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The Relationship between the Construction of Transportation Infrastructure and the Development of New Urbanization

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Abstract: Transport infrastructure plays a crucial role in facilitating the high-quality development of new urbanization. Based on the provincial panel data of 31 provinces in China from 2013 to 2020, this study empirically analyzed the impact and mechanism of transportation infrastructure on the high-quality development of new urbanization from multiple perspectives. The results showed that transportation infrastructure can significantly promote the development of new urbanization, and the promoting effect was significantly positive in the eastern and western regions, while it was positive but not significant in the central region. Transportation infrastructure can promote the development of new urbanization by promoting industrial agglomeration. When the population density is lower than the corresponding threshold value, the transport infrastructure can significantly promote the development of new urbanization; when the population density is higher than the corresponding threshold value, the transport infrastructure will significantly hinder the development of new urbanization. Transport infrastructure has a significant positive spatial spillover effect on the development of new urbanization, and the positive spatial spillover effect has been significant in the eastern, central and western regions.

Keywords: transportation infrastructure; new urbanization; industrial agglomeration; population agglomeration; spatial spillover effects

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1. Introduction

The rapid urbanization in China has led to the necessity of a new form of urbanization, which is now a crucial strategic initiative for the country's economic and social advancement. The concept of 'new urbanization' was officially introduced at the 18th National Congress of the Communist Party of China, focusing on integrated urban–rural development, efficient land use, ecological livability, and harmonious growth [1]. Emphasizing a 'people-oriented urbanization' approach, it underscored ecological sustainability and the enhancement of urban capacity during the process of urbanization. The '14th Five-Year Plan' for the implementation of new urbanization specifically highlighted the significance of improving integrated transportation networks. The success of new urbanization's six core elements heavily depends on a robust transportation infrastructure. Serving as a crucial link connecting various production factors, transportation infrastructure is not only a key aspect of the new urbanization strategy but is also a fundamental requirement for its successful implementation [2]. The development of transportation infrastructure, including urban transportation, is intricately intertwined with land use and urban planning, demonstrating a symbiotic relationship [3]. The construction of transportation infrastructure improves urban connectivity, the convenience of transportation, and economic vitality, facilitating the population's mobility [4], resource allocation, and sustainable urban development. This plays a crucial role in the progression of new urbanization [5]. Analyzing the effects and mechanisms of transportation infrastructure on new urbanization not only helps in evaluating its role in urban growth but also provides valuable insights for optimizing urban planning, enhancing operational efficiency, improving residents' quality of life, and fostering sustainable urban development.

2. Literature Review

This study examined the influence of transportation infrastructure on the high-quality advancement of new urbanization. Through a review of the existing literature, relevant research was categorized into three main themes for discussion.

Firstly, research on the connotation and level of development of new urbanization revealed a distinct departure from traditional urbanization, focusing on a 'people-oriented urbanization' approach to enhance quality of life, well-being, and inclusive prosperity [6]. This concept emphasizes coordinated urban–rural development, industry–city integration, and comprehensive benefits [7]. The 'National New Urbanization Plan (2014–2020)' introduced a comprehensive evaluation index system with primary indicators such as urbanization, infrastructure, resources, the environment, and public services, supported by 18 secondary indicators. Scholars such as Xiong Xianghui and Xu Zhangyong have developed index systems for new urbanization based on dimensions such as the population, industry, and space, utilizing factor and principal component analysis [8]. Zhao Minning et al. created an evaluation index system focusing on population-based urbanization, spatial urbanization, and economic urbanization, evaluating land use intensity and levels of new urbanization [9]. Zhou Liang et al. established an evaluation index system based on functional layers such as population-based urbanization, economic urbanization, land urbanization, and social urbanization [10]. Zhou Jian and Deng Jingjing constructed an index system covering aspects such as population-based urbanization, economic development, improvements in livelihood, integration of rural migrant workers, population–environment symbiosis, public services, infrastructure, public participation, and urban–rural coordination [11].

Secondly, scholars both domestically and internationally have extensively researched the impact of transportation infrastructure across three key dimensions: economic, social, and environmental. Aschauer's seminal work in 1989 was among the first to explore the link between infrastructure and economic growth, highlighting how public investment in infrastructure can enhance overall productivity [12]. The development of transportation infrastructure plays a crucial role in driving regional economic growth through mechanisms such as creating multiplier effects, generating employment opportunities, and spurring growth in related industries [13]. Enhancements in transportation infrastructure facilitate factor mobility [14], enhance the efficiency of resource allocation, and catalyze upgrades in the industrial structure through mechanisms such as division of labor, learning effects, and convergence effects, ultimately fostering economic development [15]. Furthermore, studies have identified the spatial spillover effects of transportation infrastructure on economic growth [16,17]. In terms of social impact, transportation infrastructure influences various aspects of daily life, including the methods, time, and costs of travel. Research in this area has often delved into how transportation infrastructure impacts quality of life [18], social welfare [19], and social equity. With regards to the environmental implications, scholars have generally argued that during the construction and operation of transportation infrastructure, environmental issues such as air pollution [20], noise pollution, water pollution, land degradation [21,22], and ecological harm are prevalent. Scholars have typically focused on the effects of transportation infrastructure on environmental quality and sustainable development.

