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Influence Mechanisms and Spatial Spillover Effects of Technological Innovation on New Urbanization

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Sustainable and high-level new urbanization cannot be achieved without the drive of technological innovation. By collecting data from 282 prefecture-level cities in China from 2007 to 2020, this paper used a two-way fixed effects model and spatial Durbin model to analyze the influence mechanisms and spatial spillover effects of technological innovation on new urbanization respectively. The research conclusions are as follows: (1) Technological innovation affects new urbanization positively and heterogeneously due to geographical location, city ranking, and city size. The threshold test reflects that the impact of technological innovation on new urbanization has the characteristic of weakening along with crossing double thresholds. (2) Technological and financial constraints are two critical variables that positively moderate how technological innovation affects new urbanization. (3) The spatial effect of technological innovation on new urbanization is significant. However, the impact intensity is inversely proportional to the geographical distance between cities, with an estimated spatial attenuation boundary of approximately 350 kilometers. Therefore, this paper proposes adhering to innovation-driven development, synchronizing the technological market with new urbanization, formulating differentiated policies in different regions, and using locational advantages well.

Keywords: *Technological Innovation; New Urbanization; Moderating Effects; Spatial Spillover Effects; Spatial Attenuation Boundary.*

Introduction

Urbanization involves reallocating resources and is the only way to achieve modernization. After 1978, China's urbanization against the background of the rich country strategy has undergone earth-shaking changes (LI *et al.,* 2020). However, continuous urbanization at high speed has gradually caused the phenomenon of "rushing," with the increasing urban-rural gap, the intensification of contradictions between people and land, and the increasing pressure of environmental carrying capacity (Shang *et al.,* 2018, Chen *et al.,* 2016). Therefore, the adjustment of urbanization development ideas has become urgent, and pursuing high-level urbanization has become a social consensus. In 2016, "Opinions on Deepening the Construction of New Urbanization," issued by the State Council, emphasized the necessity of new urbanization in achieving modernization. From the perspective of core demands, the new urbanization will return the development goals and momentum of urbanization to the people themselves, focusing on the development of human rights, abilities, and welfare, taking into account the coordinated development of the economy, society, environment, and other aspects. It is a new urbanization development model that reflects fairness, sharing, and inclusiveness. First, traditional urban diseases, such as the contradiction between human and land, and ecological and industrial structural imbalances, urgently need to be addressed, which depends on technological innovation. Second, the new structure and model of urban economic development need to be identified, such as the shift from population dividends to talent dividends, and from extensive industrial structure to intensive adjustment, which requires changing the driving force of urban development and relying on technological innovation to achieve the transformation from factor-driven to innovation-driven (Gu & Liu, 2012).

In addition, technological innovation provides leadership and foresight in cultivating urban competitiveness (Zameer *et al.,* 2020) and discovering new economic growth points in cities (Chen *et al.,* 2020). For example, Hefei has vigorously developed quantum computing, cloud computing, and new energy technologies, leading to the rapid aggregation of related technology industries and effectively promoting urban transformation and economic growth. Cities such as Wuhan, Nanjing, and Guangzhou have utilized technological innovation methods such as the construction of information technology infrastructure and the application of information technology to integrate urban residents' transportation, resources, and public medical service systems, thus driving new urbanization.

In summary, technological innovation is the key to solving the problem of urban development, as well as the foundation and guidance for achieving new urbanization. As of 2020, China's urbanization is near maturity, but the growth rate is about to slow, possibly because the advanced urban development mechanism cannot fully solve the drawbacks of traditional urbanization, and the internal transformation mechanism of cities has not been effectively stimulated. Seeking new drivers of urbanization development and enhancing the sustainability of urbanization driven by domestic demand is the focus of the next stage. Therefore, the purpose of this paper is to accurately understand the role of technological innovation in promoting new urbanization and to clarify the interfering factors that technological innovation faces in the process.

Most scholars examined the impact of technological innovation on new urbanization from macro perspectives such as industrial structure, factor flow, and capital aggregation, who view technological innovation itself as a default black box. Unlike them, this paper starts with the process and practice of technological innovation and studies the impact of technological innovation on new urbanization from two perspectives: the transformation of technological innovation achievements and the application of technological achievements. This paper uses these two perspectives as moderator variables to explore the influence mechanisms of technological innovation on new urbanization.

Literature Review

The relationship and theory between technological innovation and urbanization can be roughly divided into three stages, achieving a leapfrog discussion from their surface correlation to their internal mechanism of action.

In the early days, scholars took the lead in discussing the correlation between the urban development level and basic innovation, and many scholars discovered and verified the correlation between the number of invention patents and city size. Afterward, more detailed research was conducted on the interaction between urban development speed and patent applications. The results showed that factors such as the urban lifestyle, environment, and system provided favorable conditions for the invention and creation of technology. With the increasingly prominent position of technological innovation in the economy and society, in the third stage, the crucial role of technological innovation has been captured by scholars, and the academic community has discussed in more detail the driving mechanism of technological innovation in urban economic life.

Horizontally, when discussing the relationship between technological innovation and urbanization, paying attention to their interaction and coordination is one of the key points. Many scholars have proven that the two can interact. The interaction between these two systems is long-term and stable (He *et al.,* 2015). However, this interaction may have regional heterogeneity. Under normal circumstances, technological innovation has a more advantageous auxiliary effect on new urbanization in economically developed areas (Tian *et al.,* 2016).

Another hot topic of discussion is the use of technological innovation and urbanization as outcome variables. Most scholars have recognized the logic of the impact of technological innovation on urbanization for its fundamental role in urbanization construction. Technological innovation is the foundation of urbanization (Button, 1976). Grossman (1994) argued that technological progress is the key to urbanization and economic growth. Technological innovation can provide sufficient impetus for urbanization (Wilson & Vandenabeele, 2012). This view is also supported by the empirical evidence of other scholars (Kratke, 2011; Wei *et al.,* 2021). At the same time, urban development accelerates technological innovation (Yuan & Liu, 2014). Transformation and implementation of technological achievements in the market and their application have practical significance for the development of the urbanization economy. Utilizing students' creativity and regional productivity can promote the urban economy (Andersson *et al.,* 2009). However, the impact of technological innovation may have phased characteristics or lagged effects. The promotion effect of technological innovation on new urbanization may decline with time (Zheng, 2017).

