

Research Article

Digital Economy's Spatial Implications on Urban Innovation and Its Threshold: Evidence from China

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Received 30 June 2022; Accepted 8 September 2022; Published 27 September 2022

Academic Editor: Yong Xu

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The digital economy has great potential to sustain China's high-quality economic growth and substantially strengthen urban innovation capacity. This paper developed a digital economy index using city-level data from China and measured the level of urban innovation with patents per capita. We used a spatial econometric model to explore the spatial implications of the digital economy on urban innovation, probed into the mechanism by which the digital economy affects urban innovation, and further measured the spatial spillover distance and threshold of the digital economy on urban innovation. The findings suggest that China's digital economy and urban innovation are characterized by spatial aggregation, and the spatial distribution varies from region to region. The digital economy, with strong spatial spillover effects on the innovation capacity of cities in China, may not only enhance the innovation capacity of one city but also drive a simultaneous growth of the innovation capacity in peripheral cities. The analysis of mechanisms indicates that the digital economy enhances local innovation capacity directly through promoting human resources and increasing science and technology spending and drives the improvement of the innovation capacity in peripheral cities through the spatial spillover of human resources and science and technology spending. The effects of the latter one outweigh those of the former one. The analysis of heterogeneity shows that the central, western, and northern regions, where the digital economy is relatively less developed, have the latecomer advantage, and the digital economy has more prominent effects on innovation capacity. Calculating the spillover distance and threshold demonstrates that the digital economy influences urban innovation within a spatial spillover range and threshold of approximately 500 kilometers. Within 500 kilometers, the positive spatial spillover effects prevail, while beyond 500 kilometers, the negative siphon effect prevails. Therefore, it is necessary to consider the differences in the impact and role of the digital economy on urban innovation from a spatial perspective.

1. Introduction

It is a critical time for China's economy, which is undergoing structural change and transforming from high-speed growth to high-quality development. New economic engines represented by the digital economy are gathering strength and will experience explosive growth, producing inestimable energy to further develop China's economy. During a structural transformation of an economy, innovation is essential. Innovation is also necessary to transition from the old drivers to the new engines of China's economic growth

and the nation's shift from an economic powerhouse to a superpower in innovation. As the spatial units of economic growth, cities are where innovation activities and outcomes congregate and urban innovation activities are promoted; strengthening urban innovation capacity has formed the foundation of the nation's innovation strategy. The ongoing development of the digital economy has presented tremendous strategic opportunities for enhancing urban innovation capacity. According to the White Paper on the Global Digital Economy published by the China Academy of Information and Communications Technology (CAICT), in

2020, the global digital economy reached 32.6 trillion US dollars, accounting for 43.7% of the global GDP. China's digital economy was worth 5.4 trillion US dollars, ranking second in the world, rising from 14.2% in 2005 to 38.6% in 2020. Meanwhile, China's aggregate innovation capacity has improved substantially. It ranked 14th in the Global Innovation Index (GII) 2020, making progress by 15 spots compared to its ranking in 2015. The development of the digital economy and the enhancement of innovation capacity in China has aroused extensive attention and provoked thought in academic circles. Can the growing digital economy drive China's urban innovation capacity? How can the digital economy enhance urban innovation capacity? What are the mechanisms? In addition, along with the spatial differentiation of economic growth, the growing digital economy and urban innovation development have also gradually shown the feature of spatial differentiation. As for regions, the digital economy and urban innovation in the eastern coastal regions are ahead of those of China's central and western regions. At a provincial level, the digital economy and urban innovation in capital cities outpace those of other cities. Then, how to account for the impact of the digital economy on urban innovation from the spatial perspective? Can the digital economy cause spatial spillover effects on urban innovation, synergistically enhancing the level of innovation across cities and even regions? Exploring this issue could not only help us consider the role of developing the digital economy rationally and comprehensively, creating appropriate ideas for developing the digital economy and encouraging urban innovation in China but also provide authorities with the basis and valuable references for making decisions on developing the digital economy and strengthening urban innovation.

The rest of this paper comprises several sections. Section 2 reviews and summarizes the relevant research literature. Section 3 sets out the empirical design of this research, including how to create a spatial econometric model, the method for constructing the spatial weight matrix, the decomposition of the spatial effects, the calculation of the spatial spillover distance, the method for mechanism analysis, and the description of variables as well as the sources of data. Section 4 illustrates the results of the empirical analysis in this research, including the results of the estimation of the spatial econometric models, the results of the decomposition of the spatial effects, how to address the endogeneity problem, and the results of robustness testing. Section 5 further explores the spatial implications of the digital economy on urban innovation, including the results of the mechanism analysis, the results of the analysis of heterogeneity, and the results of the calculation of the spatial spillover distance and threshold. Section 6 summarizes and discusses the conclusions and policy recommendations.

2. Literature Review

In recent years, the digital economy's theoretical research and application have become hot topics in academic circles, and scholars have explored relevant issues from various aspects. The first key area of research is the concept and

definition of the digital economy. This term was coined for the first time by Tapscott in his book, in which he explains multiple aspects of the digital economy, such as the next-generation digital economy and its fundamentals, industrial governance against the context of the Internet [1]. In 1998, the US Department of Commerce released a report, the Emerging Digital Economy, which focuses on analyzing the decisive role of information as a core resource in the economy at the macro and microlevels. Thus, the term "digital economy" was officially defined [2]. The widely used definition of the digital economy was proposed in the G20 Digital Economy Development and Cooperation Initiative passed at the 2016 G20 Hangzhou Summit. In this initiative, the digital economy refers to a broad range of economic activities that include using digitized information and knowledge as the key factor of production, modern information networks as an important activity space, and the effective use of information and communication technology as an important driver of productivity growth and economic structural optimization [3]. The China Academy of Information and Communications Technology (CAICT) provided further supplementation and clarification for the definition, arguing that the digital economy shall include not only the emerging digital industries—such as the Internet, cloud computing, big data, the Internet of Things, and e-commerce—but also the digital transformation of traditional industries. As there has been no universally agreed variable for measuring the digital economy, many institutions and scholars have adopted different indicator systems to measure the digital economy. The United Nations World Bank, International Monetary Fund, and OECD defined relevant matters concerning the digital economy and provided an overall approach for measuring the digital economy in the System of National Accounts 2008. Scholars and institutions, such as the US Department of Commerce, International Telecommunication Union, and CAICT, also evaluated and measured the digital economy by using multiple evaluation models, such as the TOPSIS method, entropy weight method, principal component analysis (PCA) approach, and expert scoring method [4–7]. The second key area of research is the digital economy by country. Scholars performed calculations and studies on the degree of digital economy development in major economies, such as the measures of the digital economy in China [8, 9]; the patterns of spatial distribution, and regional differences of the digital economy in China [10, 11]; the measurement approaches and development trend of the digital economy in the USA [12, 13]; the development and drivers of the EU digital economy [14–16]. The last key area of research is the impact of the digital economy on different aspects of economic growth. Scholars discussed the impact of the digital economy on economic growth [17, 18]; industrial structural upgrading [19, 20]; Ecology and Environment [21, 22]; and total factor productivity [23, 24]. Their findings proved that the digital economy could prominently play a positive role and indicated that the digital economy could have a positive impact on every aspect of economic growth.

The impact of the digital economy on innovation and entrepreneurial activities has been one of the most active

fields of research in recent years. With the growing digital economy, innovation and entrepreneurial activities are increasingly influenced by the digital economy, and the digital economy has become an essential factor influencing entrepreneurial activities and innovation capacity. Many papers on the digital economy and innovation activities were published. Most scholars explored the impact of the digital economy on corporate innovation activities mainly at a microlevel, such as the influence of the digital economy on business model innovation [25, 26]; the role of digital transformation in innovation activities [27, 28]; the application of the digital technologies and corporate innovations [29, 30]; the influence of artificial intelligence on corporate innovation activities [31, 32]. These studies found that digital economy development can play a significant role in the process of corporate innovation and serves as an essential factor for enterprises that conduct innovation activities. Many microlevel studies have explored the impact of the digital economy on corporate innovation activities; however, not so many papers discussed the outreach and impact of the growing digital economy on urban innovation capacity at a macrolevel. Since the digital economy is the main direction of future economic development, cities, as the main body of the regional economy, will inevitably increase their investment in the digital economy to continuously improve their capacity and level of innovation to gain a sufficient leading edge in economic competition. Some papers mainly focused on the effects of the digital economy on urban innovation. For example, Caragliu and Del Bo [33] used building a smart city as a quasinnatural experiment to measure the level of the digital economy and reached the conclusion that European cities, with a higher level of smart cities, may tend to apply for more patents and therefore improve urban innovation capacity and levels. J. Li and B. Li [34] used the digital financial inclusion index to measure the level of the digital economy and adopted the difference-in-difference (DID) model to explore the effects of digital financial inclusion on innovation in China's cities. Li found that promoting digital financial inclusion could increase the number of patents in cities by 5.3%, and digital financial inclusion could play a positive role in urban innovation. Wang et al. [35] discussed the effects of the digital economy on green innovation at a city level and confirmed the positive effects of the digital economy on urban green innovation. Lu et al. [36] studied the relationship between the digital economy and urban innovation capabilities from a macro perspective, with a focus on the role of the innovation environment, concluded that the digital economy can significantly strengthen a city's innovation capabilities and explored the mechanisms of the digital economy to influence urban innovation.

The above studies showed that much microlevel research on the effects of the digital economy on innovation activities has been carried out. However, the macrodiscussion on the impact of the digital economy on the innovation capability at the city level is insufficient. Available literature has, to a certain extent, explored how the digital economy can affect a city's capacity and level of innovation, but it is still far from being sufficient. The following flaws and weaknesses can also be found in those papers. First, most research on the digital

economy and urban innovation does not take into account the spatial effects and spatial implications. Some latest research believes that the digital economy, as a knowledge-intensive economy, can push the geographical boundaries and have an impact on the economic activities in other regions, resulting in strong spatial spillover effects. Ding et al. [37] found that the digital economy displays pronounced spatial spillover effects when promoting high-quality economic development. The digital economy can not only directly promote the high-quality development of the local economy but also play a positive role in the high-quality economic growth in other surrounding areas. Ma and Zhu [38] also identified that the digital economy in a region can play a role in the high-quality green development in surrounding areas through spatial spillover effects. Therefore, ignoring the spatial implications and spillover effects may produce biased coefficient estimates for the impact of the digital economy on urban innovation, which could hinder us from understanding the impact of the digital economy on urban innovation. Second, some research on the impact of the digital economy on urban innovation analyzed the mechanisms, i.e., how and through what channels the digital economy affects urban innovation, but those mechanisms have not undergone sufficient research. Particularly, if the spatial implications and spillover effects are taken into account, it needs to further discuss the mechanisms of the digital economy to influence urban innovation. Last, currently published research verified the trend and size of the impact of the digital economy on urban innovation, and almost all of them turned out to be positive. However, will this conclusion be somehow different from a spatial perspective? How long is the meaningful spatial spillover distance of the digital economy for urban innovation, and how extensive is the range that it takes effect? In other words, within what distance can the growing digital economy in a city influence and drive the enhancement of innovation capacity in other cities? Is there any threshold for such impetus and enhancement? They are seldom mentioned in currently published papers.

This paper's novel features and marginal contributions are to improve the weaknesses of the above-given research. First, we examined the impact of the digital economy on urban innovation from a spatial perspective and found that both the digital economy and urban innovation are characterized by spatial aggregation. The digital economy can drive innovation in local cities to a higher level and boost peripheral cities' innovation. Therefore, while developing the digital economy and improving the innovation capacity, the local areas need to attach importance to the synergy across regions. This is of great significance for developing the intercity digital economy and enhancing innovation capacity. Second, this paper sought to enrich and improve the mechanisms of the digital economy to influence urban innovation and identified how the digital economy had improved urban innovation capacity in the context of spatial spillover effects. We not only focused on the direct mechanisms of the digital economy to influence urban innovation but also analyzed how the spatial spillover effects of the digital economy may work on urban innovation. Last, we

explored the spillover distance, range, and threshold of the digital economy to influence the spaces of urban innovation. Different from most studies, we found that the digital economy can only strengthen the innovation capacity of other cities within a distance of 500 kilometers that roughly reaches the provincial boundaries; beyond this range, the digital economy often has a negative siphon effect on urban innovation, indicating that the digital economy could force regions to scramble for urban innovation. This finding is this paper's most significant marginal contribution and a novel feature. We hope it will provide meaningful references for theorists and policy-makers who seek to appropriately understand the impact of the digital economy on urban innovation and improve the strategies for developing the digital economy and urban innovation.

3. Design of Empirical Research on the Impact of the Digital Economy on Urban Innovation

3.1. Building the Spatial Econometric Models for Empirical Research. Spatial econometrics is a branch of econometrics that originated in the 1970s and 1980s. It refers to multiple methods for estimating and testing spatial effect models by adding factors into an empirical model to measure the spatial implications of variables. Over the last decades, academic circles have been increasingly actively engaged in spatial econometric theories and empirical applications, which have become a widely used modeling approach in the field of economics now. For research on spatial implications and spatial spillover, spatial econometric models have often been a preferred option for empirical modeling. The spatial econometric models mainly include the spatial lag model (SLM), the spatial error model (SEM), and the spatial Durbin model (SDM) [39]. These models are presented in equations (1)–(3):

(1) the Spatial Lag Model:

$$y_{it} = a + \rho \sum_{i=1}^n w_{ij} y_{jt} + \beta x_{it} + u_i + v_t + \varepsilon_{it}, \quad (1)$$

(2) the Spatial Error Model:

$$y_{it} = \alpha + \beta x_{it} + \mu_{it}, \mu_{it} = \rho \sum_{i=1}^n \mu_{jt} + \varepsilon_{it}, \quad (2)$$

(3) the Spatial Durbin Model:

$$y_{it} = \alpha + \rho \sum_{i=1}^n w_{ij} y_{jt} + \beta x_{it} + \theta \sum_{i=1}^n w_{ij} x_{jt} + u_i + v_t + \varepsilon_{it}, \quad (3)$$

where y_{it} is the dependent variable and refers to the level of urban innovation we study herein; x_{it} is the explanatory variable and includes the level of the digital economy as the core explanatory variable and a variety of control variables that affect the level of urban innovation. w_{ij} is the spatial weights matrix; $w_{ij} x_{jt}$ represents the spatial lag term of the dependent variable; ρ represents the spatial autocorrelation

coefficient. $w_{ij} x_{jt}$ represents the spatial lag term of the explanatory variable; μ_{it} is the error term; μ_{jt} is the spatial lag term of the error term; u_i and v_t represent individual and time fixed effects, respectively; ε_{it} is a disturbance term. Among these three spatial econometric models, the spatial Durbin model (SDM) is the most common one, and LeSage [40] compared and discussed these three spatial econometric models in his paper. In his opinion, the SDM is a spatial econometric model that can produce unbiased estimates even if there are modeling mistakes. This paper selected the optimal one from the SLM, SEM, and SDM through the model selection tests and used it in the following empirical analysis.