Thirdly, research has shown that transportation infrastructure plays a fundamental pioneering, leading, and service role in the development of new urbanization [2]. Scholars generally believe that transportation infrastructure can promote the development of new urbanization [23], driving the development of new urbanization through its multiplier effects, improving the quality of new urbanization by increasing the road network's density and regional accessibility [24]. Transportation infrastructure is an important carrier of the population's mobility, and the accessibility and convenience of transportation can greatly promote the population's migration, reduce the time and cost of the population's mobility, and promote the population's urbanization [25].

The existing literature has highlighted the significant influence of transportation infrastructure on economic and social development. However, there is a scarcity of empirical studies specifically focusing on the impact of transportation infrastructure on the development of new urbanization, with a lack of in-depth analysis on the underlying mechanisms of this impact. The study makes significant contributions in several areas. Firstly, it constructed a comprehensive evaluation system for new urbanization based on the concept of new urbanization. It then analyzed the impact of transportation infrastructure on the development of new urbanization. Secondly, the study explored whether transportation infrastructure can influence the development of new urbanization by promoting industrial agglomeration. Thirdly, the study highlighted the importance of population density in the construction of transportation infrastructure and new urbanization, and analyzed the nonlinear effects of transportation infrastructure on the development of new urbanization at different levels of population density. Lastly, it investigated the spatial spillover effects of transportation infrastructure on the development of new urbanization and decomposed these effects. Overall, the study provides valuable insights into the complex relationship between transportation infrastructure and new urbanization.

3. Theoretical Analysis and Research Hypotheses

In the early stages of new urbanization, the construction of transportation infrastructure is crucial for expanding cities. Improving the transportation infrastructure allows city boundaries to extend, transforming rural areas into urban centers. This transformation attracts more investment, drives industrial and commercial development, and accelerates urbanization. As new urbanization progresses, the transportation infrastructure promotes optimization of the industrial structure and economic transformation. Efficient transportation networks enhance logistics, lower costs, and support industrial upgrading and agglomeration. In advanced stages, the transportation infrastructure plays a vital role in coordinating urban–rural planning and construction of ecological civilization. Integrated urban–rural transportation networks break down divides, promote resource sharing, enhance rural accessibility, and equalize public services. Looking ahead, new urbanization will depend on the continued development and optimization of transportation infrastructure. Enhancing the efficiency of transportation, reducing congestion and accidents, and improving residents' quality of life are key goals [26]. Thoughtful planning can address negative impacts such as noise and air pollution, promoting sustainable and eco-friendly travel [27].

The intermediary effect of industrial agglomeration is multifaceted. Firstly, the construction and enhancement of transportation infrastructure can lower the costs of logistics, enhance industrial efficiency, attract more businesses and industrial assets to the city, and foster industrial clusters. Secondly, development of the transportation infrastructure can expand the markets' size, drive industrial advancement, enhance the appeal and competitiveness of the city, create an industrial agglomeration effect, and bolster economic and social progress [28]. Additionally, industrial agglomeration can boost the efficiency of production and innovation capabilities through proximity, the exchange of information, and diffusion of knowledge, while also fueling economic growth and urbanization through factor concentration, optimization of the industrial structure, and upgrades [29]. This phenomenon can guide the rational organization of urban space, promote resource efficiency, spur job creation, raise residents' income levels [30], foster the development community and social cohesion, and establish a strong social base for new urbanization. This leads to the second hypothesis that industrial agglomeration plays a mediating role in the relationship between the development of transportation infrastructure and the advancement of new urbanization.

In regions with a low population density, urban residents and economic development are typically limited. The construction of transportation infrastructure can increase urban appeal, attracting more people and capital to facilitate urban development and new urbanization. However, as the population and economy grow, the demand for transportation rises, necessitating greater investment and efficiency in transportation infrastructure to sustain urban progress and new urbanization. This phase may also bring about congestion and environmental issues, potentially hindering urban development and new urbanization. Hence, the third hypothesis suggests a threshold effect of population density on the role of transportation infrastructure in promoting the development of new urbanization.

In the context of new urbanization, the impact of transportation infrastructure on spatial spillover effects is significant. The construction and development of transportation infrastructure not only enhance the convenience of traffic [31] but also attract more people, goods, and capital flows to adjacent regions, thereby promoting new urbanization. Furthermore, the expansion of market reach, stimulated by the transportation infrastructure, leads to increased economic activities and industrial development, contributing to the advancement of new urbanization [32]. Moreover, the construction of transportation infrastructure facilitates the population's mobility, resulting in a larger and more optimized population structure [4] that enhances economic vitality and fosters new urbanization. Additionally, improved transportation conditions support the equalization of infrastructure and public services, allowing more regions to access urban centers and benefit from urban resources and services [33], thus promoting balanced development between urban and rural areas and further advancing new urbanization. Therefore, the fourth hypothesis is that transportation infrastructure plays a crucial role in the spatial spillover effects on the development of new urbanization.

4. Methodology

4.1. Measurement

4.1.1. Dependent Variable

The concept of the development of new urbanization (Nu) differs from traditional urbanization by prioritizing a people-centered approach. It is characterized by aspects such as coordination between urban and rural areas, the integration of urban and rural areas, interactive development of industries, efficient and intensive land use, ecological livability, and harmonious development. Recognizing that a single indicator cannot fully capture the complexity of new urbanization, this study aimed to construct a comprehensive evaluation system based on the principles of objectivity, systematicity, and operability. Drawing on the work of scholars such as Xiong X [8] and Zhao et al. [9], the evaluation system encompasses five dimensions: economic development, population growth, social services, resources and environment, and urban–rural coordination (as shown in Table 1). The entropy method was then applied to assess the level of development of new urbanization in each region.