In summary, the contribution of technology to promoting urbanization has been fully and widely recognized. However, technological innovation is a dynamic process. In the current situation, the impact of technological innovation on new urbanization is subject to some constraints. Clarifying what these constraints are is still a topic worth studying. In addition, when analyzing the impact of technological innovation on new urbanization, there is also a lack of attention given to spatial effects, and the exact boundary of spillover effects is still unknown.

Therefore, we attempt to summarize the marginal contribution of this paper. First, this paper uses a two-way fixed effects model and threshold regression model to determine the effect and characteristics of technological innovation on new urbanization. Heterogeneity in this process is explored from three dimensions: geographical location, city ranking, and city size. Second, we empirically studied the changes in the impact of technological innovation on new urbanization under technological and financial constraints. Third, the effect of technological innovation on new urbanization is extended to the spatial dimension. The possible spatial spillover effects are tested, and by constructing a spatial matrix with distance thresholds, the specific range of the spatial spillover effects of technological innovation is further determined.

Theoretical Mechanism and Hypotheses

The population is the driving force behind urbanization (Friedmann, 2006). However, as the development of urbanization approaches the late stage, the marginal utility of the population will inevitably decline, and the fundamental requirement for healthy urbanization is the clustering of innovation rather than the capacity to accommodate the population (Wang & Zhou, 2020). Technological innovation impacts new urbanization in the following ways: First, it increases the urbanization rate by creating employment opportunities. Innovation clusters provide cities with new means to attract and retain foreign residents (Pancholi *et al.,* 2015). Cultivating and spawning new economic forms, creating jobs, and generating worker income have accelerated population migration to cities and towns. Second, the key to technological innovation can also be found in promoting regional economic development and improving people's livelihoods. The urban-rural dual public service supply system still leads to significant disparities in education, social security, and security between the two regions (Yang & Chen, 2020). Society can use technological innovation to promote resource allocation, optimize public services in underdeveloped areas, and promote equalizing social public services. Third, technological innovation indirectly affects urbanization by effectively promoting the construction of "green cities" (Chenghu *et al.,* 2021). Examples include the use of new technologies for urban green space planning and the promotion of clean and energy-saving technology innovation. (Xu *et al.,* 2022). Additionally, the advancement and usefulness of new technologies, such as the Internet and cloud computing, have emerged in the areas of information and communication, showing that technological innovation can also effectively solve the bottleneck problem encountered in the process of promoting new urbanization (Dodgson & Gann, 2011, Nishant *et al.,* 2020). Hypothesis 1 thus proposes the following:

Hypothesis 1: *Technological innovation can play an influential role in promoting new urbanization.*

Concerning technology, the application of technology in new urbanization requires a matching technical system. It may be difficult for a single enterprise to construct a complete technical system while developing innovative core technologies. Hence, the technological trading market is indispensable. The technological trading market is a place for trading and transferring various intellectual property rights and technological achievements in the context of technological innovation and industrialization. Its purpose is to promote the transformation and application of technological innovation achievements and help inventors, innovative enterprises, research institutions, etc., better industrialize technology (Wan *et al.,* 2023). The activity level of the technological market transaction refers to the performance and situation of the frequency and scale of buying and selling technology products and services, price fluctuations, and the number and quality of participants in the market. Generally, high technological market transaction activity means strong market demand, multiple transaction opportunities, high market transparency, and intense competition among participants. A market with high transaction activity has more trading opportunities and more potent motivation for participating in competition, which is conducive to capitalization and industrialization of technological innovation achievements (Bauke *et al.,* 2016). Additionally, the level of transaction activity directly affects the transparency and timeliness of market information and demand, thereby providing more accurate market feedback and demand guidance for technological innovation. Therefore, improving transaction activity in the technological market can activate the endogenous driving force of technological innovation and make it more efficient at improving new urbanization.

At the same time, for enterprises to achieve large-scale industrial applications of laboratory-patented technological innovation, they often need to add a large amount of funding to complete the subsequent transformation process. This process can be roughly divided into four stages. The first stage involves the evaluation of technological achievements. After research and development are completed, a technological evaluation is needed to gradually confirm the maturity and application prospects of the technology. The second stage involves technology transfer and commercialization. However, it is challenging for laboratory technologies to industrialize and enter the market. They must attract capital injection through focus and network, patent transfer, and commercialization to develop technological achievements into commercial products and determine their product form and market prospects. The third stage involves technology development and promotion. After commercial investment, technological achievements must undergo product development, manufacturing, and production. This involves various engineering and process implementations to ensure large-scale production and broad application of technological achievements (Boer & During, 2001). The fourth stage involves implementing strategies and providing services. Technology companies must maintain a stable operating system in large-scale applications, including production line management, maintenance and upgrading, and user services. Therefore, when technology companies face loose financial constraints, technological innovation may more efficiently enhance new urbanization.

Hypothesis 2: *Technological and financial constraints can play a moderating role in technological innovation affecting new urbanization.*

Technological innovation is a process of innovative research and development, output, and transformation (Liu *et al.,* 2017) based on personnel mobility, R&D cooperation, and trade investment. The innovation effect is not isolated (Enkel *et al.,* 2009). Innovators are mobile between regions, which drives innovation knowledge and information exchange and builds channels for innovation dissemination (Bettencourt *et al.,* 2007). On R&D cooperation, on the one hand, the output of innovative achievements by innovators increases their market share and corporate profits. Other companies will imitate and learn from this (Wang & Bao, 2021), innovate based on the former, and generate spillover effects of innovation within the industry. On the other hand, R&D cooperation among enterprises can achieve complementary advantages, promote regional exchanges, and drive spatial innovation spillover (Damanpour *et al.,* 2009; Duranton & Puga, 2004).