3.2. Method for Constructing the Spatial Weights Matrix.

The spatial weight matrix is essential when a spatial econometric model is used for empirical analysis. In this paper, we chose the spatial distance weight matrix, which is presented in the following equation:

$$w_{ij} = \begin{cases} \frac{1}{d_{ij}^2}, & (i \neq j), \\ 0, & (i = j), \end{cases} \quad (4)$$

where d_{ij} is the straight-line distance between two cities. If the straight-line distance between two locations is longer, then the value of the matrix element $1/d_{ij}^2$ is smaller, and the degree of interaction is lower. We observed the spatial implications of each observation by assigning different weights to the observation value, thereby avoiding the homogenized defects and weaknesses of observation values in conventional econometrics.

3.3. Spatial Autocorrelation Test. A spatial correlation test was performed on the dependent and core explanatory variables before the spatial econometric analysis. In spatial econometrics, the variables at close geographic locations or adjacent areas are characterized by a tendency to approach each other. Generally, Moran's I is used to perform the spatial autocorrelation test. Values of Moran's I range from -1 to 1. Values of Moran's I between 0 and 1 indicate positive spatial autocorrelation, which means locations with high values cluster together. Values of Moran's I between -1 and 0 indicate negative spatial autocorrelation, which means locations with high values and low values are spatially mixed. The way to calculate Moran's I is presented in the following equation:

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

Apart from the global spatial autocorrelation test in equation (5), we performed a local spatial autocorrelation test. The Moran scatterplot was used to classify the cluster patterns of all locations. The four quadrants in the Moran scatterplot represent the clusters that fall into the High-High (H-H), Low-High (L-H), Low-Low (L-L), and high-

low (H-L) categories. We determined which cluster the digital economy and urban innovation at the level of Chinese cities belongs to by classifying the clusters.

3.4. Decomposition of the Spatial Effects. As we explored the spatial implications of the digital economy on urban innovation in this paper, it was necessary to study further the spatial spillover effects of the digital economy on urban innovation. However, as the spatial Durbin model includes spatial lag terms of both the independent variable and dependent variable due to modeling, the coefficient estimates of the independent variable relative to the dependent variable cannot directly reflect the impact of the independent variable on the dependent variable. In other words, it is impossible to calculate the spatial spillover effects of the digital economy on urban innovation through model estimation. In response, we adopted the method used by LeSage and Pace: divide the total effects of the digital economy on urban innovation into direct effects and indirect effects by decomposing the partial differential equation [41]. The direct effects represent the direct impact of the local digital economy on local urban innovation. In contrast, the indirect effects refer to the impact of the local digital economy on urban innovation in peripheral areas, which means the spatial spillover effects [42]. We changed the spatial Durbin model in equation (3) into the following equation:

$$\begin{aligned} y &= \sum_{r=1}^m \beta_r (I - \lambda w)^{-1} x_r + (I - \lambda w)^{-1} \varepsilon, \\ \varepsilon &= \sum_{r=1}^m S_r(w) x_r + (I - \lambda w)^{-1} \varepsilon, \end{aligned} \quad (6)$$

where $s_r(w) = \beta_r (I - \lambda w)^{-1}$ is a matrix of order m . We further transformed equation (6) into a matrix, as shown in the following equation:

$$\begin{pmatrix} y_1 \\ y_2 \\ \dots \\ y_m \end{pmatrix} = \begin{pmatrix} s_r(w)_{11} & s_r(w)_{12} & \dots & s_r(w)_{1m} \\ s_r(w)_{21} & s_r(w)_{22} & \dots & s_r(w)_{2m} \\ \dots & \dots & \dots & \dots \\ s_r(w)_{m1} & s_r(w)_{m2} & \dots & s_r(w)_{mm} \end{pmatrix} \begin{pmatrix} x_{1r} \\ x_{2r} \\ \dots \\ x_{mr} \end{pmatrix} + (I - \lambda w)^{-1} \varepsilon. \quad (7)$$

where the total effects of the digital economy on urban innovation is the average value obtained by summing up in the matrix, as shown in equation (8). It represents the overall effect of the digital economy on urban innovation across all regions.

$$\text{Total effects} = \frac{1}{n} \sum_{i=1}^n \sum_{j=1}^n s_r(w)_{ij} = \frac{1}{n} i_n' s_r(w) i_n. \quad (8)$$

The impact of the local digital economy on local urban innovation is called the direct effects, such as the effects of Beijing's digital economy on Beijing's urban innovation and those of Tianjin's digital economy on Tianjin's urban

innovation. In equation (7), it is the element that lies on the main diagonal of the matrix $s_r(w)$. The computing method is shown in the following equation:

$$\text{Direct effects} = \frac{1}{n} \text{trace}[s_r(w)]. \quad (9)$$

The impact of the local digital economy on urban innovation in peripheral areas is called the indirect effects, such as the effect of Shanghai's digital economy on urban innovation in peripheral cities, Hangzhou, Suzhou, and Nanjing. In equation (7), it is the element that lies outside the main diagonal of the matrix $s_r(w)$ and the total effects minus the direct effects, as shown in the following equation:

$$\text{Indirect effects} = \frac{1}{n} \{i_n' s_r(w) i_n - \text{trace}[s_r(w)]\}. \quad (10)$$

3.5. Calculation of the Spillover Distance and Range. With the decomposition of the spatial effects, we obtained the spatial implications and spillover effects of the digital economy on the level of urban innovation. We further explored the distance such spatial implications cover and the range within which the spillover effects occur. In other words, we attempted to explore the distance within which the digital economy can influence urban innovation. Therefore, we adopted the method Yu et al. used to calculate the threshold for the spillover effects of the digital economy on urban innovation by setting different thresholds and estimating with spatial weights matrices [43]. The thresholds are set in the following equation:

$$w_{ij}(T) = \begin{cases} \frac{1}{d_{ij}^2}, & d_{ij} \geq T, \\ 0, & d_{ij} < T, \end{cases} \quad (11)$$

where d_{ij} represents the straight-line distance between two cities, and T represents the threshold. 50 kilometers was set as the initial distance, and every 50 kilometers as a threshold (such as 50, 100, 150, and 200 kilometers) to create different spatial weights matrices. The range of spatial effects and the threshold of the spillover effects were obtained by analyzing the changes in the values of the direct and indirect effects of the digital economy on urban innovation at various distances.

3.6. Mechanism of the Empirical Research. We applied the mediation effect for mechanism analysis to identify how the digital economy acts on urban innovation. First, we performed the regression of the digital economy as the core explanatory variable relative to the mediator variable and then the regression of the mediator variable relative to urban innovation, and finally added the mediator variable to the benchmark regression model [44], as shown in the following equations:

$$Z_{it} = \alpha + \rho_z \sum_{i=1}^n w_{ij} Z_{jt} + \beta x_{it} + \theta \sum_{i=1}^n w_{ij} x_{jt} + u_i + v_t + \varepsilon_{it}, \quad (12)$$

$$y_{it} = \alpha + \rho \sum_{i=1}^n w_{ij} y_{jt} + \beta_z Z_{it} + \theta_z \sum_{i=1}^n w_{ij} Z_{jt} + u_i + v_t + \varepsilon_{it}, \quad (13)$$

$$y_{it} = \alpha + \rho' \sum_{i=1}^n w_{ij} y_{jt} + \beta' x_{it} + \theta' \sum_{i=1}^n w_{ij} x_{jt} + \beta'_z Z_{it} + \theta'_z \sum_{i=1}^n w_{ij} Z_{jt} + u_i + v_t + \varepsilon_{it}, \quad (14)$$

where for the sake of brevity, y_{it} represents urban innovation; x_{it} represents the digital economy solely; Z_{it} represents the mediator variable. Only the following conditions are met could we prove that the digital economy does influence urban innovation through the mediator variable Z_{it} . First, the coefficient estimates of the digital economy relative to the mediator variable shall be significant. Second, the coefficient estimates of the mediator variable relative to urban innovation shall be significant. Lastly, when the mediator variable is added to the benchmark model, the coefficient estimate of the impact of the digital economy on urban innovation decreases or is no more significant. While in the spatial Durbin model, the total effects of the digital economy on urban innovation are decomposed into direct effects and indirect effects. Therefore, the analysis of the mechanisms of mediation effect testing should also be divided into two sections: direct effects and indirect effects. In this way, we can understand the mechanisms of how the digital economy acts on and influences urban innovation from the perspectives of spatial implications and spillover effects.

Then, how to identify the mediator variables for the impact of the digital economy on urban innovation? Generally, it is impossible to achieve scientific and technological innovations in cities without human engagement. All innovation activities involve human participants. When the high-caliber talent pool in a city expands, the city will have greater potential for innovation, which could be translated into more innovative output, taking urban innovation to a higher level. Therefore, human resources may be a vital mechanism of the digital economy to influence urban innovation. In addition, strong government support is necessary for urban scientific and technological innovations. Governments generally support local scientific and technological innovation activities via financial expenditure. The more they spend on science and technology, the more robust protection and support for innovation activities they will provide, and thus the more likely to boost urban innovation in local areas. For this reason, science and technology spending may also be a vital mechanism of the digital economy to influence urban innovation. The mechanism analysis further explored whether the digital economy acts on urban innovation through human resources and scientific and technological innovations.

3.7. Variable Explanation and Date Sources. The variables used in this paper are set out as follows: the first one is the explained variable, Urban Innovation. This paper measured urban innovation with city-level patents per capita. The more patents per capita, the higher the level of urban innovation is. The city-level data for patents granted include the number of invention patents, utility model patents, and design patents granted. In this paper, the sum of those three was used to compute the patents per capita in a city. The core explanatory variable is the Digital Economy. The approach from Zhao et al. [45] was applied herein for measuring the city-level digital economy index. The composite digital economy index was calculated as the average of five standardized indicators, including the number of Internet and broadband users per 10,000 people, the number of practitioners in the computer service and software industries per 10,000 people, the total telecommunication business per capita, the number of mobile users per 10,000 people, and the digital financial inclusion index. Other control variables are set out as follows: (1) Economic Development. The level of the local economy could influence innovation activities, so the control variable Economic Development was incorporated and measured by local GDP per capita. (2) Population Size. The larger and denser population in a local area indicates the growing market size, which can provide a broader market space for innovative activities and innovative products. The Population Size was measured by the total local population. (3) Fixed Investment. Increasing investment in local fixed assets and improving infrastructure can provide innovation activities with more infrastructure support. This indicator was measured by the local investment in fixed assets per capita. (4) Industrial Level. A higher local industrial level can offer more industrial support and initial incubation for local innovation activities and provide innovation activities with more technological support. The industrial level was measured by local gross output by industry per capita. (5) Wages level. The higher wage level indicates that the overall local benefits are favorable, which can offer better benefit support and create a better environment for entrepreneurs and innovation activities. This indicator was measured by local wage per capita. (6) Road Condition. If road conditions improve, they can facilitate accessibility inside and outside cities, benefit people's mobility and communication and accelerate the dissemination of knowledge and information. This indicator was expressed as the local road density. (7) Urbanization Level. With a higher local urbanization level and improved urban function, it is more likely to provide urban innovation activities with high-quality public services. This indicator was expressed as the local urbanization level. (8) Financial Development. The better financial development and more developed financial market in the region can better provide urban innovation and entrepreneurial activities with the necessary financial support and easy access to financing and facilitate the healthy development of urban innovation. This indicator was expressed as the total local loans and deposits per capita. (9) Foreign Investment. It reflects the degree of cooperation between the local area and international markets. More state-of-the-art technology and management

experience will be introduced into places where foreign investment is more active, significantly contributing to local urban innovation activities. This indicator was expressed as the local foreign direct investment. Lastly, there are mediator variables, mainly Human Resources and Technology Spending. They were expressed as the number of local college students per 10,000 people and local government spending on science and technology per capita, respectively. In addition, several variables, such as Urban Innovation, Economic Development, Population Size, Fixed Investment, Industrial Level, Wages Level, Road Condition, Financial Development, Foreign Investment, Human Resources, and Technology Spending, were subject to the logarithmic transformation.

The data sources used in this paper include but are not limited to China City Statistical Yearbook, CEIC, and China Economic and Social Data Platform (CNKI). The digital financial inclusion index used for creating the digital economy index is based on The Digital Financial Inclusion Index of China prepared by Guo (2020) from the Institute of Digital Finance, Peking University [46]. The results for the descriptive statistics of each variable are shown in Table 1.

4. Spatial Econometric Analysis of Empirical Findings on the Impact of the Digital Economy on Urban Innovation

4.1. Results of the Spatial Autocorrelation Test of Urban Innovation and Digital Economy. When exploring the impact and role of the digital economy on urban innovation through spatial econometric analysis, the first step was to test the spatial autocorrelation of urban innovation and the digital economy and explore its spatial correlation and clustering features. The spatial econometrics was not applicable until this test was passed and all conditions were satisfied. Using the Moran's I , we carried out the spatial autocorrelation test, and the test results are shown in Table 2. In Table 2, from 2011 to 2020, all test values of the Moran's I on urban innovation and the digital economy are positive and significant, above 1%. This indicates that in space, the two variables: urban innovation and digital economy demonstrate a positive and strong spatial correlation, that is, the feature of spatial clustering. From the perspective of the urban space, both the urban innovation and digital economy are characterized by high-high clusters and low-low clusters. These are in line with reality: in the city clusters in the wealthy east coastal areas in China, the level of urban innovation and the digital economy index is higher, while in most western cities, these two indicators are lower, with large spatial differences and a distinct feature of clustering. Therefore, using spatial econometrics to analyze the impact of the digital economy on urban innovation is reasonable.