Table 1. Comprehensive evaluation system of new urbanization.

Dimension	Indicator	Unit	Weight	Indicator Type
Economic development	Per capita GDP	Yuan	3.99%	+
	The proportion of output value of tertiary industries within GDP	%	1.66%	+
	Total imports and exports as a share of GDP	%	5.56%	+
Population-based development	The proportion of the urban population in the total population	%	0.81%	+
	The ratio of total population to area	People per square kilometer	8.31%	+
	Ratio of urban population to area	People per square kilometer	9.97%	+
	Number of ordinary undergraduate and college students	People	2.83%	+
	Unemployment as a proportion of the working population	%	2.43%	−

Table 1. *Cont.*

Dimension	Indicator	Unit	Weight	Indicator Type
Social services	Number of community health service centers	Units	4.33%	+
	Number of community health service stations	Units	3.12%	+
	Number of public transportation vehicles	Vehicles	5.29%	+
	Number of taxis	Vehicles	3.00%	+
	Volume of domestic waste collection	Ten thousand tons	3.44%	+
	Number of harmless treatment plants	Units	1.94%	+
	The ratio of the number of toilets to the population	Units	8.90%	+
	Ratio of urban road area to the population	Square meters	9.97%	+
Resources and environment	Built-up area/provincial area	%	1.80%	+
	Green area of built-up area/provincial area	%	16.31%	+
	Urban green area/provincial area	%	2.51%	+
	Number of parks	Units	0.90%	+
	The ratio of park green space to population	Square meters	1.31%	+
Urban–rural coordination	Urban and rural residents' per capita disposable income as a ratio	%	1.14%	–
	Urban and rural residents' per capita consumption expenditure as a ratio	%	0.51%	–

4.1.2. Independent Variable

The independent variable was the density of the transportation infrastructure (Td). This study evaluated the construction of transportation infrastructure by measuring the density of transportation route, taking the operational mileage of highways and railways and the navigable mileage of inland waterways in each province into account. These values were then divided by the land area of each province to determine the density of the transportation infrastructure.

4.1.3. Mechanism Variables

Industrial agglomeration (Ic): Utilizing the location entropy index proposed by Haggett [34] and the processing methods outlined by Ji et al. [35], an extended location entropy index was used to assess the degree of agglomeration of primary, secondary, and tertiary industries in different provinces of China. The specific method of calculation can be found in Table 2.

Table 2. Methods of calculation of the degree of industrial agglomeration.

Variables	Methods of Calculation
Primary industrial agglomeration (Fic)	(Regional GDP of the primary industry/Resident population at the end of the year in the region)/(National GDP of the primary industry/National resident population at the end of the year)
Secondary industrial Agglomeration (Sic)	(Regional GDP of the secondary industry/Resident population at the end of the year in the region)/(National GDP of the secondary industry/National resident population at the end of the year)
Tertiary industrial agglomeration (Tic)	(Regional GDP of the tertiary industry/Resident population at the end of the year in the region)/(National GDP of the tertiary industry/National resident population at the end of the year)

4.1.4. Threshold Variables

Population density (Pd) is a measure of the population's aggregation in different regions, calculated by dividing the population count by the units of area (e.g., per square kilometer).

4.1.5. Control Variables

Dependence on foreign trade (Ftd) indicates the reliance of a country or region on foreign trade, showing the proportion of total imports and exports in the national economy.

Fiscal expenditure (Fe) as a percentage of GDP is a key indicator of the impact of fiscal policy on the economy, representing the government's use of funds for fiscal expenditure compared with the gross domestic product.

The intensity of R&D (Rd) measures the proportion of funds allocated to research and development activities relative to GDP, reflecting the level of scientific and technological innovation.

The industrial structure (Is) is represented by the ratio of value-added of tertiary industry to that of secondary industry, highlighting changes in the industrial structure and the growing importance of the service industry in the economy, which has significant implications for economic development and social welfare.

4.2. Statistical Models Used in the Examination

4.2.1. Baseline Model

Following the approach of scholar Jin Xin et al. [36], we selected the individual fixed effects model to study the impact of transportation infrastructure on the level of development of new urbanization. The model was constructed as follows

$$\ln Nu_{i,t} = \alpha_0 + \alpha_1 \ln Td_{i,t} + \alpha_2 Ftd_{i,t} + \alpha_3 \ln Fe_{i,t} + \alpha_4 \ln Rd_{i,t} + \alpha_5 Is_{i,t} + \mu_i + \varepsilon_{i,t} \quad (1)$$

where i represents provinces; t represents years; Nu is the dependent variable; Td is the core explanatory variable; Ftd, Fe, Rd, and Is are the control variables; α is the regression coefficient of the corresponding variable; μ is the fixed effects of provinces; and ε is the random error term.