Moreover, as an economic activity, technological innovation has a specific directionality and dynamic mechanism in the flow of innovative factors such as R&D capital and technological personnel. In a free market environment, innovative factors such as R&D capital and technological personnel will spontaneously flow to regions with higher economic development levels and aggregation to obtain greater marginal benefits (Cao *et al.,* 2020), which to some extent promotes the diffusion of innovation and causes technological innovation to have spillover effects.

The spillover effect of technological innovation is related to the innovation source's innovation capabilities, the radiation area's absorptive capacity (Bettencourt et al., 2007), and the channels of communication between regions (Zhang, 2020). In a city cluster with close geographical proximity, there is a certain similarity in the market, economy, and social background (Chua *et al.,* 2019). Knowledge spillover costs are low, and innovation is more conducive to diffusion in neighboring areas (Bode, 2004). However, cities that are far apart generally have significant differences in economic development, fewer opportunities for cooperation and exchange between regions, a lower degree of factor mobility, and possible institutional barriers between different administrative regions, which increase the threshold for innovation spillover. The more significant development gap between regions may also make it difficult for radiation areas to digest and absorb advanced technology spillovers, making it more difficult to convert them into driving forces for urbanization development. Therefore, the spillover effect of technological innovation may have an inverse relationship with the geographical distance between cities.

Hypothesis 3: *Technological innovation has spatial spillover effects on new urbanization, but this spillover effect weakens as geographical distance increases.*

Figure 1 shows the theoretical analysis framework of this paper.

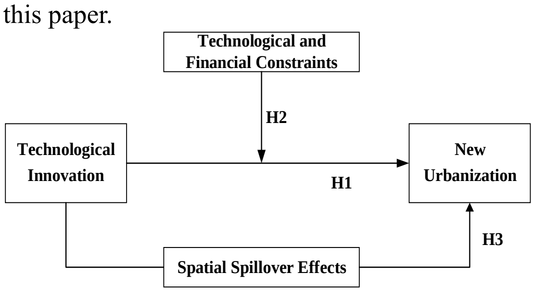

Figure 1. Theoretical Analysis Framework

Model Construction and Method Explanation

Model Construction

The focus of this paper is to analyze the impact of technological innovation on new urbanization and to examine the moderating role of technological and financial constraints in this process. The following regression model was established:

$$\ln NUR_{it} = \beta_0 + \beta_1 \ln TI_{it} + \beta_2 \ln X_{it} + u_i + v_t + \varepsilon_{it} \tag{1}$$

where $\boldsymbol{NUR_{it}}$ and $\boldsymbol{TI_{it}}$ represent new urbanization and technological innovation, respectively, in city i in year t. $\boldsymbol{X_{it}}$ represents control variables. $\boldsymbol{u_i}$ and $\boldsymbol{v_t}$ represent the individual-fixed and time-fixed effects, respectively. $\boldsymbol{\varepsilon_{it}}$ is the random error term. In addition, this paper utilizes all variables to reduce the effect of heteroscedasticity.

In terms of specific spatial econometric model settings, spatial econometric models can be further divided into spatial autoregression model (SAR), spatial error model (SEM), and spatial Durbin model (SDM). The specific forms of the three models are as follows:

$$\text{SAR:} \quad y = \rho W y + X\beta + \varepsilon \tag{2}$$

$$\text{SEM:} \quad y = X\beta + \lambda W\mu + \varepsilon \tag{3}$$

$$\text{SDM:} \quad y = \rho W y + X\beta + WX\delta + \varepsilon \tag{4}$$

In the above equation, W is the spatial weight matrix, y is the explained variable, representing new urbanization in a certain region in a certain year, and X is a series of driving factors. The specific choice of model needs to be determined based on the test results of LM and LR.

Figure 2 shows the research procedures and methodology of this paper.

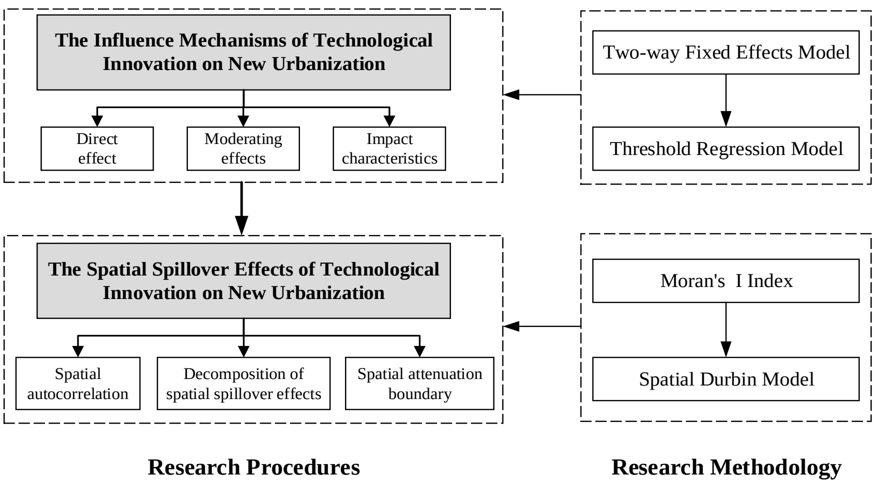

Figure 2. Research Procedures and Methodology

Variable Description

Explained Variable

New urbanization (NUR) is the primary variable that this paper focuses on. The strategy of enriching people centered on economic construction began to be implemented after the reform and opening up, and traditional urbanization has indeed embarked on the track of rapid development. However, urban diseases such as a significant urban-rural economic development gap, the identity problem of the agricultural population, and the waste of land resources cannot be ignored. Compared with the traditional development model, the new urbanization is a series of exploratory projects to transform the urbanization development model into quality.

New urbanization has undergone a series of explorations over the past decade. In 2007, the principles and concepts of urbanization with Chinese characteristics were initially clarified, including urban-rural connotations, coordination, and rational urban layout. Five years later, the State Council further noted that it is necessary to promote the reform of the household registration system, highlighting people-oriented, population urbanization, and coordination with the development of different cities. In 2017, the sustainable development of urbanization became the focus of new urbanization. First, society began to focus on improving cities' basic public service level and sharing the development achievements with all residents. Second, urban boundaries avoid the disorderly spread of urban space, and the concept of green development is integrated throughout urban construction. From a comprehensive perspective, new urbanization is a significant change in the development concept, quality of urbanization construction, and promotion strategy.