4.2. Spatial Clustering Features of Urban Innovation and Digital Economy. After analyzing the spatial autocorrelation feature of urban innovation and digital economy, the second step was to explore their spatial clustering features divided by the Moran scatterplot. Cities in the upper right quadrant

are identified as the high-high ("H-H") cluster, where the level of urban innovation and the digital economy index are higher. Cities in the upper left quadrant are identified as the low-high ("L-H") cluster, where cities with a lower level of urban innovation and digital economy index are surrounded by those with higher indicators. Cities in the lower left quadrant are identified as the low-low ("L-L") cluster, where the level of urban innovation and the digital economy index are lower. Cities in the lower right quadrant are identified as the high-low ("H-L") cluster, where cities with a higher level of urban innovation and digital economy index are surrounded by those with lower indicators. The results are shown in Figures 1 and 2. The two figures suggest that, for urban innovation and digital economy indicators, most cities are in the upper right and lower left quadrants and belong to the H-H cluster and L-L cluster, respectively. This aligns with the results of the spatial autocorrelation test. We also provide a spatial distribution map of China's digital economy and urban innovation in 2020 (Note: this map is based on the map numbered GS (2016) No. 1063, downloaded from the standard map service website of the China Bureau of Surveying, Mapping and Geographic Information, and the base map has not been modified), as shown in Figures 3 and 4. It can be seen that the level of the digital economy and urban innovation is higher in eastern coastal regions and capital cities of China. In comparison, the typical cases in the central and western regions are the L-L cluster with a lower level of the digital economy and urban innovation.

After we found that both urban innovation and digital economy demonstrate a positive and strong spatial correlation and an identical spatial clustering pattern, we explored the relationship between urban innovation and urban economy. The scatterplot was used to express their relationship, and a scatterplot with a line of best fit and the linear equation were obtained, as shown in Figure 5. This figure indicates a perfect positive correlation between them. The line of best fit with a positive slope and the value of r (0.534) for the linear relationship both indicate that, irrespective of other factors, the digital economy has positive implications on urban innovation and strong explanatory power concerning urban innovation. This should be further analyzed and explored by empirical analysis.

4.3. Estimation Results of Spatial Econometric Models for Impact of the Digital Economy on Urban Innovation. Table 3 shows that the OLS model, the SLM, SEM, and SDM were used to analyze the impact of the digital economy on urban innovation. The spatial Durbin models included the random effects model, city fixed effects model, year fixed effects model, and individual-year fixed effects model. The model estimation results are presented in Rows (1)–(7) of Table 3. In the OLS model, the coefficient estimate of the digital economy relative to urban innovation is 1.691, positive and significant at the 1% level. In the spatial econometric models, the coefficient estimates of the digital economy relative to urban innovation are 0.564, 1.157, 1.102, 0.961, 1.414, and 0.961, respectively, all positive and

TABLE 1: Results for the descriptive statistics of variables.

Variable	Variable explanation	N	Mean	Sd	Min	Max
lnUI	Urban innovation	3370	1.609	0.988	0.000	4.927
DE	Digital economy	3370	0.178	0.080	0.017	0.679
lnED	Economic development	3370	10.653	0.590	8.707	12.324
lnPS	Population size	3370	5.336	1.425	0.277	8.885
lnFII	Fixed investment	3370	6.519	1.661	0.363	10.663
lnIL	Industrial level	3370	6.812	2.197	0.008	12.374
lnWL	Wages level	3370	10.921	0.328	9.753	12.207
lnRC	Road condition	3370	0.640	0.293	0.029	1.421
UL	Urbanization level	3370	52.313	17.205	7.370	100.000
lnFD	Financial development	3370	2.353	0.687	0.914	4.835
lnFOI	Foreign investment	3370	1.243	1.166	0.000	5.498
lnHR	Human resources	3370	1.441	1.171	0.000	5.110
lnTS	Technology spending	3370	3.875	1.922	0.000	9.011

TABLE 2: Spatial autocorrelation test results of urban innovation and digital economy.

Year	lnUI (urban innovation)		DE (digital economy)	
	Moran's I	p-value	Moran's I	p-value
2011	0.471***	0.001	0.258***	0.001
2012	0.476***	0.001	0.214***	0.001
2013	0.484***	0.001	0.257***	0.001
2014	0.474***	0.001	0.251***	0.001
2015	0.472***	0.001	0.252***	0.001
2016	0.461***	0.001	0.244***	0.001
2017	0.456***	0.001	0.258***	0.001
2018	0.471***	0.001	0.231***	0.001
2019	0.464***	0.001	0.185***	0.001
2020	0.436***	0.001	0.148***	0.001

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively.

Moran scatterplot (Moran's I = 0.1476 and P- value = 0.0000) DE2020

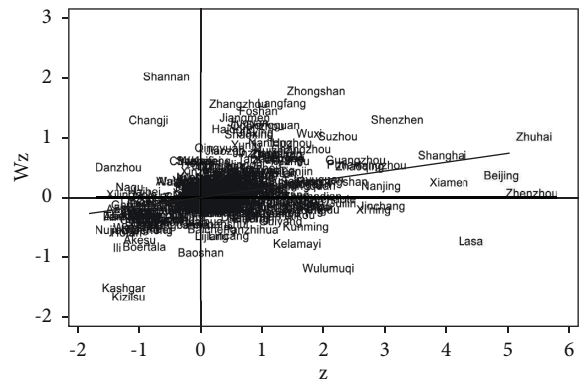


FIGURE 2: Moran's I in spatial clustering of digital economy in 2020.

Moran scatterplot (Moran's I = 0.4356 and P- value = 0.0000) lnUI2020

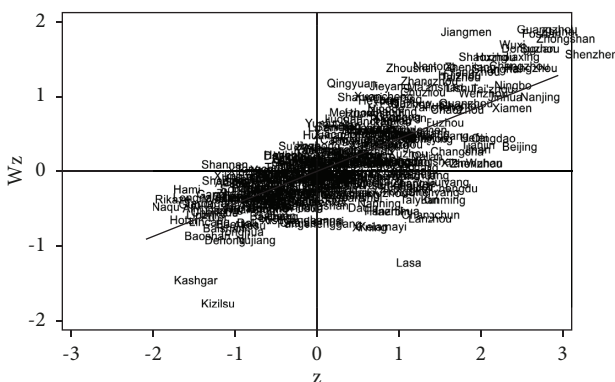


FIGURE 1: Moran's I in spatial clustering of urban innovation in 2020.

significant at the 1% level. Those coefficient estimates are less than that obtained from the OLS model (1.691), indicating that the OLS estimation may have a higher coefficient estimate which needs to be corrected by taking into account the spatial factors and applying the spatial econometric

approach. In addition, the spatial autocorrelation coefficient estimates in Rows (1)–(7) are 0.640, 0.743, 0.748, 0.696, 0.695, and 0.696, respectively, demonstrating the obvious spatial spillover effects of urban innovation. 1% of the level of urban innovation in a region improved would drive the level of urban innovation in peripheral cities to increase by about 0.7%, playing a very significant role as impetus and enhancement.

Table 3 provides the analysis results for the SLM, SEM, and SDM with different effects. Thus, the optimal model was selected from those models for further analysis. Table 4 represents the model selection tests for the spatial econometric approach. In the first step, model selection tests were run, in which the optimal model was chosen from the SLM, SEM, and SDM. This was accomplished through the Wald and LR tests, as shown in Table 4. The corresponding chi-square test values are 202.94, 145.90, and 72.89, and the corresponding p-values are all 0.001. It indicates that the SDM model is optimal among these three models. The next step was the fixed effects tests. The results of the Hausman test show that the SDM needs to use fixed effects. In the final step, we identified which form of the fixed effects model should be applied for the SDM. The corresponding results of the LR test are 31.50 and 4351.18, and the p-values are 0.001

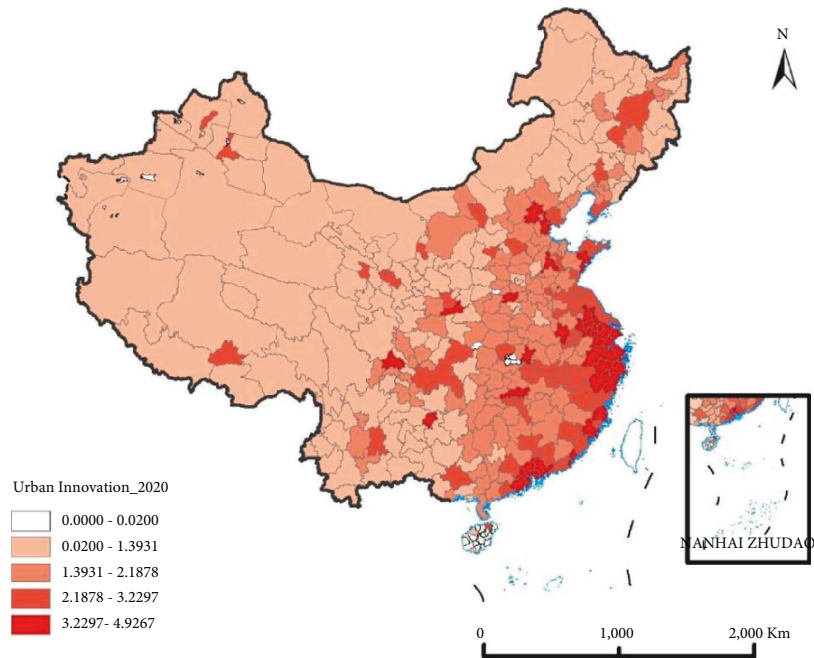


FIGURE 3: Spatial distribution map of China's urban innovation in 2020.

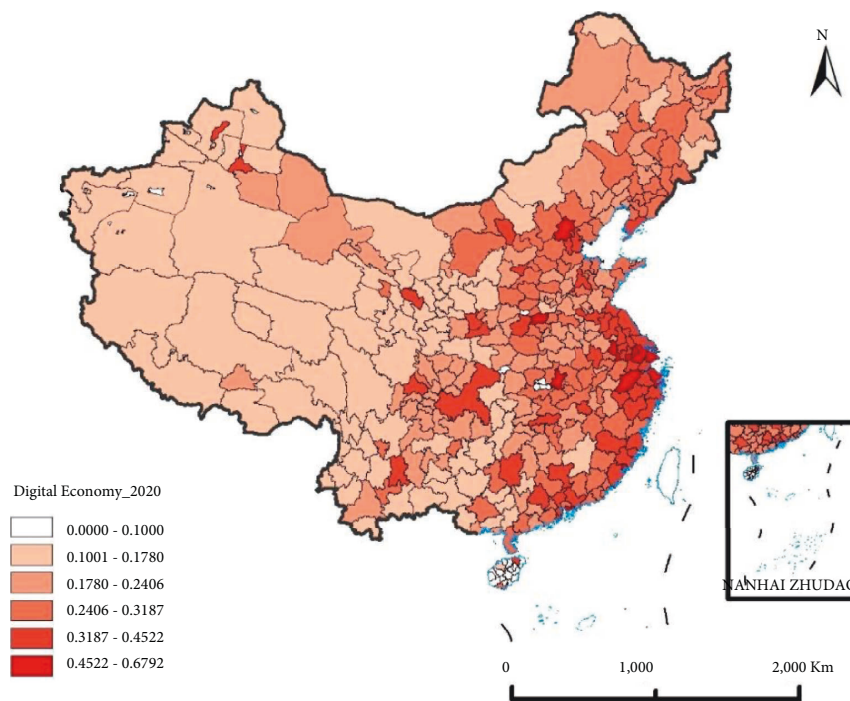


FIGURE 4: Spatial distribution map of China's digital economy in 2020.

and 0.001. It indicates that the individual-year fixed SDM should be selected with respect to the fixed effects. Therefore, the optimal model used in the following empirical analysis is the individual-year fixed SDM.

4.4. Decomposition of the Spatial Effects of the Digital Economy on Urban Innovation. In spatial econometrics, the results of the SDM are relatively special as the coefficient estimates of

its explanatory variables cannot directly reflect its impact on the explained variables. Therefore, the method of decomposing the spatial effects was applied to classify the impact of the digital economy on urban innovation into direct, indirect, and total effects. The direct effects refer to the direct effects of the local digital economy on local urban innovation, and the indirect effects refer to the spatial spillover effects of the local digital economy on urban innovation in peripheral regions. The results are shown in Table 5. In

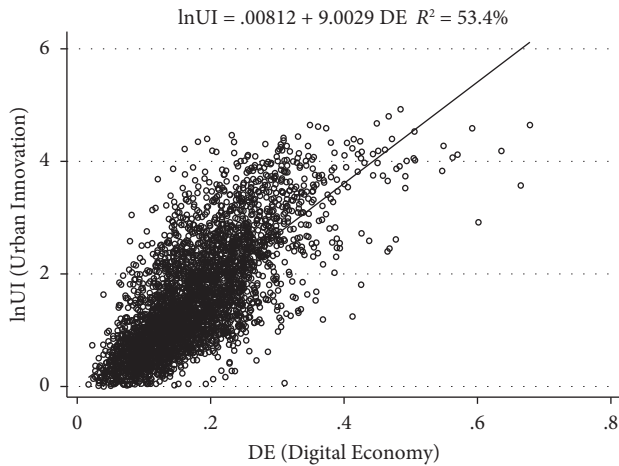


FIGURE 5: Fitted scatter plot of urban innovation and digital economy.

Table 5, the coefficient estimates of the direct effects, indirect effects, and total effects of the digital economy on urban innovation are 1.095, 4.368, and 5.463, respectively; they are all positive and significant at the 1% level, which indicates that the development of the local digital economy can not only directly promote local urban innovation but also have a positive effect on the level of urban innovation in peripheral regions as there are strong spatial spillover effects. Therefore, we must encourage regions to promote the remarkable progress of the digital economy, enhance the level of the digital economy, and, on that basis, remarkably drive the innovation in local and peripheral regions to a higher level, which helps create a countrywide environment conducive to urban innovation driven by digital economy and growth driven by innovation.