4.2.2. Mediation Model

To test Hypothesis 2, namely, that industrial agglomeration has a mediating effect promoting the development of new urbanization via the transportation infrastructure, we drew on the research of Wen et al. [37] and constructed the following model based on Equation (1)

$$\ln Nu_{i,t} = \beta_0 + \beta_1 \ln Td_{i,t} + Control + \mu_i + \varepsilon_{i,t} \quad (2)$$

$$\ln Nu_{i,t} = \alpha_0 + \alpha_1 \ln Td_{i,t} + \alpha_2 \ln Ic_{i,t} + Control + \mu_i + \varepsilon_{i,t} \quad (3)$$

where Ic represents the intermediate mechanism variable, namely industrial agglomeration, which is specifically divided into primary industrial agglomeration (Fic), secondary industrial agglomeration (Sic), and tertiary industrial agglomeration (Tic); control represents the control variables.

4.2.3. Threshold Model

To test Hypothesis 3, namely, the existence of a threshold effect of economic development on the promotion of new urbanization by transportation infrastructure, we used a panel threshold model for empirical testing, with the model set as follows

$$\begin{aligned} \ln Nu_{i,t} = \alpha_0 + \alpha_1 \ln Td_{i,t} I(Pd_{i,t} < \gamma_1) + \alpha_2 \ln Td_{i,t} I(\gamma_1 \le Pd_{i,t} < \gamma_2) \\ + \alpha_3 \ln Td_{i,t} I(\gamma_2 \le Pd_{i,t} < \gamma_3) + Control + \mu_i + \varepsilon_{i,t} \end{aligned} \quad (4)$$

where Pd is the threshold variable; I is the indicator function, which is equal to 1 when the corresponding condition is met and 0 otherwise; and γ_1, γ_2, and γ_3 are the threshold values to be estimated.

4.2.4. Spatial Econometric Model

Spatial econometric models commonly used include spatial error models, spatial lag models, and spatial Durbin models. Drawing on the research of Yan et al. [38], this study used the spatial Durbin model (SDM) to investigate the spatial spillover effects of transportation infrastructure on new urbanization. The model is specified as follows:

$$\ln N\mathrm{u}_{it} = \rho W_{ij} \ln N\mathrm{u}_{jt} + c + \alpha_1 T\mathrm{d}_{it} + \sum \beta x_{it} + \theta W_{ij}(T\mathrm{d}_{it} + \sum \beta x_{it}) + \mu_i + \lambda_t + \varepsilon_{it} \quad (5)$$

In Equation (5), W is an $n \times n$ weighting matrix, where n is the number of provincial administrative regions; ρ and θ are the coefficients of the lagged terms of the spatially dependent variable and spatially explanatory variable, respectively; and λ represents the time-fixed effects.

Two types of spatial matrices were selected: the adjacency matrix (W_a) and the geographical distance matrix (W_b). The adjacency matrix is calculated as follows:

$$W_a = \left\{ \frac{1,\ City\ i\ is\ adjacent\ to\ city\ j}{0,\ City\ i\ is\ not\ adjacent\ to\ city\ j} \right. \quad (6)$$

The formula for calculating the geographical distance matrix is as follows:

$$W_b = \begin{cases} \frac{1}{d_{ij}^2}, i \neq j \\ 0, others \end{cases} \quad (7)$$

In Equation (5), d represents the distance between two regions, calculated on the basis of the longitude and latitude of the administrative centers of each provincial administrative region.

4.3. Study Area and Data Sources

Considering the data's integrity and availability, this study focused on 31 provinces (including autonomous regions and municipalities) in China, excluding the Hong Kong Special Administrative Region, the Macau Special Administrative Region, and Taiwan Province. Due to changes in the measurement standards and methods of some variables during the study period, we set the study years from 2013 to 2020 to ensure the data's consistency and comparability, thereby minimizing analysis bias and errors caused by inconsistent standards and methods.

Data were sourced from the *China Statistical Yearbook*, *China Transport Yearbook*, and *China Population and Employment Statistics Yearbook*, as well as the statistical yearbooks of each province from 2013 to 2020. Descriptive statistics are presented in Table 3.

Table 3. Descriptive statistics of the variables.

Variables	Sample Size	Mean	Standard Deviation	Minimum	Maximum
ln*Nu*	248	−0.839	0.234	−1.299	−0.145
ln*Td*	248	−0.587	0.539	−4	0
Ftd	248	0.235	0.245	0.007	1.271
ln*Fe*	248	−0.601	0.205	−0.924	0.14
ln*Rd*	248	−1.867	0.289	−2.715	−1.191
ln*Is*	248	0.075	0.169	−0.242	0.724
lnFic	248	−0.052	0.283	−1.121	0.361
lnSic	248	−0.02	0.181	−0.417	0.43
lnTd*c*	248	−0.05	0.207	−0.303	0.551
Pd	248	0.046	0.07	0	0.392

5. Empirical Analysis

5.1. Baseline Regression

For the method utilizing a panel-fixed effects model to analyze Equation (1), Table 4 displays the results with and without control variables, denoted M(1) and M(2), respectively. The coefficient of the density of transportation infrastructure on the development of new urbanization decreased notably after including the control variables. Initially, in M(1), the coefficient was 0.136, which was significant at the 1% level. With the control variables, the coefficient shifted to 0.102, remaining significant at the 1% level. This suggested that a higher density of transportation infrastructure significantly fosters the growth of new urbanization. The increase in the density of transportation infrastructure can have several positive impacts on urban areas. Firstly, it can enhance urban transportation's capacity, efficiency, and connectivity between cities, attracting more population and capital, and driving economic development. Secondly, it can create employment opportunities in transportation-related industries, attracting the labor force and increasing employment rates and residents' income levels. Thirdly, it can optimize the urban spatial layout, facilitate urban expansion, and promote urban functional division and industrial transformation. A well-developed transportation network can connect cities, expand their reach, and promote diversified urban development and regional economic coordination. Additionally, an increase in the density of transportation infrastructure can improve residents' quality of life and urban environment by reducing congestion, emissions, energy consumption, and pollution, and by enhancing air quality and ecological balance. Lastly, it can provide residents with more travel choices and convenience, enriching urban cultural and social activities. These findings support Hypothesis 1, suggesting that the transportation infrastructure plays a significant role in promoting new urbanization.