Regarding the development concept, new urbanization highlights the people-oriented nature, promoting population urbanization and achieving social equity, urban development achievements, and spatial sharing. In terms of the development mode, overall industrial upgrading and layout optimization should be pursued. It establishes an intensive and efficient urbanization development perspective. The urban development form considers the coordination and rationality of cities of different sizes and regions. Sustainable development emphasizes green development and ecological livability. Therefore, new urbanization is the organic unity of production, life, and ecology. It is difficult to fully describe a single index; thus, scholars often use a series of indicators for comprehensive evaluation. Based on conceptual interpretation and reading academic research, this paper incorporates new urbanization into the five first-level dimensions of population, economy, society, space, and green urbanization. The entropy method is adopted for the index integration calculation. The results are shown in Table 1.

The specific reasons for choosing secondary indicators are as follows. First, rural population agglomeration to urban areas is a fundamental characteristic of urbanization, which is mainly reflected in the flow of population between urban and rural areas and residents' employment. This paper uses the urbanization rate to describe the population agglomeration in urban areas and uses the employment rate and the proportion of employment in the tertiary sector to reflect the urban employment level.

Second, economic urbanization mainly refers to the transformation of production methods toward efficiency and intensiveness. This paper uses indicators such as per capita social consumer goods retail sales to describe commodity circulation and uses per capita GDP and per capita fixed asset investment to reflect industry efficiency and investment levels.

Third, there are three main aspects of social urbanization: the equalization of public services, social security, and urban-rural coordination. Therefore, this paper uses per capita library collection to reflect the equalization of public services and uses the ratio of urban and rural residents' disposable income to indicate the degree of urban-rural integration and coordination.

Fourth, to prevent the disorderly spread of city size boundaries and promote the rationalization of internal urban space, in terms of spatial urbanization, this paper uses per capita park and green space area and population density to reflect spatial carrying capacity and spatial compactness.

Finally, green urbanization is reflected in the urban construction process, which pays more attention to urban ecology and sustainable development. This paper uses indicators such as the sewage treatment rate and the harmless treatment rate of domestic waste to reflect urban greening and environmental governance. Among the above indicators, the ratio of urban and rural residents' disposable income and population density are negative indicators, while the rest are positive indicators.

Table 1

New Urbanization Index System

Primary indicators	**Secondary indicators**	**Unit**	**Attribute**
Population Urbanization	Urban employment density	%	POSITIVE
	The proportion of secondary and tertiary industry employees	%	POSITIVE
	Urbanization rate of resident population	%	POSITIVE
Economic Urbanization	GDP per capita	Yuan	POSITIVE
	Retail sales of social consumer goods per capita	Yuan	POSITIVE
	Fixed asset investment per capita	Yuan	POSITIVE
	Library collections per capita	Book/person	POSITIVE

Primary indicators	Secondary indicators	Unit	Attribute
Social Urbanization	Number of hospital beds per 10,000 people	Number of hospital beds/10,000 people	POSITIVE
	Number of public buses and trams per 10,000 people	Vehicles/10,000 people	POSITIVE
	Number of Internet broadband access subscribers	10,000 households	POSITIVE
	Ratio of disposable income of urban and rural residents	/	POSITIVE
Spatial Urbanization	Population density	People/km2	NEGATIVE
	Green space per capita	hectares	POSITIVE
	Urban construction land as a proportion of urban area	%	NEGATIVE
Green Urbanization	Harmless disposal rate of domestic waste	%	POSITIVE
	General industrial solid waste comprehensive utilization rate	%	POSITIVE
	Centralized treatment rate of sewage treatment plants	%	POSITIVE
	Greening coverage of built-up areas	%	POSITIVE

Explanatory Variable

Technological innovation (TI) is the explanatory variable of this paper. On the one hand, scholars believe that the innovation output efficiency of a city is more advantageous for reflecting the comprehensive technological innovation capacity of the region (Bian et al., 2019). On the other hand, the available data at the urban level are limited, and urban patents can intuitively reflect the knowledge output of technological innovation. Therefore, we use the total number of three invention patents in the sample cities to measure technological innovation, including authorized invention patents, utility model patents, and design patents.

Moderator Variables

The essence of technological innovation to promote new urbanization is to transform and apply technological achievements in urban spatial governance, human settlement environment improvement, and enterprise green production. Technological innovation must be transformed and applied within the urban domain to promote new urbanization effectively. Typical technological applications that promote new urbanization include smart transportation, green buildings, smart city management, medical and health data platforms, and a new energy revolution (Nishant et al., 2020). Therefore, a suitable mechanism for transforming and applying technological innovation can help promote new urbanization more efficiently. Conversely, an incomplete mechanism for technology transfer may lead to ineffective innovation. In the process of new urbanization, the transformation and application of technological innovation face two issues: technology and funding.

Considering the effects of technological innovation on new urbanization under technological and financial constraints, this paper uses the "technological market transaction amount", which reflects the degree of technological market transactions and technology transfer intensity and is used to describe technological constraints (TC), to measure technological market activity. The "Digital Inclusive Finance Index" measures the intensity of financial constraints (FC). These two variables are used as moderator variables and interact with technological innovation.

Control Variables

Some missing variables can lead to estimation bias. Hence, the control variables in this paper include government intervention (GOV), which uses fiscal expenditure as a surrogate indicator. Due to the limited data on prefecture-level cities, this paper estimates the proportion of urban college students per 10,000 people and the density of the road network, which are used to represent the level of human capital (HUM) and the degree of transportation convenience (Traffic), respectively. The degree of openness (OPEN) is related to the economic level of a city. We calculate the ratio of foreign capital utilized by each city to GDP in the current year and convert it into the currency unit of the RMB according to the year's exchange rate. The market mechanism (MAR) is expressed as the proportion of urban private workers to self-employed workers. The degree of manufacturing agglomeration (MIG) is measured by the location entropy of manufacturing personnel and urban employees at the end of the year.