Next, we analyzed the impact of the control variables on urban innovation. In control variables, Economic Development (lnED) has positive and significant direct effects on urban innovation. In contrast, its indirect effects are negative and significant, which shows that local economic development can promote local urban innovation only but has a negative siphon effect on the urban innovation of peripheral regions. The indirect and total effects of Population Size (lnPS) and Fixed Investment (lnFII) on urban innovation are all positive and significant, while their direct effects are not significant, indicating that the population size and fixed investment have particularly strong spatial spillover effects on urban innovation. Foreign Investment (lnFOI) and Industrial Level (lnIL) have no significant direct effects or strong spatial spillover effects. Wages Level (lnWL) has positive and significant direct effects on urban innovation, indicating that higher local wages would better boost local urban innovation. However, local wages have neither significant indirect effects nor strong spatial spillover effects on urban innovation in peripheral regions. The direct, indirect, and total effects of Road Condition (lnRC) on urban innovation are all positive and significant, which indicates that the road condition can not only substantially promote local urban innovation but also enable a massive increase in the

urban innovation of peripheral regions. Urbanization Level (UL) has positive and significant direct effects on urban innovation, indicating that an increase in the local urbanization level may directly drive local urban innovation. However, its indirect effect is not significant, showing that the urbanization level has no strong spatial spillover effects on urban innovation in peripheral regions. The direct effects of Financial Development (lnFD) on urban innovation are positive and significant, indicating that a higher level of financial development tends to more effectively provide financial support for local urban innovation activities and drive urban innovation. However, the indirect effects of Financial Development on urban innovation are negative and significant, indicating that better financial development in local areas is easy to impose a siphon effect as it attracts innovation activities in peripheral regions to flow into the local areas and weakens the urban innovation capacity of peripheral regions at the expense of urban innovation improvement of peripheral regions.

4.5. Addressing the Endogeneity Problem of Impact of the Digital Economy on Urban Innovation. For the impact of the digital economy on urban innovation, the endogeneity problem arises due to the reciprocal cause-and-effect relationships between the digital economy and urban innovation; that is, the digital economy may influence urban innovation and vice versa. Therefore, instrumental variables were used to address the endogeneity problem in this section. When selecting the instrumental variables, we considered two criteria: correlation and exogeneity. For correlation, an instrumental variable must be correlated with the digital economy. For exogeneity, an instrumental variable must be uncorrelated with other factors that affect urban innovation. We adopted panel models to perform the estimation of instrumental variables. Meanwhile, instrumental variables with a spatial factor were taken into account. In this paper, the spatial lag term and spatio-temporal lag term of the digital economy were selected as the instrumental variables. The spatial lag item of the digital economy is the average value of the digital economy of other cities except for the city in the province where the city is located. The spatio-temporal lag term is the spatial lag term with a lag of one period. From the perspective of correlation, the digital economy of cities in the same province is highly correlated, even though the lag period is considered, which meets the assumption of correlation. From the perspective of exogeneity, the possibility that the spatial lag term and spatio-temporal lag term of the digital economy are correlated with other factors that affect urban innovation is limited, which generally meets the requirements of exogeneity. The results of the instrumental variables estimation are shown in Table 6.

In Table 6, with the spatial lag term and spatio-temporal lag term of the digital economy as instrumental variables, the instrumental variables estimates for the impact of the digital economy on urban innovation are 2.856 and 2.585, both positive and significant at the 1% level. The coefficient and significance level are consistent with the results of OLS estimation and spatial econometric model estimation.

TABLE 3: Results of spatial econometric analysis for impact of the digital economy on urban economy.

Variable	SDM						
	OLS (1)	SAR (2)	SEM (3)	RE (4)	Individual-FE (5)	Year-FE (6)	Individual-year-FE (7)
DE	1.691*** (8.37)	0.564*** (3.46)	1.157*** (6.52)	1.102*** (6.21)	0.961*** (5.47)	1.414*** (6.75)	0.961*** (5.19)
lnED	0.118*** (3.78)	0.056** (1.99)	0.115*** (3.41)	0.157*** (4.86)	0.114*** (3.35)	0.130*** (3.92)	0.114*** (3.18)
lnPS	0.111 (1.26)	-0.191** (-2.37)	-0.177** (-2.19)	0.096*** (3.48)	-0.119 (-1.51)	0.050** (2.23)	-0.119 (-1.43)
lnFII	0.002 (0.15)	-0.013 (-1.39)	-0.016 (-1.64)	-0.018* (-1.82)	-0.008 (-0.89)	-0.046*** (-3.43)	-0.008 (-0.84)
lnIL	-0.002 (-0.12)	0.010 (0.89)	0.014 (1.15)	0.018 (1.62)	0.014 (1.28)	0.059*** (4.74)	0.014 (1.22)
lnWL	0.365*** (6.73)	0.137*** (3.43)	0.466*** (10.33)	0.355*** (7.08)	0.408*** (8.16)	0.101* (1.90)	0.408*** (7.74)
lnRC	0.251** (2.42)	0.260*** (2.75)	0.199** (2.10)	0.149* (1.86)	0.208** (2.31)	0.320*** (5.54)	0.208** (2.19)
UL	0.005*** (3.00)	0.004** (2.30)	0.007*** (4.21)	0.007*** (5.94)	0.006*** (3.61)	0.005*** (6.55)	0.006*** (3.43)
lnFD	0.150*** (3.68)	0.107*** (3.07)	0.229*** (6.15)	0.316*** (10.11)	0.205*** (5.73)	0.392*** (14.73)	0.205*** (5.44)
lnFOI	0.022* (1.78)	0.026** (2.33)	0.012 (1.03)	0.034*** (2.97)	0.015 (1.31)	0.113*** (12.17)	0.015 (1.25)
Wx_DE				-0.338 (-0.95)	0.671* (1.87)	1.928*** (3.73)	0.671* (1.78)
Wx_lnED				-0.195*** (-2.93)	-0.194*** (-2.85)	-0.075 (-0.87)	-0.194*** (-2.70)
Wx_lnPS				0.030 (0.47)	1.257*** (5.74)	-0.088 (-1.60)	1.257*** (5.45)
Wx_lnFII				0.046** (2.27)	0.045** (2.19)	-0.025 (-0.80)	0.045** (2.08)
Wx_lnIL				-0.064** (-2.13)	-0.058* (-1.88)	-0.016 (-0.46)	-0.058* (-1.78)
Wx_lnWL				-0.366*** (-4.03)	-0.303*** (-3.07)	0.676*** (5.13)	-0.303*** (-2.91)
Wx_lnRC				-0.019 (-0.10)	0.804*** (2.90)	0.281** (2.20)	0.804*** (2.75)
Wx_UL				-0.002 (-0.86)	-0.006* (-1.69)	-0.001 (-0.31)	-0.006 (-1.60)
Wx_lnFD				-0.221*** (-3.23)	-0.408*** (-4.85)	-0.382*** (-6.00)	-0.408*** (-4.60)
Wx_lnFOI				0.008 (0.33)	0.029 (1.07)	-0.096*** (-4.32)	0.029 (1.01)
Rho/lambda		0.640*** (26.87)	0.743*** (30.77)	0.748*** (34.34)	0.696*** (29.14)	0.695*** (30.07)	0.696*** (27.64)
Individual-FE	Yes	Yes	Yes	No	Yes	No	Yes
Year-FE	Yes	Yes	Yes	No	No	Yes	Yes
Adj. R-sq	0.7090	0.6858	0.6904	0.6902	0.7102	0.6837	0.7102
N	3370	3033	3033	3370	3370	3370	3033

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values t .

Moreover, in Table 6, the coefficient estimates of the results in the first stage regression are 0.828 and 0.797, both positive and significant at the 1% level. Values of the KP Wald-F statistic test performed by instrumental variables are

1055.908 and 424.375, both much higher than 10 (recognized critical value). These demonstrate that the results of modeling and estimation for the impact of the digital economy on urban innovation are reasonable and reliable,

TABLE 4: Model selection tests for the spatial econometric approach.

Model selection test	Chi2 statistic	<i>p</i> -value
Hausman test	31.76	0.001
Wald test	202.94	0.001
LR test (SDM vs SAR)	145.90	0.001
LR test (SDM vs SEM)	72.89	0.001
LR test (Ind-year-FE vs individual-FE)	31.50	0.001
LR test (Ind-year-FE vs year-FE)	4351.18	0.001

and the digital economy can remarkably boost urban innovation.

4.6. Robustness Tests for Impact of the Digital Economy on Urban Innovation. We performed robustness tests to ensure the robustness of the empirical results to the impact of the digital economy on urban innovation and measured the reliability and credibility of the empirical results through changes in criteria. The robustness tests were mainly conducted in the following ways. First, the explained variable, Urban Innovation, was replaced, which means other indicators were used to replace Urban Innovation and included in the model's regression. On the one hand, this paper adopted the Innovation Index of Cities in China released by Professor Kou Zonglai-led team from Fudan University to measure the level of urban innovation [47]. On the other hand, in the existing patent data, the urban patent density used to measure the innovation level of a city was obtained by calculating the regional area of the city. Second, the core explanatory variables were replaced. On the one hand, the underlying data of the digital economy were replaced by those with a lag of one period to measure the impact of the digital economy on urban innovation. On the other hand, after standardizing the five indicators for measuring the digital economy, their aggregate was incorporated into the model's regression to replace the average as an alternative indicator of the digital economy. Third, the spatial weights matrix was replaced. Different weights matrices may also affect the results of model estimation. On the one hand, the spatial distance matrix was replaced by the spatial contiguity matrix. The spatial contiguity weights matrix was constructed in the following way: all matrix elements in cities of the same province are 1, and the others are 0. On the other hand, we used the mixing spatial matrix which was obtained by mixing and summing up the spatial distance matrix and spatial contiguity matrix. Different spatial weights matrices were used to replace the original matrix for regression. Lastly, the sampling period was adjusted. Different sampling periods were adopted to measure the robustness of the estimation results. In this paper, the samples are divided into samples of even-numbered years and those of odd-numbered years, and the regressions were conducted, respectively, to verify the impact of different sampling periods on the empirical results.

The results of the robustness tests are shown in Table 7. In rows (1)–(8) of Table 7, the coefficient estimates and the spatial autocorrelation coefficients of the impact of the digital economy on urban innovation are all positive and

significant at the 1% level. Meanwhile, they are overall close to the coefficient estimates obtained in Table 7; the direct effects, indirect effects, and total effects of the digital economy on urban innovation are all statistically positive and significant. Therefore, it reflects that the results of the estimates in the model of the impact of the digital economy on urban innovation are robust, which means the digital economy can boost urban innovation. Such impetus is not only evidenced by the local digital economy as an incentive for local urban innovation but also reflected in the spatial spillover effects of the local digital economy on urban innovation in peripheral regions.

5. Further Analysis of the Spatial Implications of the Digital Economy on Urban Innovation

5.1. Analysis of Mechanisms of the Digital Economy to Influence Urban Innovation. After the robustness tests, we analyzed the mechanisms of how the digital economy influences urban innovation. The mechanisms were analyzed by considering the mediation effect of two variables: Human Resources and Technology Spending. The results are shown in Table 8, where Row (1) presents the results of the regression benchmark for the impact of the digital economy on urban innovation, which is not intended to repeat in this section. Rows (2) and (3) reflect the impact of the digital economy on the mediator variables, a.k.a., Human Resources and Technology Spending. The spatial autocorrelation coefficients are 0.348 and 0.557, both positive and significant at the 1% level. It indicates a strong positive spatial correlation between Human Resources and Technology Spending. An increase of 1% in Human Resources and Technology Spending in a region can drive a simultaneous growth of Human Resources and Technology Spending in peripheral regions by 0.348% and 0.557%. Such spatial spillover values are smaller overall than urban innovation (0.696%). The values of the direct effects show that the coefficients of the direct effects of the digital economy on Human Resources and Technology Spending are 0.486 and 2.660, respectively, both positive and significant at the 1% level. It means the growing local digital economy can boost the growth of local human resources and science and technology spending. In actual circumstances, the development of the digital economy in a region could attract workers to flow into this region; likewise, a region with a more established digital economy may invest more in scientific and technological innovations. This has been adequately reflected in the size of spending on human resources and science and technology by Chinese governments at all levels in recent years. The values of the indirect effects that represent the indirect effects of the digital economy on Human Resources and Technology Spending are 0.963 and 1.248, respectively; only the former is positive and significant at the 1% level. This result indicates that the development of the local digital economy can drive a substantial accumulation of human resources in peripheral regions, serving as a model and providing good practices, which in turn leads to positive spatial spillover effects.

TABLE 5: Results of decomposition of the spatial effects of digital economy on urban innovation.

Variable	Direct effect		Indirect effect		Total effect	
	Coefficient value	<i>t</i> -statistic	Coefficient value	<i>t</i> -statistic	Coefficient value	<i>t</i> -statistic
DE	1.095***	(5.90)	4.368***	(3.53)	5.463***	(4.30)
lnED	0.099***	(3.30)	-0.372*	(-1.78)	-0.273	(-1.28)
lnPS	-0.002	(-0.02)	3.734***	(4.91)	3.732***	(4.69)
lnFII	-0.003	(-0.28)	0.140**	(2.10)	0.137*	(1.95)
lnIL	0.007	(0.51)	-0.160	(-1.45)	-0.153	(-1.31)
lnWL	0.409***	(8.34)	-0.056	(-0.19)	0.353	(1.19)
lnRC	0.305***	(3.08)	3.145***	(3.40)	3.449***	(3.61)
UL	0.005***	(3.42)	-0.005	(-0.44)	0.001	(0.07)
lnFD	0.178***	(5.12)	-0.899***	(-3.37)	-0.721***	(-2.63)
lnFOI	0.019	(1.51)	0.129	(1.36)	0.148	(1.54)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

TABLE 6: Results of instrumental variables estimation for impact of the digital economy on urban economy.

Variable	Urban innovation					
	(1)			(2)		
2SLS two-stage regression results spatial lag term/space-time lag term	2.856*** (8.33)			2.585*** (5.36)		
Simplified result	2.365*** (5.44)			2.061*** (3.56)		
The first stage regression results	0.828*** (21.96)			0.797*** (16.17)		
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Individual-FE	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	3370	3370	3370	3033	3033	3033
Adj. <i>R</i> -sq	0.655	0.692	0.907	0.602	0.647	0.864
KP Wald-F statistic	1055.908			424.375		

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

TABLE 7: Results of the robustness tests for impact of the digital economy on urban innovation.