Table 4. Results of the baseline regression.

Variables	M (1)	M (2)
ln*Td*	0.136 *** (0.0249)	0.102 *** (0.0139)
Ftd		0.100 *** (0.0333)
ln*Fe*		−0.334 *** (0.0491)
ln*Rd*		0.316 *** (0.0371)
ln*Is*		0.362 *** (0.0259)
Intercept	−0.760 *** (0.0149)	−0.442 *** (0.0767)
Province effect	Yes	Yes
Observations	248	248
R^2	0.121	0.744

Note: Standard errors are in parentheses, where *** $p < 0.01$.

The control variables in the base regression exhibited coefficients of 0.100 for Ftd, −0.334 for lnFe, 0.371 for lnRd, and 0.362 for lnIs, all significant at the 1% level. These results imply that dependence on foreign trade, the intensity of RD, and the industrial structure positively influence the development of new urbanization, while increased fiscal expenditure hinders it.

5.2. Robustness Test

To address potential endogeneity issues in the model, this study utilized lags of one period and two periods of the density of transportation infrastructure as instrumental variables and performed endogeneity tests using the two-stage least squares method. The specific results can be found in Table 5. Additionally, to assess the robustness of the regression results, several methods were used for the robustness tests. These included regression using lags of one period and two periods of the density of transportation infrastructure, removing outliers' impact on the regression by truncating the density of transportation infrastructure and the development level of new urbanization at the 1% and 99% levels, and changing the estimation method by conducting panel quantile regression at nine quantile points from 0.1 to 0.9 to examine the effect of the density of transportation infrastructure under varying levels of development of new urbanization. The detailed results are presented in Tables 5 and 6.

Table 5. Lag test and endogeneity test.

	Lag 1 Period as the Explanatory Variable	Lag 2 Period as the Explanatory Variable	Lag 1 Period as the Instrumental Variable	Lag 2 Period as the Instrumental Variable
lnTd	0.194 ***	0.249 ***	0.0896 ***	0.0949 ***
	(0.0285)	(0.0336)	(0.0144)	(0.0144)
Intercept			−0.476 ***	−0.373 ***
			(0.0817)	(0.0878)
Control	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes
Observations	217	186	217	186
R^2	0.759	0.766	0.719	0.715

Note: Standard errors in parentheses, where *** $p < 0.01$.

Table 6. Truncated processing and quantile regression.

	Truncation are Handling	τ = 0.1	τ = 0.2	τ = 0.3	τ = 0.4	τ = 0.5	τ = 0.6	τ = 0.7	τ = 0.8	τ = 0.9
ln*Td*	0.266 ***	0.0112	0.132 ***	0.155 ***	0.145 ***	0.126 ***	0.0664 ***	0.0833 ***	0.0836 ***	0.129 ***
	(0.0262)	(0.0171)	(0.0219)	(0.0149)	(0.0133)	(0.0190)	(0.0142)	(0.0181)	(0.0214)	(0.0113)
Intercept	−0.345 ***	−0.438 ***	−0.408 ***	−0.370 ***	−0.402 ***	−0.439 ***	−0.405 ***	−0.382 ***	−0.406 ***	−0.354 ***
	(0.0614)	(0.0836)	(0.107)	(0.0729)	(0.0649)	(0.0928)	(0.0695)	(0.0883)	(0.105)	(0.0553)
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	248	248	248	248	248	248	248	248	248	248
R^2	0.991									

Note: Standard errors are in parentheses, where *** $p < 0.01$.

From Tables 5 and 6, it is evident that using lags of one period and two periods of the density of transportation infrastructure as instrumental variables resulted in coefficients of 0.194 and 0.249, respectively, both significant at the 1% level. This suggested that even when one accounts for endogeneity issues, the density of transportation infrastructure continues to significantly influence the level of development of new urbanization, highlighting the robustness of the findings. The coefficients for lags of one period and two periods of the density of transportation infrastructure were 0.0896 and 0.0949, respectively, both significant at the 1% level, indicating a lag effect of the density of transportation infrastructure on the development of new urbanization. Additionally, after truncating, the positive coefficient of the density of transportation infrastructure remained significant, further supporting the robustness of the conclusions. In the panel quantile regression analysis, it was noted that when the quantile points ranged between 0.2–0.5 and 0.9, the coefficient of the density of transportation infrastructure was above 0.1 and significant at the 1% level, while at other quantile points, the coefficient was relatively small. This suggests that in areas with lower and extremely high levels of development of new urbanization, the density of the transportation infrastructure has a more pronounced promoting effect, whereas in areas with very low and high levels of development of new urbanization, the impact of the density of transportation infrastructure is less significant.