The data in this paper have been collected since 2007 because the 17th National Congress of the Communist Party of China included the new urbanization project in the category of the "New Five Modernizations," which was the beginning of a new era of development. In addition, the data for 282 prefecture-level cities in China do not include cities with significant data gaps, such as Bijie, Tongren, and Chaohu, or cities with significant administrative division adjustments. The data sources are the National Bureau of Statistics website, the China National Intellectual Property Administration of China database, the China Urban Statistical Yearbook, and the City Statistical Bulletin.

Spatial Autocorrelation and Spatial Weight Matrix

The spatial econometric model is a statistical model used to analyze economic data, taking into account the correlation and interaction in geographical space.

The Moran's I index can be used to detect the spatial spillover effect of variables. This paper uses it to test whether there is a spatial spillover effect on two main variables. The specific formula is as follows:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} \sum_{i=1}^{n} (x_i - \bar{x})^2} \quad (5)$$

where $\mathbf{n}$ represents the total number of cities, and $\boldsymbol{w_{ij}}$ is the spatial weight matrix. I is the global Moran index with a value ranging between -1 and 1. Whether a variable has a positive spatial correlation is indicated by whether I is greater than 0, and the closer the value of I is to 1, the more significant the positive spatial correlation between the variables, and vice versa.

There are many types of spatial matrices in spatial econometrics. This paper calculates the geographic distance between two cities based on their latitudinal and longitudinal coordinates. It constructs an inverse geographic matrix using their reciprocal. The advantage is that the sample size does not limit its explanatory power.

$$W_1 = \begin{cases} \dfrac{1}{d_{ij}}, & \text{if } i \neq j \\ 0, & \text{if } i = j \end{cases} \quad (6)$$

where $\boldsymbol{d_{ij}}$ indicates the geographic distance between cities.

Empirical Results and Analysis

Baseline Regression Results and Analysis

The OLS, time-fixed, city-fixed, and two-way fixed regression results are shown in columns (1) to (4) of Table 2, respectively. Before analysis, we added the quadratic term of technological innovation to the equation to test whether it has a U-shaped relationship with the explanatory variable. The results indicate that the inflection point of technological innovation is not within the sample value range, indicating that there is no significant quadratic relationship between it and new urbanization. Therefore, the following discussion focuses on the linear impact of technological innovation on new urbanization.

The first to fourth columns in Table 2 represent the regression results without controlling for any fixed effects, controlling only for time fixed effects, controlling only for city fixed effects, and controlling for two-way fixed effects, respectively. The results show that the coefficients of technological innovation are significantly positive at the 1 % level in all cases, indicating that technological innovation can promote new urbanization. Additionally, we found that the coefficient is largest when we do not control for any fixed effects, at 0.198. It decreases to 0.123 when controlling for time fixed effects and to 0.133 when controlling for city fixed effects. This suggests that time inertia and regional differences can lead to an overestimation of the impact of technological innovation on new urbanization. Therefore, controlling for two-way fixed effects is necessary.

The Hausmann test result is 233.45, and its p-value is 0.000. This suggests that the following analysis is based on the two-way fixed model of time and individuals, and the results are shown in (4). The elasticity of technological innovation is 0.159. This result passes the significance test, which demonstrates the efficiency of technological innovation in promoting new urbanization and preliminarily verifies hypothesis 1. Technological innovation has led to changes in the urban employment structure improved resource allocation and contributed to improving the quality of urbanization. In addition, new technologies and products can be used to improve social and public services, opening up a broader perspective for addressing bottlenecks encountered in urbanization development. At the same time, the elasticity values of market mechanism (MAR), government intervention (GOV), human capital (HUM), and traffic convenience (TRAFFIC) are 0.014, 0.093, 0.112, and 0.157, respectively, all of which are significantly positive. This indicates that the greater the degree of marketization is, the greater the government intervention, the greater the human capital, and the more convenient the transportation, the more conducive it is to promoting new urbanization. The degree of industrialization in the manufacturing industry (MIG) is measured by location entropy, and the smaller the location entropy is, the more concentrated the industry. The elasticity value of location entropy is -0.101, which is significantly negative, indicating that the higher the concentration of the manufacturing industry is, the more conducive it is to improving new urbanization.

Table 2

Basic Regression Results

Variables	（1）	(2)	(3)	（4）
LnTI	0.198***	0.123***	0.133***	0.159***
	(0.006)	(0.009)	(0.019)	(0.015)
LnMAR	-0.029***	0.002	-0.001	0.014*
	(0.009)	(0.007)	(0.010)	(0.007)
LnGOV	-0.050***	0.055***	0.048***	0.093***
	(0.010)	(0.015)	(0.014)	(0.018)
LnHUM	0.148***	0.124***	0.155***	0.112***
	(0.006)	(0.009)	(0.017)	(0.013)
LnOPEN	-0.066***	0.007**	0.083***	0.003
	(0.002)	(0.003)	(0.001)	(0.003)
LnTRAFFIC	-0.122***	-0.010	0.064*	0.157***
	(0.010)	(0.017)	(0.033)	(0.024)
LnMIG	-0.062***	-0.062***	-0.094***	-0.101***

Variables	（1）	(2)	(3)	（4）
	(0.008)	(0.010)	(0.019)	(0.014)
Constant	-2.611***	-3.001***	-3.407***	-3.010***
	(0.071)	(0.093)	(0.122)	(0.111)
Year Effect		YES		YES
City Effect			YES	YES

Note: *** p<0.01, ** p<0.05, * p<0.1; Values in parentheses are regression standard errors.

Moderating Effects Analysis

As mentioned earlier, technological innovation needs to be nurtured and transformed within cities with the advancement of new urbanization. In this process, on the one hand, the activity in the transaction market directly affects the transparency and timeliness of market information and demand, providing more accurate market feedback and demand guidance for technological innovation. The various stages of technological innovation, including the evaluation of technical achievements, technology transfer and commercialization, technology development, promotion, and implementation services, all rely on sufficient financial conditions. Therefore, applying technological innovation achievements for transformation faces technological and financial issues. This section takes technological and financial constraints as regulating variables. It interacts with technological innovation to verify the two's moderating role.