Variable	Replace the explained variable		Replace the explanatory variable		Replacing the spatial weight matrix		Adjusted sample period	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
DE	0.259** (2.38)	1.147*** (5.51)	1.047*** (4.39)	0.192*** (5.19)	1.029*** (5.55)	1.013*** (5.48)	0.578** (2.19)	1.392*** (4.56)
Wx_DE	0.846*** (4.15)	1.354*** (3.20)	0.577 (1.26)	0.137* (1.81)	0.563* (1.83)	0.593* (1.83)	0.923* (1.69)	0.562 (0.91)
Rho	0.772*** (26.51)	0.661*** (24.70)	0.711*** (27.49)	0.695*** (27.58)	0.577*** (30.65)	0.620*** (31.72)	0.695*** (17.83)	0.688*** (18.04)
DE-direct effect	0.390*** (3.46)	1.340*** (6.43)	1.187*** (4.90)	0.220*** (5.91)	1.169*** (6.43)	1.155*** (6.34)	0.712*** (2.69)	1.543*** (5.05)
DE-indirect effect	4.605*** (4.70)	6.164*** (4.87)	4.567*** (2.82)	0.880*** (3.57)	2.641*** (3.97)	3.130*** (3.98)	4.368** (2.36)	4.882** (2.51)
DE-total effect	4.995*** (4.92)	7.504*** (5.78)	5.754*** (3.43)	1.099*** (4.34)	3.811*** (5.57)	4.285*** (5.33)	5.081*** (2.68)	6.425*** (3.23)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. <i>R</i> -sq	0.7046	0.7674	0.6697	0.7105	0.7157	0.7157	0.7012	0.7373
<i>N</i>	1685	3033	2696	3033	3033	3033	1348	1348

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

TABLE 8: Results of analysis of mechanisms of the digital economy to influence urban innovation.

Variable	lnUI (1)	lnHR (2)	lnTS (3)	lnUI (4)	lnUI (5)	lnUI (6)	lnUI (7)
DE	0.961*** (5.19)	0.462*** (4.54)	2.619*** (7.95)			0.908*** (4.89)	0.648*** (3.51)
lnHR				0.152*** (4.60)		0.133*** (4.02)	0.148*** (4.55)
lnTS					0.089*** (8.82)		0.088*** (8.62)
W _x _DE	0.671* (1.78)	0.470** (2.29)	-0.906 (-1.35)			0.652* (1.71)	0.317 (0.83)
W _x _lnHR				-0.029 (-0.35)		-0.106 (-1.26)	-0.144* (-1.73)
W _x _lnTS					0.101*** (4.34)		0.086*** (3.63)
Rho	0.696*** (27.64)	0.348*** (10.19)	0.557*** (19.03)	0.720*** (29.90)	0.668*** (26.05)	0.697*** (27.75)	0.657*** (25.02)
DE-direct effect	1.095*** (5.90)	0.486*** (4.84)	2.660*** (8.16)			1.036*** (5.51)	0.711*** (3.83)
lnHR-direct effect				0.161*** (4.75)		0.128*** (4.31)	0.142*** (5.21)
lnTS-direct effect					0.104*** (10.34)		0.101*** (9.31)
DE-indirect effect	4.368*** (3.53)	0.963*** (2.96)	1.284 (0.85)			4.136*** (3.27)	2.013** (2.13)
lnHR-indirect effect				0.299 (0.94)		-0.067 (-0.28)	-0.101 (-0.47)
lnTS-indirect effect					0.478*** (6.57)		0.408*** (6.05)
DE-total effect	5.463*** (4.30)	1.449*** (4.50)	3.944** (2.56)			5.171*** (3.97)	2.725*** (2.78)
lnHR-total effect				0.460 (1.41)		0.060 (0.24)	0.041 (0.19)
lnTS-total effect					0.582*** (7.83)		0.509*** (7.24)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R-sq	0.7102	0.3798	0.4221	0.7029	0.7245	0.7112	0.7296
N	3033	3033	3033	3033	3033	3033	3033

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values t .

During the analysis of the mediation effect mechanism, we explored the impact of the digital economy on mediator variables (Human Resources and Technology Spending), followed by the analysis of the impact of these mediator variables on urban innovation. The results are shown in Rows (4) and (5) of Table 8. For the spatial autocorrelation coefficients, the coefficient estimates are 0.720 and 0.668, and both are positive and significant at the 1% level and close to 0.696 in Row (1). When the local urban innovation gets 1% better, it would simultaneously increase the urban innovation in peripheral cities by about 0.7%. For direct effects, the values of the direct effects of Human Resources and Technology Spending on urban innovation are 0.161 and 0.104, both positive and significant at the 1% level. It indicates that local human resources and science and

technology spending can directly boost local urban innovation. For indirect effects, the values of the indirect effects of Human Resources and Technology Spending on urban innovation are 0.299 and 0.478; only the latter one is positive and significant at the 1% level. It means that only increasing science and technology spending can significantly drive the improvement of urban innovation in peripheral cities, leading to robust spatial spillover effects. However, the increase of human resources cannot effectively create positive and significant spatial spillover effects on urban innovation, as human resources are mainly located in large and capital cities and flow to such cities, which provides a noticeable boost to urban innovation in large and capital cities, but its impact on urban innovation of peripheral cities is not significant.

Lastly, the mediator variables (Human Resources, followed by Technology Spending) were added to the benchmark model for regression. The results are presented in Table 8. The impact of the digital economy on urban innovation after the incorporation of the mediator variables is shown in Rows (6) and (7) of Table 8, and then whether the digital economy acts on urban innovation through two aspects, a.k.a., human resources and science and technology spending, was verified. For the spatial autocorrelation coefficients, the coefficient estimates are 0.697 and 0.657, both positive and significant at the 1% level. Upon incorporating Human Resources, the spatial autocorrelation coefficient in the benchmark model changes slightly from 0.696 to 0.697, while upon incorporating Technology Spending, the spatial autocorrelation coefficient in the benchmark model is decreased from 0.697 to 0.657. The significant decline indicates that the incorporation of Technology Spending has a greater impact on the benchmark model's regression results, which means the digital economy is more likely to act on local urban innovation via a rise in science and technology spending. For direct effects, upon incorporating the mediator variables, the coefficient estimates of the impact of the digital economy on urban innovation are 1.036 and 0.711, both positive and significant at the 1% level. In comparison with the regression result in Row (1) (1.095), the former just changes slightly while the latter sees a more considerable decline, indicating that science and technology spending is more likely to be the mechanism of the digital economy to influence urban innovation. The local digital economy prominently boosts the cities' level of innovation through more spending on science and technology. For indirect effects, upon incorporating the mediator variables, the values of the indirect effects of the digital economy on urban innovation are 4.136 and 2.103, both positive and significant. In comparison with the benchmark model, by adding Human Resources, the value of indirect effects of the digital economy on urban innovation is decreased from 4.368 to 4.136; by adding Technology Spending, the value of indirect effects sees a sharp decline, from 4.136 to 2.013. It demonstrates that from the perspectives of indirect effects and spatial spillover, both human resources and science and technology spending are the mechanisms of the digital economy to create spatial spillover effects on urban innovation; from the perspective of the coefficient estimates, the impact of science and technology spending outweighs that of human resources. The development of the digital economy in the local region puts the spatial spillover effects on urban innovation in peripheral regions via two channels, a.k.a., human resources and science and technology spending, and the effects of the latter one outweigh those of the former one.

5.2. Analysis of Heterogeneity in the Impact of the Digital Economy on Urban Innovation. After the mechanism analysis, we explored the heterogeneity in the empirical results. In this paper, samples were categorized by the

regions where the cities are located, namely, the eastern, central and western, southern, and northern regions, to compare the effects of policies in different regions. The results are presented in Table 9. First, we compared the eastern region with the central and western regions. In Rows (1) and (2), the coefficient estimates of the impact of the digital economy on urban innovation are 0.394 and 0.874, and only the latter is significant at the 1% level. For the spatial autocorrelation coefficients, the coefficients of the eastern region and the central and western regions are 0.532 and 0.650, both positive and significant at the 1% level. The results of the decomposition of the spatial effects show that only the direct effects, indirect effects, and total effects of the central and western regions' digital economy on urban innovation are positive and statistically significant, while all coefficient estimates in relation to the eastern region are not significant. This means, in comparison with the eastern region, the digital economy in the central and western counterpart is more likely to substantially improve urban innovation, primarily for the following reasons that we found in the eastern region: the innovation atmosphere and entrepreneurial activities are more favorable; the overall level of urban innovation is higher; it is challenging for the growing digital economy to create more substantial marginal effects on urban innovation. On the contrary, as the western region sees a lower level of urban innovation and a less developed digital economy, along with the greater potential for improving urban innovation, making more efforts to develop the digital economy may provide urban innovation with solid support in information infrastructure and services, which could help transform the digital economy into innovation activities and boost urban innovation.

Next, we compared the southern region and northern region. The coefficient estimates of the impact of these regions' digital economy on urban innovation are 1.162 and 1.605, both positive and significant at the 1% level. Their spatial autocorrelation coefficients are 0.641 and 0.627, both positive and significant at the 1% level. These indicate a positive spatial correlation of urban innovation in southern and northern regions. For the decomposition of the spatial effects, the direct, indirect, and total effects of the northern region's digital economy on urban innovation are positive and significant at the 1% level. In contrast, only the direct and total effects in the southern region are positive and significant, and the indirect effects are not significant. For the values of the coefficients, those coefficient estimates of the southern region are smaller than those of the northern region, which indicates that the effects of the northern region's policies on the digital economy relative to urban innovation are better than those of the southern region. Such results are closely related to the overall level of the digital economy and urban innovation in these two regions. As such, the southern region, with a higher level of the digital economy and urban innovation, is home to a large group of companies in the digital economy, such as Hangzhou-based Alibaba and Shenzhen-based Tencent. Urban innovation there is very active. However, generally speaking, the digital economy and urban innovation in the northern region lag behind those in the southern region. Therefore, the northern

TABLE 9: Results of analysis of heterogeneity in the impact of the digital economy on urban innovation.

Variable	Eastern (1)	Middle-western (2)	Southern (3)	Northern (4)
DE	0.394 (1.29)	0.874*** (3.74)	1.162*** (4.69)	1.605** (2.12)
W _x _DE	-0.497 (-0.78)	0.747* (1.73)	-0.138 (-0.27)	1.383*** (2.66)
Rho	0.512*** (11.54)	0.633*** (21.43)	0.641*** (17.49)	0.627*** (18.82)
DE-direct effect	0.375 (1.22)	1.013*** (4.32)	1.219*** (4.89)	1.812*** (2.82)
DE-indirect effect	-0.452 (-0.33)	3.478*** (3.06)	1.746 (1.18)	4.602*** (3.42)
DE-total effect	-0.077 (-0.05)	4.490*** (3.80)	2.965* (1.94)	6.414*** (3.83)
Control variable	Yes	Yes	Yes	Yes
Individual-FE	Yes	Yes	Yes	Yes
Year-FE	Yes	Yes	Yes	Yes
Adj. R-sq	918	2115	1620	1413
N	0.7910	0.7002	0.7698	0.6661

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values t .

region has latecomer advantages, and the effects of its policies on the digital economy relative to urban innovation surpass those of the southern region.

5.3. Spatial Spillover Distance and Threshold of the Digital Economy on Urban Innovation. In the above-given analysis, we explored the spatial implications and mechanisms of the digital economy on urban innovation and discovered that the digital economy has significant direct effects and more potent spatial spillover effects on urban innovation. We further analyzed the specific forms of spatial spillover effects of the digital economy on urban innovation, including the distance within which the spatial spillover effects occur and how the spatial spillover effects change with geographic distance. Furthermore, we sought to determine the range within which the digital economy can influence urban innovation and the threshold of its impact. In this regard, we performed a regression with the spatial weights matrices of different thresholds to obtain the coefficient estimates of the direct and indirect effects of different thresholds, which were mapped to the corresponding thresholds. The results are shown in Table 10 and Figure 4. In Table 10, the coefficient estimates of direct effects within the range of 50–2,000 kilometers are all positive and significant at the 1% level, which indicates that even at different thresholds the development of the local digital economy can have a significant positive effect on local urban innovation. From the perspective of indirect effects, within the range of 500 kilometers, the digital economy has positive and strong spatial spillover effects on urban innovation, and the development of the local digital economy can substantially drive the significant improvement of urban innovation in other cities within the range of 500 kilometers. However, within the range of 600–1,600 kilometers, the coefficient estimates of the indirect effects of the local digital economy development on

urban innovation are primarily negative, which means that within this range, the digital economy fails to boost urban innovation in other regions, and instead, it considerably weakens the innovation of cities in these regions, leading to a strong siphon effect.

Why can the digital economy generate positive spatial spillover on urban innovation within 500 kilometers? In his research, Yu et al. argues that 500 kilometers generally reach the provincial boundaries [43]. We also provide new evidence for the 500 kilometers provincial boundaries, where we plot the geographic distances of cities from provincial capital cities as a histogram. Figure 6 shows that except for a few extreme values (16, less than 5%), the distance between most cities and their provincial capital cities will not exceed 500 kilometers. Such a provincial boundary imposes considerable influence and a specific limit on the spatial spillover effects; there is a particular regional threshold that is often created by local markets. On the one hand, giving preference to local companies, producers and service providers tend to do business with local companies they are familiar with. On the other hand, local protectionism could also contribute to the regional threshold for spatial spillover effects; provincial authorities often seek to maximize the benefits within the administrative region, preventing the effects of policies from spilling over outside the province. Yu's conclusion can help explain why the spatial spillover of the digital economy on urban innovation has a threshold within 500 kilometers. The main reasons are that during the development of the digital economy in regions, those that benefit most are local companies and individuals; there is a local market effect; local companies and individuals can fully benefit from the policies on the digital economy due to geographic advantages and an accurate grasp of market information and policies in their provinces. In addition, due to local protectionism, the primary purposes for each

TABLE 10: Spatial spillover distance of the digital economy on urban innovation.