5.3. Regional Heterogeneity Test

Due to significant geographical variations among the provinces in China, there are notable differences in the transportation infrastructure and the level of the development of new urbanization across regions. As a result, the influence of transportation infrastructure on new urbanization can vary regionally. According to the standard divisions of the National Bureau of Statistics of China, this study divided 31 provinces into three major regions: east, middle and west. The eastern region includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The central region includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, and Hunan. The western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. Panel data regression analysis was performed on the eastern, central, and western regions based on Equation (1), with the results of the heterogeneity tests for each region detailed in Table 7.

Table 7. Results of the heterogeneity tests.

	Eastern	Central	Western
ln*Td*	0.272 ***	0.0954	0.125 ***
	(0.0630)	(0.107)	(0.0212)
Intercept	−0.469 ***	−0.379 ***	−0.575 ***
	(0.0720)	(0.0948)	(0.184)
Control	Yes	Yes	Yes
Province effect	Yes	Yes	Yes
Observations	88	64	96
R^2	0.813	0.890	0.763

Note: Standard errors are in parentheses, where *** $p < 0.01$.

The findings in Table 7 revealed that between 2013 and 2020, the density of transportation infrastructure positively impacted the development of new urbanization in both the eastern and western regions, with statistically significant coefficients at the 1% level. In the central region, although the coefficient for the density of transportation infrastructure was positive, it was not statistically significant. The reasons for the positive impact of the of density transportation infrastructure on the development of new urbanization in the eastern and western regions may stem from various factors such as investments into infrastructure, levels of economic development, and regional development policies. Conversely, the lack of significance in the relationship between the density of transportation infrastructure and the development of new urbanization in the central region could be attributed to factors such as the data's characteristics, regional disparities, and policy-related influences.

5.4. Mediating Effect of Industrial Agglomeration

To test Hypothesis 2, which proposes that industrial agglomeration plays a mediating role in the relationship between transportation infrastructure and the development of new urbanization, empirical tests were conducted using Equations (1)–(3). The results are presented in Table 8.

The results of the regression in Column (1) indicate that an increase in the density of transportation infrastructure significantly contributes to the development of new urbanization. Column (2) shows that a higher density of transportation infrastructure promotes the agglomeration of primary industries. Both coefficients between the density of transportation infrastructure and the agglomeration of the primary industries in Column (3) are statistically significant at the 1% level, suggesting a partial mediating effect. The Sobel test revealed an effect size of 0.0083 for this mediation. Moving to Column (4), it can be observed that an increased density of transportation infrastructure also leads to the agglomeration of secondary industries. Similarly, in Column (5), the coefficients between the density of transportation infrastructure and the agglomeration of secondary industries are significant at the 1% level, indicating another partial mediating effect. The Sobel test for this mediation yielded an effect size of 0.0222. Conversely, Column (6) shows that the inhibitory effect of the density of transportation infrastructure on the agglomeration of the tertiary industries was not significant. In Column (7), the agglomeration of the tertiary industries was found to significantly promote the development of new urbanization, but no significant mediating effect was observed. Overall, the results supported Hypothesis 2, suggesting that industrial agglomeration indeed mediates the process by which transportation infrastructure fosters the development of new urbanization.

Table 8. Results of the mediation effect test.

	Direct Effect	**Primary Industry**		**Secondary Industry**		**Tertiary Industry**	
	Nu	**Fic**	**Nu**	**Sic**	**Nu**	**Tic**	**Nu**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
lnTd	0.1021 *** (0.0139)	0.0461 ** (0.0205)	0.0938 *** (0.0136)	0.0627 *** (0.0157)	0.0799 *** (0.0133)	−0.0077 (0.0138)	0.1033 *** (0.0138)
Fic			0.1794 *** (0.0451)				
Sic					0.3538 *** (0.0562)		
Tic							0.1627 ** (0.0685)
Sobel test		0.0083 * (0.0042)		0.0222 *** (0.0066)		−0.0013 (0.0023)	
Mediation effect		Significant		Significant		Not Significant	
Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	248	248	248	248	248	248	248
R^2	0.744	0.227	0.762	0.802	0.785	0.561	0.751

Note: Standard errors are in parentheses, where *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

5.5. Threshold Effect of the Population Density

To test Hypothesis 3 on the threshold effect of population density in the promotion of new urbanization through transportation infrastructure, we utilized empirical tests with a panel threshold model, as represented by Equation (4). Initially, threshold effect tests were conducted, and the outcomes are displayed in Table 9.

Table 9. Threshold test.

Threshold Variable	**Threshold Number**	**F-Value**	***p*-Value**	**Critical Value**		
				1%	**5%**	**10%**
Pd	Single	42.49	0.0167	43.54	31.60	28.33
	Double	26.73	0.1800	77.66	52.20	35.88
	Triple	40.37	0.2067	104.31	72.58	54.29

From the results in Table 9, it is evident that the threshold variable Pd passed the single threshold test at a significance level of 5% but did not pass the double or triple threshold tests. The threshold estimation and confidence intervals for Pd can be found in Table 10, while the estimation results of the threshold model are presented in Table 11.

Table 10. Threshold estimation and confidence intervals.

Threshold Variable	**Estimated Value**	**95% Confidence Interval**
Pd	0.0213	[0.0211, 0.0216]

Table 11. Estimation results of the threshold model.