Column (1) in Table 3 adds interactive items between technological innovation and technological constraints, while column (2) adds interactive items between technological innovation and financial constraints. The coefficient of the interaction term between technological innovation and technological constraints is 0.0032, which is significantly positive. This means that for every one-unit increase in the logarithm of technological constraints, the elasticity of technological innovation in promoting new urbanization increases by 0.32%. The coefficient of the interaction term between technological innovation and financial constraints is 0.1085, which is significantly positive. This means that for every one-unit increase in the logarithm of financial constraints, the elasticity of technological innovation in promoting new urbanization increases by 10.85%. This finding verifies hypothesis 2, indicating that technological and financial constraints play a positive moderating role in the relationship between technological innovation and new urbanization.

Table 3

Regression Results for Moderating Effects

Variables	(1)	(2)	(3)
LnTI	0.1552***	0.1531***	0.1503***
	(0.0148)	(0.0143)	(0.0143)
LnTI#LnTC	0.0032**		0.0026**
	(0.0013)		(0.0012)
LnTI#LnFC		0.1085***	0.1081***
		(0.0065)	(0.0065)
Control Variables	YES	YES	YES
Year Effect	YES	YES	YES
City Effect	YES	YES	YES

Note: *** p<0.01, ** p<0.05, * p<0.1; Values in parentheses are regression standard errors.

Heterogeneity Analysis

As the impact of technological innovation on new urbanization may vary due to the characteristics of city development, this section conducts subsample regressions based on the city's geographical location, ranking, and size. First, the sample is divided according to geographical location, with regression results shown in columns (1) to (3) of Table 4. The coefficients of technological innovation in all regions of the country are significantly positive, indicating that technological innovation can significantly promote new urbanization. Second, according to the ranking of cities, the sample is divided into three parts: first-tier cities, second-tier and third-tier cities, and cities below the fourth-tier. The regression results are shown in columns (4) to (6) of Table 4. Third, based on the 2020 urban population, this paper divides the sample into several different types of city sizes, defining small and medium-sized cities, large cities, and supercities and megacities as populations of less than 1 million, populations between 1 million and 5 million, and populations above 5 million, respectively. The regression results are shown in columns (7) to (9) of Table 4.

Technological innovation can further promote new urbanization, and this effect is closely related to the characteristics of cities. This heterogeneity is mainly reflected in the limited effect in the western region and low-tier cities. This may be because the generation of technological innovation depends on the environmental context cities provide to drive R&D and export innovation. The market mechanism's perfection and innovation capital adequacy are essential. The active flow and rational allocation of innovation factors within a city are limited in backward cities, so innovation results can be smoothly transformed into new driving forces to support urban development and ultimately fail to promote new urbanization effectively.

Regarding city size, the role of technological innovation in promoting new urbanization in small and medium-sized cities is weak. The degree of population agglomeration is an essential driving force affecting technological innovation to promote new urbanization. The agglomeration effect of large cities themselves causes advanced production factors such as technology and talent to concentrate in cities (Tappeiner *et al.,* 2008), thereby improving the productivity of knowledge-based industries and economic growth rates.

However, it is not easy to prove that the economic prosperity of cities is directly proportional to the efficiency of technological innovation in promoting new urbanization. Furthermore, in the eastern region, first-tier cities, and cities with a population of more than 5 million, the promotion effect of technological innovation is lower than that in underdeveloped regions. Therefore, we speculate that the marginal promoting effect of technological innovation on new urbanization may be decreasing.

Table 4

Heterogeneity Analysis

Variables	**Geographical location**			**City ranking**			**City size**		
	Eastern region	**Central region**	**Western region**	**First-tier cities**	**Second-tier and third-tier cities**	**Cities below the fourth-tier**	**Supercities and megacities**	**Large cities**	**Small and medium-sized cities**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
LnTI	0.095***	0.191***	0.079**	0.094	0.159***	0.092***	0.220***	0.224***	0.093
	(0.021)	(0.024)	(0.033)	(0.142)	(0.020)	(0.021)	(0.028)	(0.017)	(0.059)
Control Variables	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES
City Effect	YES	YES	YES	YES	YES	YES	YES	YES	YES

Note: *** p<0.01, ** p<0.05, * p<0.1; Values in parentheses are regression standard errors.

Threshold Test

As mentioned above, technological innovation can significantly promote new urbanization. However, combined with heterogeneity analysis, technological innovation is not the most efficient in promoting new urbanization in the eastern region or economically developed cities. Furthermore, this section will use the threshold regression model to test whether they have a nonlinear relationship. Technological innovation passed the double threshold test, indicating a double threshold for the effect of technological innovation on new urbanization.

The technological innovation coefficient is significantly greater than 0 within the three threshold intervals, as shown in Table 5, further validating hypothesis 1. Overall, technological innovation is the key driving force affecting new urbanization. When technological innovation is less than 0.012 (lnTI = -4.431), its elasticity coefficient is 0.209. After crossing the first and second thresholds, it decreases to 0.170. Although the elasticity coefficient decreases, it remains positive, indicating that although there is no apparent quadratic relationship between these two variables, the marginal promotion effect of technological innovation has a decreasing characteristic.

Combined with the results of the heterogeneity analysis in Table 4, the cities, new first-tier, and first-tier cities, as well as the extra-large and super-large cities in the eastern region, belong to relatively economically developed areas, and the marginal promotion efficiency of technological innovation in these cities for new urbanization has been reduced. This paper speculates that the reason may be that new urbanization in economically developed cities is relatively high, and the growth rate is slowing down. Additionally, the space for further improvement is limited, the accumulation of technological innovation factors and innovation efficiency are facing development bottlenecks, and the size of cities is too large to achieve comprehensive coverage of innovation results within the city and sharing of national development, so the promotion effect of new urbanization is gradually reduced.