Distance threshold (km)	Direct effect		Indirect effect		Distance threshold (km)	Direct effect		Indirect effect	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic		Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
50	1.236***	(6.60)	8.814***	(3.55)	1050	1.605***	(8.08)	-13.719***	(-5.12)
100	1.196***	(6.14)	23.590***	(3.11)	1100	1.732***	(8.68)	-14.941***	(-5.46)
150	1.119***	(5.62)	25.373**	(2.25)	1150	1.753***	(8.79)	-14.937***	(-5.97)
200	1.005***	(4.94)	25.018**	(2.46)	1200	1.778***	(8.86)	-15.720***	(-6.41)
250	1.075***	(5.29)	25.246***	(2.92)	1250	1.823***	(9.07)	-14.624***	(-5.55)
300	1.235***	(6.02)	30.410***	(2.87)	1300	1.884***	(9.30)	-12.793***	(-5.12)
350	1.280***	(6.24)	31.194***	(2.86)	1350	1.864***	(9.20)	-12.028***	(-5.36)
400	1.391***	(6.72)	33.692***	(2.85)	1400	1.759***	(8.66)	-10.877***	(-5.48)
450	1.460***	(7.10)	17.557**	(2.49)	1450	1.802***	(8.92)	-9.590***	(-4.66)
500	1.391***	(6.78)	9.572*	(1.75)	1500	1.739***	(8.56)	-6.770***	(-3.66)
550	1.465***	(7.15)	0.087	(0.02)	1550	1.655***	(8.13)	-3.377*	(-1.94)
600	1.453***	(7.16)	-10.970**	(-2.51)	1600	1.536***	(7.54)	-0.801	(-0.51)
650	1.525***	(7.60)	-14.189***	(-3.50)	1650	1.406***	(6.92)	1.922	(1.30)
700	1.487***	(7.46)	-14.165***	(-4.50)	1700	1.389***	(6.86)	2.196	(1.62)
750	1.509***	(7.59)	-14.920***	(-4.61)	1750	1.486***	(7.41)	2.985**	(2.29)
800	1.516***	(7.59)	-15.817***	(-4.79)	1800	1.517***	(7.66)	3.560***	(2.96)
850	1.373***	(6.88)	-14.943***	(-5.27)	1850	1.566***	(8.02)	3.392***	(3.02)
900	1.441***	(7.22)	-14.397***	(-5.36)	1900	1.603***	(8.24)	2.985***	(2.74)
950	1.509***	(7.58)	-14.771***	(-5.28)	1950	1.551***	(8.05)	3.540***	(3.50)
1000	1.536***	(7.73)	-13.766***	(-5.18)	2000	1.587***	(8.18)	1.960**	(2.02)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

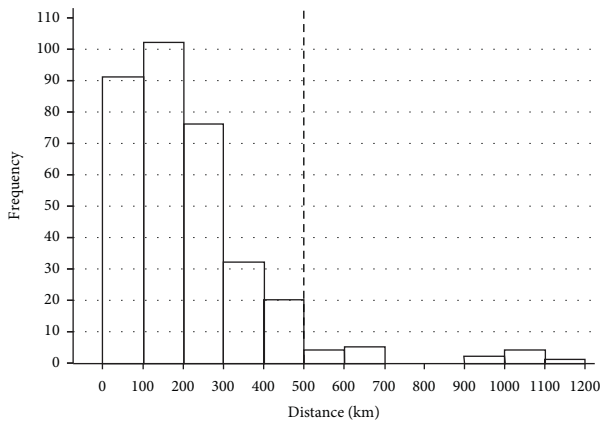


FIGURE 6: The distance distribution between cities and provincial capital cities.

province to develop the digital economy are to serve local companies and residents, boost urban innovation in the province, and maximize the effects of policies and benefits in the province.

Why does the digital economy have a considerable siphon effect on urban innovation in 600–1600 kilometers? For geographic distance, 600 kilometers are generally beyond the provincial boundaries and categorized as a cross-province, cross-region case. In this range, the development of the digital economy in a province will generate a pronounced siphon effect on other provinces, attracting various resources to aggregate in provinces with a developed digital economy. Nationwide, the imbalance is a challenge in China’s digital economy and urban innovation. The digital economy and urban innovation in the wealthy east coastal

provinces are generally at a higher level. However, the central and western counterpart, especially underdeveloped provinces in the west, generally has a less developed digital economy and urban innovation. The trend is that various resources flow from the central and western regions and inland provinces to the southeastern coastal regions and accumulate there to cause a siphon effect on the central and western regions and inland provinces. Therefore, even though in empirical econometrics, we reached the conclusion that the digital economy can put prominent spatial spillover effects on urban innovation, from the spatial perspective, such spatial spillover effects could only occur within 500 kilometers, in most cases, without crossing provincial boundaries. However, in a larger space, the digital economy imposes a significant siphon effect on urban innovation, in line with the regional dualism of China’s current economy. Therefore, the conclusions of this paper are also characterized by regional dualism. The digital economy can significantly boost urban innovation within the provincial boundaries, i.e., 500 kilometers. In other words, the digital economy can only contribute to substantial improvements in urban innovation of other cities in the same province, but it imposes an obvious siphon effect on the innovation of other cities outside the province.

Figure 7 describes the trends of the digital economy’s direct and indirect effects on urban innovation with changes in distance. We found that the direct effects of the digital economy on urban innovation have small coefficient estimates and change little, while the coefficient estimates of indirect effects are positive in the first place and then fall into the negative territory, with a trend of “rise, fall, and rise.” Therefore, the indirect effects of the digital economy on urban innovation demonstrate distinct changes and

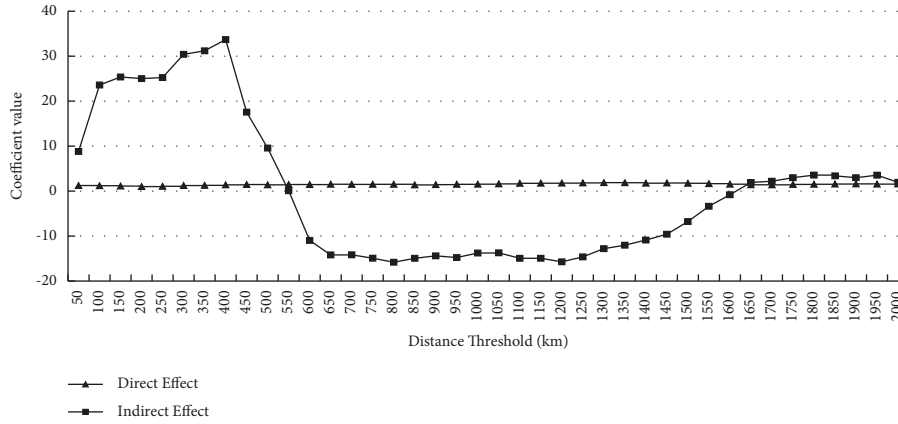


FIGURE 7: Spatial trends of the impact of the digital economy on urban innovation.

TABLE 11: Spatial spillover distance of the impact of the eastern region’s digital economy on urban innovation.

Distance threshold (km)	Direct effect		Indirect effect		Distance threshold (km)	Direct effect		Indirect effect	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic		Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
50	0.370	(1.19)	-0.405	(-0.22)	1050	-0.020	(-0.06)	-1.960	(-0.83)
100	0.356	(1.15)	1.635	(0.63)	1100	0.110	(0.35)	-2.647	(-1.08)
150	0.158	(0.50)	3.986	(1.34)	1150	0.167	(0.53)	-1.146	(-0.51)
200	0.101	(0.32)	8.424***	(2.68)	1200	0.115	(0.36)	-4.274*	(-1.87)
250	0.331	(1.02)	6.548**	(2.23)	1250	0.254	(0.79)	-2.369	(-1.00)
300	0.137	(0.41)	8.500***	(2.62)	1300	0.351	(1.10)	2.498	(0.96)
350	0.140	(0.42)	1.466	(0.38)	1350	0.341	(1.07)	2.643**	(2.10)
400	0.117	(0.35)	-0.325	(-0.07)	1400	0.400	(1.25)	2.231	(0.85)
450	-0.060	(-0.18)	-3.738	(-0.82)	1450	0.528	(1.62)	2.829	(1.35)
500	-0.042	(-0.13)	-1.886	(-0.43)	1500	0.528	(1.63)	3.626*	(1.73)
550	0.070	(0.22)	0.372	(0.09)	1550	0.397	(1.23)	2.125***	(2.72)
600	0.061	(0.19)	0.366	(0.09)	1600	0.279	(0.88)	2.481*	(1.84)
650	0.051	(0.16)	-4.505	(-1.03)	1650	0.286	(0.92)	1.337	(1.35)
700	-0.042	(-0.13)	-4.059	(-0.89)	1700	0.453	(1.46)	1.166	(1.44)
750	0.108	(0.35)	-3.524	(-0.81)	1750	0.569*	(1.88)	0.998	(1.54)
800	0.058	(0.19)	-3.737	(-0.87)	1800	0.685**	(2.27)	-0.246	(-0.46)
850	0.052	(0.17)	-0.178	(-0.05)	1850	0.383	(1.27)	-0.502	(-0.89)
900	0.171	(0.54)	-1.110	(-0.36)	1900	0.226	(0.74)	-0.520	(-0.94)
950	0.142	(0.45)	-0.883	(-0.32)	1950	0.266	(0.88)	-1.169*	(-1.73)
1000	0.011	(0.04)	-2.465	(-0.96)	2000	0.321	(1.05)	-0.939	(-1.39)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

volatility, which indicates that the impact of the digital economy on urban innovation is dominated by indirect effects and mainly presented with spatial spillover effects. Therefore, in the process of developing the digital economy, bringing the digital economy of cities to the next level, and promoting urban innovation, it is necessary to focus on the intercity synergy and collaboration for developing a province’s digital economy and give full play to the spatial spillover effects of the digital economy on urban innovation through coordination and cooperation to maximize the effects of policies within the province.

After a nation-level analysis of the spatial spillover effects and spatial threshold of the digital economy on urban innovation, we explored the spillover distance and threshold

from the regional perspective. First, we looked at the eastern region. As shown in Table 11 and Figure 8, for direct effects, the values of the direct effects of the eastern region’s digital economy on urban innovation are small and not statistically significant, which means, for the eastern region, the local digital economy does not have a major impact on local urban innovation, in line with the results of the analysis of heterogeneity. For indirect effects, in the range of 200–300 kilometers, the values of the indirect effects of the digital economy on urban innovation are positive and significant, indicating that the digital economy can remarkably drive urban innovation in other cities within this range. In comparison with the nation-level results, the range of the spatial spillover of the eastern region’s digital economy on

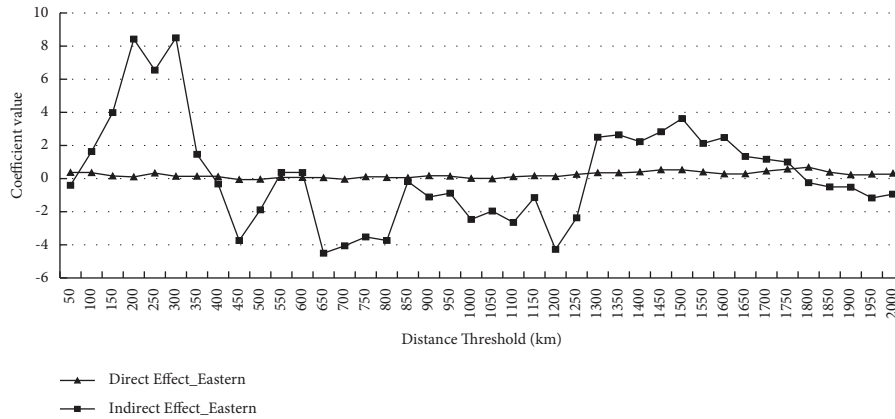


FIGURE 8: Spatial trends of the impact of the eastern region's digital economy on urban innovation.

urban innovation is smaller. For the eastern region, there are no adjacent and obvious areas with a siphon effect, which indicates the eastern region is characterized by a developed digital economy, balanced intercity digital economy and innovation, weak spatial spillover effects, and no strong intercity siphonage.

Next, we looked at the central and western regions. The digital economy and urban innovation in the central and western regions are generally at a low level, with enormous potential for growth and plenty of scope for improvement. As shown in Table 12 and Figure 9, for direct effects, the values of the direct effects of the digital economy on urban innovation are all positive and significant, which shows that the local digital economy can substantially boost local urban innovation at different thresholds. Compared with the nation-level results, the values of the direct effects of the central and western regions are generally higher, which indicates that the direct effects of the digital economy on urban innovation in the central and western regions outweigh the country's overall direct effects. For indirect effects, in a range of 50–250 kilometers, the development of the digital economy in the central and western regions can considerably drive urban innovation in other cities within this range. This range does not differ much from the eastern region, but the distance is shorter than the nation-level spatial spillover distance. In the range of 750–1,600 kilometers, the indirect effects of the digital economy on urban innovation are negative and significant, which indicates that the digital economy imposes a distinct siphon effect on the innovation of other cities within this range. It is in line with the nation-level characteristics but different from those of the eastern region. Moreover, the large spatial spillover range and siphonage range in the central and western regions for the impact of the digital economy on urban innovation have exacerbated the digital economy gap and lagged-behind urban innovation in the central and western regions. In this region, several capital cities, such as Chengdu, Chongqing, and Wuhan, even see their level of the digital economy and urban innovation higher than some coastal cities in the eastern region. However, this pattern of the digital economy and urban innovation, with a strong capital city as a

characteristic, is formed by siphoning the factors of resources from other small and medium cities in the central and western regions, objectively speaking, which widens the gap of the digital economy and urban innovation in the central and western regions.

After that, we looked at the northern region. In recent years, the economic differences between the north and the south in China have received increasing attention from scholars. The development gap between the north and the south has been a significant issue for China's economy. As shown in Table 13 and Figure 10, for direct effects, the values of the direct effects of the northern region's digital economy on urban innovation are all positive and significant, in line with the nation-level characteristics. For indirect effects, in the range of 50–350 kilometers, the digital economy has strong spatial spillover effects on urban innovation, indicating that the northern region's digital economy can substantially drive the innovation of other cities within this range. However, in the range of 700–2,000 kilometers, the indirect effects of the digital economy on urban innovation are generally negative and significant, which means the development of the local digital economy imposes a strong siphon effect on the innovation of peripheral cities within this range. In comparison with the nation-level results, the northern region is characterized by a shorter distance for spatial spillover effects and an ample space for the siphon effect, and the distance of the siphon effect in the northern region is not in a declining trend, which indicates that the siphon effect of the northern region's digital economy on urban innovation could occur in a larger range. The main reasons are the relatively weak impact of the northern region's overall digital economy on urban innovation capacity, the imbalanced regional development, and municipalities directly under the Central Government, especially Beijing and Tianjin, siphoning the factors of the digital economy and technological innovation resources from most areas of North China, leaving an extensive siphon range for the impact of the digital economy on urban innovation in the northern region.