Variables	Coefficient	Standard Error	t-Value
lnTd_1	0.106 ***	0.0129	8.21
lnTd_2	−0.144 ***	0.0422	−3.04
Ftd	0.0876 ***	0.0308	2.84
lnFe	−0.322 ***	0.0454	−7.10
lnRd	0.310 ***	0.0343	9.02
lnIs	0.387 ***	0.0243	15.95
Intercept	−0.485 ***	0.0712	−6.81

Note: *** $p < 0.01$.

An analysis of Table 11 indicated that with population density (Pd) as the threshold variable, there were notable variations in the regression coefficients of the density of transportation infrastructure, suggesting a nonlinear relationship between transportation infrastructure and new urbanization. Specifically, for population densities below 0.0213, the regression coefficient of transportation infrastructure on new urbanization was 0.3646, which was significant at the 1% level, signifying a positive impact on new urbanization. Conversely, for population densities exceeding 0.0213, the regression coefficient was −0.144, also significant at the 1% level, indicating a negative impact on new urbanization. These findings validate Hypothesis 3, supporting the existence of a threshold effect of population density on the promotion of new urbanization through transportation infrastructure.

5.6. Spatial Spillover Effects

To test Hypothesis 4, which examines the spatial spillover effects of transportation infrastructure on the development of new urbanization, we used the spatial Durbin model (Equation (5)) for empirical testing.

5.6.1. Spatial Autocorrelation Test

We used Moran's I index to analyze the global spatial correlations in the development of new urbanization levels across regions. The results in Table 12 show that Moran's I indices for the development of new urbanization levels in China from 2013 to 2020 were statistically significant at the 5% level, with values exceeding 0.3. This suggests a significant positive spatial correlation in the development of new urbanization levels among Chinese provinces during this period.

Table 12. Results of the spatial autocorrelation test.

Year	W_a		W_b	
	Moran's I	**p**	**Moran's I**	**P**
2013	0.475	0.000	0.340	0.000
2014	0.457	0.000	0.321	0.000
2015	0.465	0.000	0.329	0.000
2016	0.460	0.000	0.326	0.000
2017	0.462	0.000	0.326	0.000
2018	0.451	0.000	0.315	0.000
2019	0.434	0.000	0.312	0.000
2020	0.426	0.000	0.315	0.000

5.6.2. Overall Regression Results

The results of the spatial autocorrelation regression are shown in Table 13. According to the LR test, the double fixed-effect spatial Durbin model was more suitable under the adjacency matrix, while the province-fixed effect was more suitable under the geographical distance matrix. The results of the spatial autocorrelation regression in Table 13 indicated that transportation infrastructure has a positive impact on the local development of new urbanization. The coefficient of the spatial effects of transportation infrastructure under the geographical distance matrix was notably positive, confirming a spatial spillover effect on the development of new urbanization. Hypothesis 4 was supported, revealing the spatial influence of transportation infrastructure on the development of new urbanization.

Table 13. Regression results of spatial effects.

	W_a	W_b
lnTd	0.0252 **	0.0368 ***
	(0.0121)	(0.0119)
W × lnTd	0.0425	0.383 ***
	(0.0261)	(0.109)
Control	Yes	Yes
Province effect	Yes	Yes
Year effect	Yes	No
ρ	0.282 ***	0.306 ***
	(0.0835)	(0.118)
σ^2	0.00035 ***	0.00037 ***
	(0.00003)	(0.00003)
R^2	0.493	0.517

Note: Standard errors in are parentheses, where *** $p < 0.01$ and ** $p < 0.05$.

The results in Table 14 demonstrate the decomposition of the spatial effects of transportation infrastructure. The regression coefficients revealed that transportation infrastructure has a significant and positive impact on the direct effects of the development of new urbanization in both matrices. Furthermore, the regression coefficients of the indirect effects were also significant and positive, surpassing those of the direct effects. This suggests that transportation infrastructure plays a crucial role in promoting the local development of new urbanization and generates considerable positive spatial spillover effects on the neighboring areas. Notably, the spatial spillover effects were found to be stronger than the direct effects.

Table 14. Decomposition of the spatial effects of transportation infrastructure.

	Direct Effect		Indirect Effect		Total Effect	
	W_a	W_b	W_a	W_b	W_a	W_b
ln*Td*	0.0288 **	0.0560 ***	0.0679 **	0.564 ***	0.0968 **	0.620 ***
	(0.0125)	(0.0137)	(0.0322)	(0.136)	(0.0383)	(0.143)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	No	Yes	No	Yes	No

Note: Standard errors are in parentheses, where *** $p < 0.01$ and ** $p < 0.05$.

5.6.3. Regional Regression Results

To investigate the spatial impact of transportation infrastructure on the development of on new urbanization in various regions, this research categorized the area into three regions, namely eastern, central, and western, and performed sub-sample regressions. The outcomes are detailed in Table 15. Through LR tests, it was determined that the spatial Durbin model with two matrices was more appropriate for double fixed effects in the eastern and central regions, whereas in the western region, the spatial Durbin model with two matrices was more suitable for provincial fixed effects. An analysis of Table 15 revealed that the transportation infrastructure in the eastern, central, and western regions all positively influenced the local development of new urbanization. The positive spatial effect coefficients of transportation infrastructure under the two matrices indicated a beneficial spatial spillover effect on the development of new urbanization.

Table 15. Results of the regional regression of spatial effects.