Table 5

Threshold Regression Results

Variables	**Estimated value**
LnTI<=-4.431	0.209***
-4.431<LnTI<=0.127	0.188***
0.127<LnTI	0.170***
Control Variables	YES

Note: *** p<0.01, ** p<0.05, * p<0.1.

Spatial Correlation Test and Regression Results

Spatial Autocorrelation Test

This paper tests the spatial correlation of two main variables under the inverse geographic matrix based on the Moran index. The Moran index values were all positive during the statistical period, indicating significant positive spatial clustering between the two variables, supporting the rationality of considering the spatial correlation between the two variables in the empirical process.

A series of model adaptability tests are essential before spatial econometric analysis. The LM and LR tests pass the significance test at the 1% level, which reflects the necessity and rationality of using spatial econometric methods for analysis. Compared with the spatial autoregression model, the spatial Durbin model can effectively alleviate estimation bias. The Hausman test reflects that this paper needs to control effects, including time and individuals, and the statistics of Wald's test indicate that the spatial Durbin model cannot be downgraded to other models. In summary, the spatial Durbin model has the greatest rationality advantage in terms of model usage.

Spatial Model Regression Results

Table 6, column (1) shows that the technological innovation coefficient is positive and passes the significance test at the 1% level, showing that its effect on promoting new urbanization is pronounced. However, the regression coefficient is slightly smaller than that of the ordinary panel obtained above, indicating that the impact of technological innovation may be overestimated without considering the spatial spillover effect. Column (3) shows that the indirect impact of technological innovation has a significant positive effect at the 1% level, reflecting that it can not only promote new urbanization in the region but also drive the improvement of new urbanization in other regions. Therefore, hypothesis 3 is validated.

The reason may be that, first, technological innovation can promote the intensive development of urbanization in the region by improving the efficiency of resource use and can also provide new solutions for urbanization construction and urbanization problem governance in the region, thereby reducing the spread and spillover of urban problems in the region to surrounding cities. Second, the process of technological innovation is inevitably accompanied by a flow of factors, and cross-city innovation cooperation and exchange can promote knowledge and technology spillover, thereby helping to promote the efficiency of urbanization construction in surrounding areas.

Table 6

Spatial Durbin Model Regression Results

Variables	**(1)**	**(2)**	**(3)**	**(4)**
	SDM-main	**Direct effect**	**Indirect effect**	**Total effects**
LnTI	0.136***	0.142***	1.542**	1.685**
	(0.015)	(0.015)	(0.754)	(0.753)
Rho	0.823***			
	(0.043)			
Controls Variables	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
City Effect	YES	YES	YES	YES

Note: *** p<0.01, ** p<0.05, * p<0.1; Values in parentheses are regression standard errors.

Spatial Attenuation Boundary Analysis

In the previous analysis, we assumed that the spatial spillover effect of technological innovation was uniform between cities. However, this may not occur in real life. Affected by the socio-economic environment and institutional barriers of various cities, the spatial spillover effect of technological innovation weakens with increasing geographical distance between cities. To measure the spatial attenuation boundary of technological innovation, we construct a spatial weight matrix W2 with a distance threshold:

$$W_2 = \begin{cases} \frac{1}{d_{ij}}, & d_{ij} \geq d \\ 0, & d_{ij} < d \end{cases} \tag{7}$$

where d_{ij} is the geographical distance between different cities, and d is the threshold of the spatial attenuation boundary. In this paper, 25 km is used as the starting threshold, and every 25 km is used as the asymptotic distance for continuous regression. This paper uses the above formula and the spatial Durbin model to obtain the following result: an increase in geographical distance between cities will attenuate the spillover effect of technological innovation on new urbanization. Thus verifying hypothesis 3.

Specifically, technological innovation's effectiveness in peripheral cities strengthens with increasing geographic distance before 100 km, reaching its maximum value at approximately 100 km, indicating that the spillover range of technological innovation is mainly distributed in neighboring cities. The reason may be that neighboring cities have slight differences in socio-economic factors, low research and development cooperation, and communication costs, which facilitate the flow of innovative elements between cities and cooperation and communication of technical research and development among enterprises.

After 100 km, the radiation effect of technological innovation on new urbanization in the surrounding cities gradually weakens, and the spillover effect is no longer significant at approximately 350 km. According to the "Construction Outline of a Transportation Strong Country," the radius of urban agglomerations is 300 km, indicating that the spillover effect of technological innovation on new urbanization can radiate within an urban agglomeration. Due to the different levels of development of innovation subjects in different cities and their large dispersion, it is not easy to achieve large-scale and cross-regional diffusion of innovation. In addition, with increasing geographic distance, the differences in administrative management systems between cities will increase. The threshold for technical exchange between administrative regions and enterprise cooperation opportunities will increase, affecting the spillover effect of technological innovation.

Endogeneity Test

The endogeneity test is a statistical method used in econometrics to detect and address endogeneity and refers to a situation where an independent variable is correlated with the error term in a regression model. This correlation can lead to biased and inconsistent parameter estimates. There are several techniques for conducting endogeneity tests, such as the Hausman test, the Durbin-Wu-Hausman test, and the instrumental variable (IV) test. This paper uses the IV test. New urbanization and technological innovation may be endogenous variables. They may have a reverse causal relationship, resulting in biased model estimates. Therefore, this paper adopts the instrumental variable method to attempt to solve the endogeneity problems that may exist in the model.

A lag in technological innovation significantly affects the current performance of urban technological innovation. Therefore, the logarithmic form of per capita technological fiscal expenditure and the lag period of technological innovation are selected as the instrumental variables for the explanatory variable in the original paper. In the two instrumental variable tests, the P values of the non-identifiable and endogenous tests are less than 0.05 and 0.01, respectively. The weak instrumental variable test F values are greater than 10, which shows the rationality of selecting the two instrumental variables.

Table 7 shows the regression results of the instrumental variables in the two stages. The impact coefficients of the two instrumental variables on new urbanization are 0.357 and 0.389, respectively. The sign direction is positive, and both are significant at the 1% level, indicating that after solving the endogeneity problem, the promoting effect of technological innovation on new urbanization is still significant and influential.

