping the innovative potential of the new energy vehicle sector. When examining absolute coefficients, it becomes evident that multi-centered urban agglomerations experience a more pronounced impact from spatial structure than their single-centered counterparts. This observation prompts an investigation into the possibility of nonlinear relationships among the variables involved. To explore this, this paper considers spatial structure (stru) as the principal explanatory variable, while utilizing lngdp as the threshold variable. It analyzes comprehensive data from the four major urban agglomerations to develop a threshold effect model.

Table 4. The Results of Threshold Effect (1)

Threshold	RSS	MSE	F statistics	P-value	BS times
Single threshold	0.490	0.002	131.560***	0.000	500.000
Double threshold	0.442	0.001	34.910*	0.076	500.000

As illustrated in Table 4, the threshold variable related to industrial structure demonstrates significance at both the 1% and 10% levels within the frameworks of the single and double threshold models, respectively. To enhance our understanding of the estimation of the threshold values and their associated confidence intervals, this paper examine the likelihood ratio function pertinent to the threshold model, as presented in Figure 8. In accordance with the single and double threshold models, the likelihood ratio (LR) statistics for the threshold value estimations at the delineated 1% and 10% significance levels remain below the baseline value. This indicates that this paper cannot reject the null hypothesis concerning the significant presence of the threshold value, suggesting a nonlinear interrelationship among the examined variables.

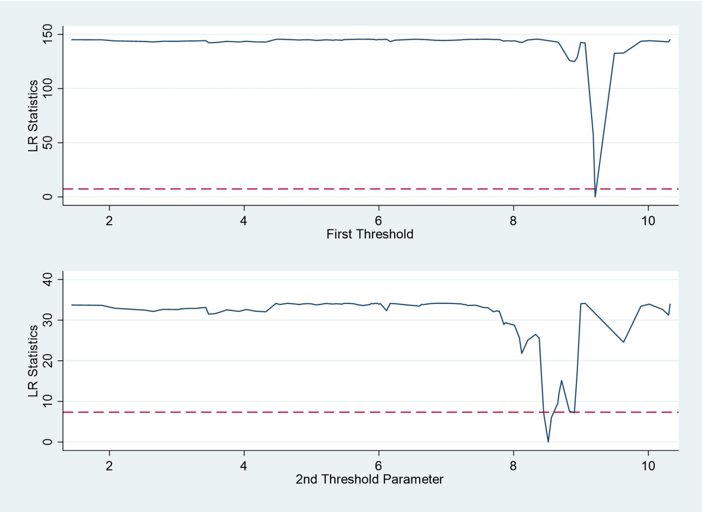

Figure 1: Curves of the likelihood ratio (LR) statistic for single and double thresholds (with "stru" as the independent variable).

As illustrated in Table 5, when the logarithm of GDP (lngdp) is less than or equal to 8.514, the spatial structure index (stru) demonstrates an insignificant effect on the innovation capacity of the electric vehicle sector within urban agglomerations, recording a coefficient of -0.0006. In the range of lngdp between 8.514 and 9.210, the spatial structure index reveals a robust and significant positive relationship with the electric vehicle industry at the 1% significance level, with a coefficient of 0.099***. When lngdp surpasses 9.210, the influence of the existing spatial structure of urban agglomerations on the innovation potential of the electric vehicle sector intensifies significantly, with the coefficient increasing to 0.987***, and achieving notable statistical significance at the 1% level. These findings indicate that at lower economic tiers, the spatial structure exerts a negative and statistically insignificant impact on industry innovation, which implies that these regions may be deficient in the necessary infrastructure, resources, and conducive environment for effective spatial structure performance. As economic development advances, the spatial structure begins to contribute to the promotion of technological innovation. Once economic development achieves a critical threshold, an appropriate spatial structure substantially accelerates the progress of technological innovation.

Table 5. The Results of Threshold Effect (2)

Explained variable	Threshold variable	range	coefficient	P-value
stru	lngdp	lngdp≤8.514	-0.0006	0.45
		8.514＜lngdp≤9.210	0.099	0.000***
		lngdp＞9.210	0.987	0.000***

4. Summary

The paper utilizes theoretical frameworks, benchmark regression analysis, threshold effect examination, and additional methodologies to arrive at several key conclusions: Centralized regions bolster the innovation capacities of the new energy vehicle sector through agglomeration phenomena, while decentralized regions achieve this through diffusion dynamics. Urban agglomerations create a cyclical mechanism for innovation via regional intelligent distribution systems and industrial planning. A multi-centered urban configuration is more beneficial for enhancing innovation capabilities within the new energy domain, with the innovation intensity of the new energy vehicle sector in multi-centered metropolitan areas—especially those led by the Yangtze River Delta—being notably shaped by spatial organization. The progression of new energy vehicles has significantly diverged from the initial industrial growth paradigm, which was primarily characterized by resource accumulation, thereby necessitating collaborative efforts across various regions and sectors as a pivotal factor driving its expansion. At lower stages of economic development, the spatial dynamics exert minimal influence on the industry’s innovation output; conversely, once economic growth attains a certain threshold, an optimized spatial framework considerably accelerates the pace of technological innovation.

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