Finally, we looked at the southern region. The digital economy is relatively well-established in the southern

TABLE 12: Spatial spillover distance of the impact of the central and western regions' digital economy on urban innovation.

Distance threshold (km)	Direct effect		Indirect effect		Distance threshold (km)	Direct effect		Indirect effect	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic		Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
50	1.232***	(5.15)	5.822***	(2.95)	1050	1.621***	(6.39)	-11.904***	(-3.48)
100	1.210***	(4.83)	14.749***	(3.06)	1100	1.742***	(6.86)	-11.981***	(-3.69)
150	1.093***	(4.37)	10.185**	(2.28)	1150	1.692***	(6.68)	-11.531***	(-4.12)
200	0.969***	(3.81)	5.302*	(1.69)	1200	1.760***	(6.88)	-11.041***	(-4.26)
250	1.106***	(4.39)	6.570*	(1.87)	1250	1.826***	(7.17)	-11.721***	(-3.88)
300	1.186***	(4.70)	5.057	(1.48)	1300	1.855***	(7.17)	-10.188***	(-3.87)
350	1.246***	(4.89)	2.836	(0.91)	1350	1.761***	(6.80)	-8.853***	(-3.73)
400	1.297***	(5.01)	3.235	(1.04)	1400	1.638***	(6.34)	-7.690***	(-3.63)
450	1.508***	(5.76)	2.936	(0.91)	1450	1.597***	(6.19)	-8.044***	(-3.19)
500	1.524***	(5.84)	1.984	(0.60)	1500	1.497***	(5.78)	-5.251**	(-2.44)
550	1.664***	(6.46)	-0.205	(-0.05)	1550	1.520***	(5.87)	-3.601*	(-1.93)
600	1.587***	(6.17)	-3.612	(-0.83)	1600	1.366***	(5.26)	-2.890*	(-1.79)
650	1.643***	(6.49)	-6.128	(-1.32)	1650	1.320***	(5.09)	-1.699	(-1.17)
700	1.610***	(6.37)	-6.999	(-1.58)	1700	1.243***	(4.77)	-1.104	(-0.86)
750	1.594***	(6.33)	-7.660*	(-1.95)	1750	1.323***	(5.14)	-0.517	(-0.44)
800	1.655***	(6.56)	-6.633**	(-2.10)	1800	1.340***	(5.24)	0.173	(0.16)
850	1.538***	(6.10)	-8.320***	(-2.75)	1850	1.524***	(5.97)	-0.337	(-0.31)
900	1.522***	(6.00)	-10.389***	(-3.12)	1900	1.642***	(6.39)	-1.024	(-0.85)
950	1.585***	(6.25)	-12.409***	(-3.20)	1950	1.551***	(6.12)	0.614	(0.51)
1000	1.596***	(6.32)	-14.328***	(-3.39)	2000	1.551***	(6.06)	1.837	(1.56)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

region, home to Internet giants Tencent and Alibaba. The economy on urban innovation are generally negative and

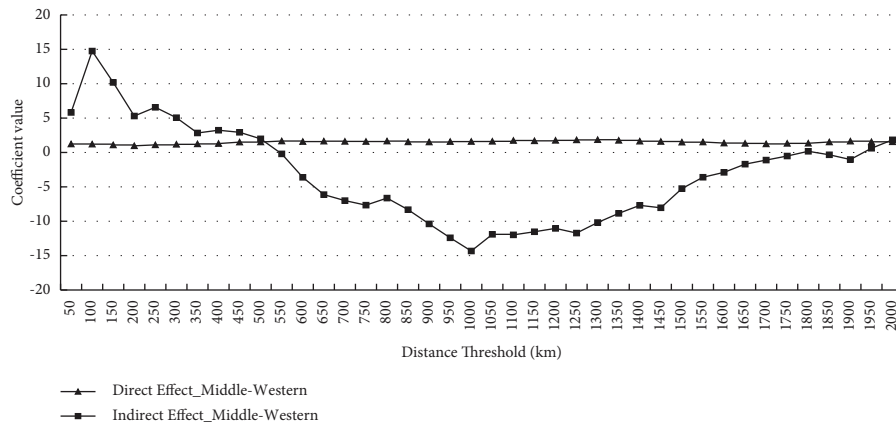


FIGURE 9: Spatial trends of the impact of the central and western regions' digital economy on urban innovation.

southern region is the leader in the digital economy in the country. As shown in Table 14 and Figure 11, for direct effects, the direct effects of the southern region's digital economy on urban innovation are all positive and significant at various thresholds. For indirect effects, in the range of 100–550 kilometers, the values of the indirect effects of the digital economy on urban innovation are positive and significant, which shows that the digital economy in the southern region can considerably drive the innovation of peripheral cities within this range. Compared with the northern region and the nation-level results, the southern region has a larger spatial spillover space, and the digital economy can reach larger peripheral areas. In the range of 650–2,000 kilometers, the indirect effects of the digital

significant, which indicates that the development of the digital economy in the southern region also imposes a strong siphon effect on the innovation of other cities within this range. The southern region sees the coexisting ranges of spatial spillover effects and the siphon effect of the digital economy on urban innovation. However, unlike the northern region, the southern region is characterized by a larger spatial spillover range and a smaller siphon effect range with a declining trend.

6. Conclusions and Policy Recommendations

6.1. Research Conclusions. The digital economy is a crucial direction for the future high-quality development of China's

TABLE 13: Spatial spillover distance of the impact of the northern region’s digital economy on urban innovation.

Distance threshold (km)	Direct effect		Indirect effect		Distance threshold (km)	Direct effect		Indirect effect	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic		Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
50	0.968***	(3.34)	8.923***	(3.67)	1050	1.228***	(3.98)	-6.420***	(-4.21)
100	1.069***	(3.51)	20.306***	(3.90)	1100	1.428***	(4.65)	-7.860***	(-4.58)
150	0.941***	(3.13)	15.580***	(3.44)	1150	1.251***	(4.12)	-8.339***	(-4.49)
200	0.932***	(3.06)	14.270***	(3.17)	1200	1.242***	(4.14)	-9.865***	(-4.82)
250	0.899***	(2.99)	12.767***	(2.87)	1250	1.104***	(3.65)	-7.549***	(-3.90)
300	0.921***	(3.08)	8.160**	(2.12)	1300	1.122***	(3.64)	-6.218***	(-3.42)
350	1.018***	(3.38)	8.560**	(2.00)	1350	1.059***	(3.42)	-4.454***	(-2.66)
400	1.080***	(3.55)	4.226	(1.12)	1400	1.091***	(3.53)	-2.684*	(-1.70)
450	1.299***	(4.18)	0.044	(0.01)	1450	1.086***	(3.47)	-3.194**	(-2.20)
500	1.221***	(3.95)	3.476	(1.00)	1500	1.084***	(3.47)	-5.446***	(-3.92)
550	1.480***	(4.78)	3.908	(1.00)	1550	1.052***	(3.34)	-5.122***	(-4.22)
600	1.584***	(5.14)	-2.629	(-0.71)	1600	0.872***	(2.75)	-3.411***	(-2.92)
650	1.690***	(5.57)	-5.621	(-1.56)	1650	0.806***	(2.60)	-3.981***	(-3.66)
700	1.596***	(5.35)	-9.826***	(-3.16)	1700	0.805***	(2.59)	-3.883***	(-3.73)
750	1.583***	(5.26)	-7.146***	(-2.81)	1750	0.965***	(3.15)	-4.501***	(-4.47)
800	1.564***	(5.24)	-5.094**	(-2.12)	1800	0.979***	(3.19)	-3.812***	(-3.79)
850	1.412***	(4.62)	-5.617***	(-2.79)	1850	0.978***	(3.20)	-4.400***	(-4.37)
900	1.444***	(4.66)	-3.221*	(-1.78)	1900	1.086***	(3.58)	-5.333***	(-5.06)
950	1.439***	(4.68)	-2.939*	(-1.83)	1950	1.089***	(3.61)	-5.303***	(-4.96)
1000	1.351***	(4.31)	-4.379***	(-3.02)	2000	1.037***	(3.39)	-4.925***	(-4.50)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

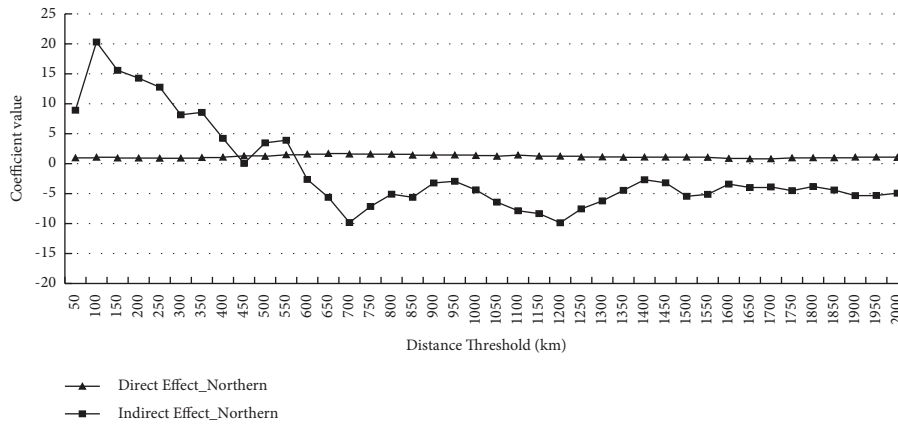


FIGURE 10: Spatial trends of the impact of the northern region’s digital economy on urban innovation.

TABLE 14: Spatial spillover distance of the impact of the southern region’s digital economy on urban innovation.

Distance threshold (km)	Direct effect		Indirect effect		Distance threshold (km)	Direct effect		Indirect effect	
	Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic		Coefficient	<i>t</i> -statistic	Coefficient	<i>t</i> -statistic
50	1.274***	(5.14)	3.240	(1.52)	1050	0.992***	(3.65)	-5.721*	(-1.87)
100	1.100***	(4.33)	7.123**	(2.30)	1100	0.985***	(3.59)	-5.860**	(-1.96)
150	1.140***	(4.46)	8.576**	(2.34)	1150	0.925***	(3.39)	-5.541**	(-2.06)
200	0.812***	(3.05)	11.568***	(3.66)	1200	0.999***	(3.64)	-7.213**	(-2.50)
250	0.884***	(3.30)	11.271***	(4.33)	1250	0.988***	(3.63)	-4.964**	(-2.20)
300	1.093***	(4.07)	16.043***	(4.37)	1300	0.933***	(3.42)	-3.392**	(-1.96)
350	1.135***	(4.19)	16.508***	(4.81)	1350	0.727***	(2.66)	-2.562**	(-2.15)
400	1.243***	(4.57)	20.724***	(5.82)	1400	0.862***	(3.16)	-1.698*	(-1.79)
450	1.275***	(4.62)	18.638***	(5.55)	1450	0.843***	(3.11)	-1.777**	(-2.15)
500	1.228***	(4.48)	12.721***	(4.37)	1500	0.793***	(2.91)	-0.949	(-1.49)
550	1.083***	(3.93)	6.174**	(2.23)	1550	0.870***	(3.23)	-0.964*	(-1.84)
600	1.103***	(4.11)	-2.619	(-0.86)	1600	0.884***	(3.27)	-1.009**	(-2.16)
650	1.234***	(4.62)	-5.272*	(-1.90)	1650	1.023***	(3.80)	-0.979**	(-2.23)
700	1.052***	(3.91)	-6.670**	(-2.35)	1700	0.957***	(3.54)	-0.904**	(-2.13)
750	0.871***	(3.27)	-7.546***	(-2.61)	1750	1.124***	(4.18)	-0.724*	(-1.83)
800	0.823***	(3.10)	-9.128***	(-2.94)	1800	1.119***	(4.11)	-1.201***	(-2.87)
850	0.716***	(2.68)	-10.419***	(-3.17)	1850	0.985***	(3.68)	-1.012**	(-2.38)
900	0.762***	(2.82)	-8.469**	(-2.51)	1900	1.077***	(4.03)	-1.274***	(-3.06)
950	0.832***	(3.05)	-7.889**	(-2.36)	1950	1.111***	(4.21)	-0.941**	(-2.18)
1000	0.944***	(3.47)	-4.970*	(-1.77)	2000	1.004***	(3.80)	-1.259***	(-3.21)

Note. ***, **, and * represent the significance level at the 1%, 5%, and 10% levels, respectively. The numbers in brackets are the test values *t*.

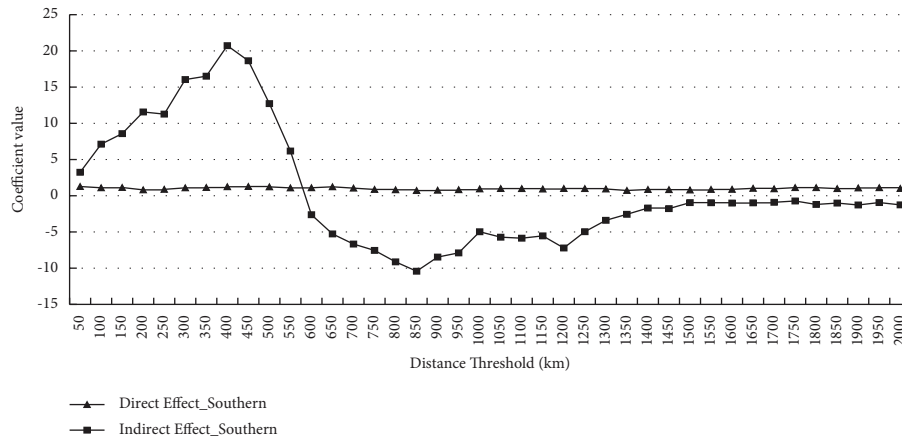


FIGURE 11: Spatial trends of the impact of the southern region’s digital economy on urban innovation.

economy and an essential safeguard for propelling urban innovation to new heights and realizing innovation-driven development. In this context, we calculated the digital economy index and measured the level of urban innovation with patents per capita. Furthermore, we discussed the spatial implications and spillover effects of the digital economy on urban innovation from the spatial perspective and explored the mechanisms of the digital economy to influence urban innovation. We drew the following conclusions:

- (1) China’s city-level digital economy and urban innovation see a significantly positive spatial correlation and the feature of spatial clustering, mainly presented as the H-H and L-L clusters, with pronounced

spatial differentiation. The level of the digital economy and urban innovation is higher in the western coastal regions of China, while the common cases in the central and western regions are the L-L cluster with a less developed digital economy and urban innovation.