Table 7

Regression Results of Instrumental Variables

Variables	**LnTI lagged one period**		**Per capita technological fiscal expenditure**	
	Stage1	**Stage2**	**Stage1**	**Stage2**
	LnTI	**LnNUR**	**LnTI**	**LnNUR**
TI	0.188***	0.357***	0.086***	0.389***
	(0.008)	(0.066)	(0.007)	(0.103)
Controls Variables	YES	YES	YES	YES
Year Effect	YES	YES	YES	YES
City Effect	YES	YES	YES	YES

Note: *** p<0.01, ** p<0.05, * p<0.1; Values in parentheses are regression standard errors.

Robustness Test

Robustness refers to the ability of a model to withstand violations of its assumptions. A robust model is capable of producing reliable estimates even in the presence of outliers in the data, violations of model assumptions, or other issues. This paper conducts robustness tests by replacing explanatory variables, changing indicator measurement methods, and adjusting the sample size. To verify the robustness of the regression results, we conduct robustness tests in both ordinary panel and spatial panel models using the following methods.

First, the previous analysis used the total number of invention patents of the three types as an explanatory variable. However, invention patents account for many of the three types of patents. Therefore, following previous research (Fan, 2021), this section assigns weights of 0.5, 0.3, and 0.2 to invention patents, utility model patents, and design patents, respectively, and uses their weighted average as the new explanatory variable.

Second, the previous analysis used the entropy method to calculate new urbanization, and the entropy method is a weighted method. In this section, the sub-indicators of new urbanization were standardized and manually assigned equal weights. The scores were recalculated and placed in the original equation.

Third, due to the advantages of resources, factors, and policy endowments, the impact of technological innovation on new urbanization may vary among non-provincial capital cities. Therefore, we exclude provincial capital cities from the sample. The robustness test results are slightly different from the regression results in Table 2.

In addition to geographical location and distance factors, economic development differences between cities also affect the spatial spillover effect of technological innovation on new urbanization. This section regresses the model using the nested economic geography matrix instead of the inverse distance matrix. The results indicate no significant change in the direction or magnitude of the regression coefficients between the direct and indirect effects of technological innovation. This indicates that the conclusions drawn earlier have a certain degree of reliability.

Conclusions and Policy Recommendations

Using panel data on 282 prefecture-level cities in China from 2007 to 2020 and a two-way fixed effects model, this paper demonstrates the effectiveness of technological innovation in promoting new urbanization. It examines the technological and financial constraints involved in this process. Through the spatial econometric model, this paper further explores the spatial spillover effect of technological innovation on new urbanization and calculates the spillover boundary.

The significant findings of this paper include the following: First, technological innovation can significantly promote new urbanization, but there is heterogeneity between different cities. The promoting effect of technological innovation shows a non-linear relationship with the threshold value. Second, technological and financial constraints positively moderate this impact. Third, technological innovation has a significant spatial spillover effect on new urbanization. However, as the geographical distance between cities increases, the impact of spatial spillover decreases, with an attenuation boundary of approximately 350 km. Therefore, the countermeasures and suggestions presented in this paper are as follows:

First, adhering to innovation-driven development is critical, and the promotion of new urbanization must give full play to the role of technological innovation. Specifically, on the one hand, local governments have increased their support for the cultivation of technological innovation. By adjusting the structure of research funding, the focus has shifted toward basic research and high-precision and critical fields. Incentive measures for innovation and research and development will increase the frequency of school-enterprise cooperation, reduce barriers to cooperation, and provide intellectual resources for developing new technological innovations. On the other hand, technological innovation in the process of new urbanization in China has a spatial correlation, and the spatial spillover effect of technological innovation will attenuate with increasing geographical distance. All cities should pay attention to the role of the spatial spillover effect of technological innovation in neighboring cities on their cities, pay attention to the development of multi-level, differentiated technological innovation patterns, and better play the radiation role of technological innovation.

Second, market support and financial support systems for technological innovation should be established to improve the marketability of the technological market. Technological innovation is a process of high investment, risk, and return. Therefore, local governments, while controlling the innovation investment mechanism, should formulate diversified policies to encourage and improve the marketability of the technological market, establish university-centered innovation hosts, unite knowledge-based and R&D-oriented companies to gather, encourage the establishment of industry-university-research independent innovation alliances and innovation parks, and eliminate inefficient industries that are not conducive to sustainable development on time. They can help innovative enterprises overcome the technological and financial constraints of technological innovation, provide financial incentives or preferential tax policies to companies or organizations that apply innovative technologies, create a relaxed and flexible institutional environment, stimulate the innovation potential of regional technological innovation themes, and promote the smooth transformation and application of technological innovation results in the technological market.

Third, there are regional differences in the promotional effect of technological innovation on new urbanization. The effect is greatest in the eastern coastal areas to the central and western regions, with the central region, third and fourth-tier cities, and large cities being the most significant. The spatial spillover boundary of technological innovation exceeds 300 km. Therefore, this paper suggests strengthening regional planning coordination, strengthening the cultivation of technological innovation in the cities mentioned above, and increasing the frequency of cross-city communication of new technologies through exchanges between universities and research platforms. Cross-city barriers in technology drive the coordinated development of small and medium-sized cities and balance the economic development gap between different regions.

Limitations and Prospects of the Research

The measure of technological innovation is limited by data availability, and targeted research on different kinds of technological innovation cannot be conducted. While the number of patents is the most common way to measure technological innovation, there may be large differences between different types of technological innovation.

With the proposal of the new development concept, China's new urbanization is entering a new stage. A new round of technological revolution, focusing on artificial intelligence, big data, and new energy, is profoundly changing the world, including China. The new technological revolution will unleash tremendous productivity, transforming the entire process of technological research and development, innovation, and application. Moreover, the mode, method, and path of technological innovation are undergoing fundamental changes. Therefore, under the new technological revolution, the emergence of the new technological innovation model will have a profound impact on new urbanization, which is worthy of further research.

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