	Eastern		Central		Western	
	W_a	W_b	W_a	W_b	W_a	W_b
lnTd	0.316 ***	0.260 ***	0.130 **	0.136 **	0.0240	0.0445 **
	(0.0526)	(0.0585)	(0.0575)	(0.0615)	(0.0184)	(0.0205)
W × lnTd	0.332 ***	0.308 *	0.591 ***	0.632 ***	0.0723 *	0.0731
	(0.104)	(0.162)	(0.112)	(0.147)	(0.0400)	(0.113)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Province effect	Yes	Yes	Yes	Yes	Yes	Yes
Year effect	Yes	Yes	Yes	Yes	No	No
ρ	−0.532 ***	−0.405 **	−0.271 **	−0.295 *	0.327 ***	0.268
	(0.110)	(0.162)	(0.128)	(0.159)	(0.118)	(0.164)
σ^2	0.00005 ***	0.00007 ***	0.00005 ***	0.00005 ***	0.00047 ***	0.00059 ***
	(0.00001)	(0.00001)	(0.00001)	(0.00001)	(0.00007)	(0.00001)
Observations	88	88	64	64	96	96
R^2	0.438	0.341	0.082	0.523	0.095	0.063

Note: Standard errors are in parentheses, where *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Table 16 presents the decomposed spatial effects of transportation infrastructure across different regions. The results revealed that the regression coefficients for both the direct and indirect effects of transportation infrastructure on the development of new urbanization in the eastern, central, and western regions were positive. In the eastern regions, the direct effects' coefficient surpassed that of the indirect effects, whereas in the central and western regions, the direct effects' coefficients were lower than those of the indirect ones. This suggests that transportation infrastructure in all regions plays a role in promoting the local development of new urbanization, with a positive spatial spillover effect. Furthermore, the spatial spillover effect of transportation infrastructure was less pronounced than the direct effect in the eastern region, while in the central and western regions, it was stronger than the direct effect.

Table 16. Decomposition of the spatial effects of transport infrastructure by region.

	Eastern		Central		Western	
	W_a	W_b	W_a	W_b	W_a	W_b
	lnTd	lnTd	lnTd	lnTd	lnTd	lnTd
Direct effect	0.272 ***	0.239 ***	0.0487	0.0601	0.0318	0.0492 **
	(0.0603)	(0.0586)	(0.0695)	(0.0687)	(0.0195)	(0.0244)
Indirect effect	0.148 *	0.164	0.525 ***	0.539 ***	0.116 **	0.121
	(0.0761)	(0.111)	(0.103)	(0.126)	(0.0540)	(0.153)
Total effect	0.420 ***	0.403 ***	0.573 ***	0.599 ***	0.148 **	0.170
	(0.0698)	(0.119)	(0.123)	(0.152)	(0.0651)	(0.169)

Note: Standard errors are in parentheses, where *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

6. Conclusions

This study examined the impact and mechanism of the construction of China's transportation infrastructure on the high-quality development of new urbanization. The main conclusions are as follows. (1) Transportation infrastructure significantly promotes the development of new urbanization, with a significant effect observed in both the eastern and western regions. (2) Industrial agglomeration acts as a mediator in the process of transportation infrastructure, promoting the development of new urbanization. (3) There is a threshold effect in the promotion of transportation infrastructure on the development of new urbanization, whereby it exhibits a significant promoting effect when the population density is below the threshold value, and a significant inhibiting effect when the population density is above the threshold value. (4) Overall, transportation infrastructure has a positive spatial spillover effect on the development of new urbanization, which is significant in the eastern, central, and western regions.

This study offers valuable insights into the high-quality development of new urbanization in China. By conducting a systematic analysis of the data and utilizing various economic models, the research has uncovered the positive impact of transportation infrastructure on new urbanization and elucidated its influencing mechanisms. These findings provide a solid foundation for government officials and decision-makers. The study underscores the significance of the development of transportation infrastructure in urban progress, underscoring the need to stimulate economic growth, optimize the industrial structure, enhance the residents' quality of life, and preserve the environment. As a result, the study contributes important insights for achieving sustainable urban development and serves as a crucial reference for future urban planning and policy formulation. It is noteworthy that governments must always consider the concept of 'opportunity cost,' which entails weighing the benefits and drawbacks of investing in a particular type of transportation infrastructure against other potential investment opportunities. When promoting the construction of transportation infrastructure, governments must comprehensively assess its economic benefits and opportunity costs to make optimal decisions.

Future research can be expanded in several key areas. Firstly, further investigations into the mechanisms through which transportation infrastructure influences the development of new urbanization, taking regional differences and different stages of economic development into account, will enhance understanding of its underlying processes. Secondly, a long-term analysis of the dynamic relationship between the construction of transportation infrastructure and the quality of new urbanization, incorporating additional factors such as environmental protection and resource efficiency, is necessary to establish a more comprehensive analytical framework for promoting sustainable urbanization. Thirdly, future research could explore the synergies between the construction of transportation infrastructure and other fields of urban development, such as urban planning and land use, to achieve the overall optimization of urban development. Lastly, it is important to consider the impacts of unexpected events such as the COVID-19 pandemic in research to enrich its content and provide insights for responding to similar events in the future. The COVID-19 pandemic has significantly affected the transportation infrastructure and new urbanization, leading to reduced traffic flows, decreased usage of public transportation, and the emergence of telecommuting and e-commerce. These changes will have lasting effects on urban layout, transportation demand, and the construction of infrastructure, necessitating thorough exploration.

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