- (2) The digital economy has a distinctly positive impact on urban innovation. The estimation results of spatial econometrics show that if the spatial effect is excluded, the impact of the digital economy on urban innovation will be overestimated. The spatial implications of the digital economy on urban innovation are reflected in the direct effects and indirect effects. The direct effects mean the development of

the digital economy will directly and considerably drive local urban innovation. The indirect effects mean the digital economy can not only directly boost the urban innovation in its region but imposes distinct spatial spillover effects that promote urban innovation of cities in peripheral regions. After addressing the endogeneity problem and conducting various robustness tests, the research conclusions remain robust and reliable.

- (3) The analysis of the mechanisms of the digital economy to influence urban innovation shows that the digital economy enhances local innovation capacity directly through promoting the concentration of human resources and increasing science and technology spending and drives the improvement of the innovation capacity in peripheral cities through the spatial spillover of human resources and science and technology spending. The effects of science and technology spending outweigh those of human resources. The policy effect in the central and western regions outperforms the eastern region, and the northern region outperforms the southern region. Regions with a relatively less developed digital economy and lower levels of urban innovation have the latecomer advantage.
- (4) The calculating results demonstrate that the digital economy may not always have a significantly positive spatial spillover on urban innovation. Within 500 kilometers, the digital economy's impact on other cities' innovation is primarily presented as positive spatial spillover effects. When it is beyond 500 kilometers, the negative siphon effect prevails. Regarding space, the spatial implications of the digital economy on urban innovation are characterized by the range of spatial spillover effects and the siphon effect. These two ranges are roughly divided by provincial boundaries. Therefore, we should explore the spatial differences of the impact and effects of the digital economy on urban innovation from the spatial perspective and in a comprehensive and objective way.

6.2. Policy Recommendations. With the research conclusions of this paper, we propose several policy recommendations for the future development of the digital economy and urban innovation, hoping to provide authorities with a reference for promoting the digital economy and boosting urban innovation.

Firstly, we should give due weight to the development of the digital economy and make substantial efforts to conduct digital infrastructure construction. Therefore, we should increase the investment in digital infrastructure construction, including but not limited to the investment and support for 5G technology, artificial intelligence (AI), industrial Internet, Internet of things, data centers, and cloud computing. We should improve the integration of digital technology into infrastructure construction, provide more convenient digital, information, and AI-enabled safeguards

for urban industrial upgrading and innovative and entrepreneurial activities, and drive urban innovation through the digital economy.

Secondly, we should pay adequate attention to the significance and urgency of innovative activities and continue to take urban innovation to the upper level. COVID-19 is continuing to spread around the world and dealing a severe blow to the global economy already marked by slow growth. In the future, the global economy will still be sluggish and even see the potential for a financial crisis. We should strengthen the efforts made to encourage and support innovative activities, offer incentives, such as tax incentives and government subsidies, to the innovative activities of enterprises and individuals, provide innovative activities and startups with the necessary financial support, and reduce the costs and risks of innovative activities and startups for all walks of life.

Thirdly, we should attach importance to human resources for the digital economy and urban innovation. Therefore, we should pay adequate attention to building a pipeline of talent, make more investments in all types of schools and research institutes, and encourage personal growth. Meanwhile, we should promote rational human mobility and mobilize human resources to move to less developed areas, such as the central and western regions. Governments should maximize the value of various human resources and encourage people to engage in activities to develop the digital economy and promote urban innovation.

Lastly, we should be fully aware of the differences of the digital economy and urban innovation among different regions and take actions to mitigate the spatial differentiation of the digital economy and urban innovation. It should raise concerns from governments at all levels, and efforts should be made to minimize the spatial mismatch of various resource factors. In particular, we should mobilize the flow of surplus factors of production from the eastern region to the central and western regions to relieve the shortage of factors of production and then achieve a better spatial match for resource factors, maximizing the spatial economic benefits.

Data Availability

The data used to support the findings of this study are available from the first and corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

References

- [1] D. Tapscott, "Digital economy, the promise and peril in the age of networked intelligence," *Language*, vol. 18, no. 342, 1995.
- [2] US Department of Commerce, *The Emerging Digital Economy*, US Department of Commerce, Washington, DC, USA, 1998.

- [3] *G20 Digital Economy Development and Cooperation Initiative*, G20 Research Group at the University of Toronto G, Toronto G, Canada, 2016.
- [4] T. L. Mesenbourg, *Measuring the Digital Economy*, US Bureau of the Census, Washington, DC, USA, 1998.
- [5] D. Fudenberg and J. M. Villas-Boas, “In the digital economy,” *The Oxford Handbook of the Digital Economy*, vol. 254, 2012.
- [6] R. Bukht and R. Heeks, “Defining, conceptualising and measuring the digital economy,” *Development Informatics working paper*, vol. 68, 2017.
- [7] E. Brynjolfsson and A. Collis, “How should we measure the digital economy,” *Harvard Business Review*, vol. 97, no. 6, pp. 140–148, 2019.
- [8] A. García-Herrero and J. Xu, *How big is China’s digital economy?*, Bruegel Working Papers, Brussels, Belgium, 2018.
- [9] X. Xu and M. Zhang, “Research on the scale measurement of China’s digital economy—based on the perspective of international comparison,” *China Industrial Economics*, vol. 5, pp. 23–41, 2020.
- [10] Z. Li and Y. Liu, “Research on the spatial distribution pattern and influencing factors of digital economy development in China,” *IEEE Access*, vol. 9, Article ID 63094, 2021.
- [11] L. Tang, B. Lu, and T. Tian, “Spatial correlation network and regional differences for the development of digital economy in China,” *Entropy*, vol. 23, no. 12, Article ID 23121575, 2021.
- [12] K. Barefoot, D. Curtis, W. Jolliff, J. R. Nicholson, and R. Omohundro, *Defining and Measuring the Digital Economy*, US Department of Commerce Bureau of Economic Analysis, Washington, DC, USA, 2018.
- [13] I. V. Danilin, “Development of the Digital Economy in the USA and China: Factors and Trends,” *Outlines of Global Transformations: Politics, Economics, law*, vol. 12, no. 6, pp. 246–267, 2019.
- [14] N. Milošević, M. Dobrota, and S. B. Rakočević, “Digital economy in Europe: evaluation of countries’ performances,” *Zbornik Radova Ekonomskog Fakulteta U. Rijeci*, vol. 36, no. 2, pp. 861–880, 2018.
- [15] A. Stavitskiy, G. Kharlamova, and E. A. Stoica, “The analysis of the digital economy and society index in the EU,” *Baltic Journal of European Studies*, vol. 9, no. 3, pp. 245–261, 2019.
- [16] M. R. Szeles and M. Simionescu, “Regional patterns and drivers of the EU digital economy,” *Social Indicators Research*, vol. 150, no. 1, pp. 95–119, 2020.
- [17] M. Baxtiyarjon Bulturbayevich and M. Baxriddin Jurayevich, “The impact of the digital economy on economic growth,” *International Journal of Business, Law, and Education*, vol. 1, no. 1, pp. 4–7, 2021.
- [18] B. M. Mardonakulovich and M. B. Bulturbayevich, “Digital economy: sustainable and high-quality economic growth,” *Academia Globe: Inderscience Research*, vol. 1, no. 1, pp. 9–16, 2020.
- [19] J. Su, K. Su, and S. Wang, “Does the digital economy promote industrial structural upgrading? — a test of mediating effects based on heterogeneous technological innovation,” *Sustainability*, vol. 13, no. 18, Article ID 131810105, 2021.
- [20] Y. Liu, Y. Yang, H. Li, and K. Zhong, “Digital economy development, industrial structure upgrading and green total factor productivity: empirical evidence from China’s cities,” *International Journal of Environmental Research and Public Health*, vol. 19, no. 4, Article ID 19042414, 2022.
- [21] Y. Su, Z. Li, and C. Yang, “Spatial interaction spillover effects between digital financial technology and urban ecological efficiency in China: an empirical study based on spatial simultaneous equations,” *International Journal of Environmental Research and Public Health*, vol. 18, no. 16, Article ID 18168535, 2021.
- [22] S. Jia, Y. Qiu, and C. Yang, “Sustainable development goals, financial inclusion, and grain security efficiency,” *Agronomy*, vol. 11, no. 12, Article ID 11122542, 2021.
- [23] J. Tian and Y. Liu, “Research on total factor productivity measurement and influencing factors of digital economy enterprises,” *Procedia Computer Science*, vol. 187, pp. 390–395, 2021.
- [24] W. Pan, T. Xie, Z. Wang, and L. Ma, “Digital economy: an innovation driver for total factor productivity,” *Journal of Business Research*, vol. 139, pp. 303–311, 2022.
- [25] M. Rachinger, R. Rauter, C. Müller, W. Vorraber, and E. Schirgi, “Digitalization and its influence on business model innovation,” *Journal of Manufacturing Technology Management*, vol. 30, no. 8, pp. 1143–1160, 2019.
- [26] S. Vaska, M. Massaro, E. M. Bagarotto, and F. Dal Mas, “The digital transformation of business model innovation: a structured literature review,” *Frontiers in Psychology*, vol. 11, Article ID 539363, 2020.
- [27] O. Buhaichuk, “Strategies of information and innovation activity development at enterprise in digital conditions,” *Human Studies*, vol. 1(78), no. 1, pp. 75–85, 2019.
- [28] R. Li, J. Rao, and L. Wan, “The Digital Economy, enterprise Digital Transformation, and enterprise Innovation,” *Managerial and Decision Economics*, vol. 43, no. 7, pp. 2875–2886, 2022.
- [29] R. Mancha and G. Shankaranarayanan, “Making a digital innovator: antecedents of innovativeness with digital technologies,” *Information Technology & People*, vol. 34, no. 1, pp. 318–335, 2020.
- [30] P. F. Borowski, “Innovative processes in managing an enterprise from the energy and food sector in the era of industry 4.0,” *Processes*, vol. 9, no. 2, p. 381, 2021.
- [31] L. Liu, “The impact and challenge of artificial intelligence on enterprise innovation based on research overview,” *World Scientific Research Journal*, vol. 5, no. 7, pp. 42–48, 2019.
- [32] J. Liu, H. Chang, J. Y. L. Forrest, and B. Yang, “Influence of artificial intelligence on technological innovation: evidence from the panel data of China’s manufacturing sectors,” *Technological Forecasting and Social Change*, vol. 158, Article ID 120142, 2020.
- [33] A. Caragliu and C. F. Del Bo, “Smart innovative cities: the impact of Smart City policies on urban innovation,” *Technological Forecasting and Social Change*, vol. 142, pp. 373–383, 2019.
- [34] J. Li and B. Li, “Digital inclusive finance and urban innovation: evidence from China,” *Review of Development Economics*, vol. 26, no. 2, pp. 1010–1034, 2022.
- [35] X. Wang, X. Sun, H. Zhang, and C. Xue, “Digital economy development and urban green innovation CA-pability: based on panel data of 274 prefecture-level cities in China,” *Sustainability*, vol. 14, no. 5, p. 2921, 2022.
- [36] H. Lu, C. Song, and L. Lingling, “Digital economy, innovation environment and urban innovation capabilities,” *Science Research Management*, vol. 42, no. 4, 2021.
- [37] C. Ding, C. Liu, C. Zheng, and F. Li, “Digital economy, technological innovation and high-quality economic development: based on spatial effect and mediation effect,” *Sustainability*, vol. 14, no. 1, p. 216, 2021.
- [38] D. Ma and Q. Zhu, “Innovation in emerging economies: research on the digital economy driving high-quality green development,” *Journal of Business Research*, vol. 145, pp. 801–813, 2022.

- [39] J. P. Elhorst, "Specification and estimation of spatial panel data models," *International Regional Science Review*, vol. 26, no. 3, pp. 244–268, 2003.
- [40] J. P. LeSage, "Spatial econometric panel data model specification: a bayesian approach," *Spatial Statistics*, vol. 9, no. 1, pp. 122–145, 2014.
- [41] J. LeSage and R. K. Pace, *Introduction to Spatial Econometrics*, Chapman and Hall/CRC, Boca Raton, FL, USA, 2009.
- [42] S. Jia, C. Yang, M. Wang, and P. Failler, "Heterogeneous impact of land-use on climate change: study from a spatial perspective," *Frontiers in Environmental Science*, vol. 10, Article ID 840603, 2022.
- [43] Y. Z. Yu, D. Y. Liu, and Y. Xuan, "The spatial spillover effect and regional damping boundary of productive services agglomeration on manufacturing productivity: empirical research based on spatial econometric Model," *Journal of Financial Research*, vol. 2, pp. 23–36, 2016.
- [44] J. Zhou, X. Fan, and A. Yu, "The impact of high-speed railway accession on agricultural exports: evidence from Chinese agriculture-related enterprises," *Complexity*, vol. 2021, Article ID 4225671, 19 pages, 2021.
- [45] T. Zhao, Z. Zhang, and S. K. Liang, "Digital economy, entrepreneurship, and high-quality economic development: empirical evidence from urban China," *Management World*, vol. 36, no. 10, pp. 65–76, 2020.
- [46] F. Guo, J. Wang, F. Wang, T. Kong, X. Zang, and Z. Chenng, "Measuring China's digital financial inclusion: index compilation and spatial characteristics," *China Economic Quarterly*, vol. 19, no. 4, pp. 1401–1418, 2020.
- [47] Z. Kou and X. Liu, *FIND Report on City and Industrial Innovation in China*, Fudan University, Shanghai, China, 2017.