

Article

Does Digital Technology Development Promote Entrepreneurial Activity? Evidence from Spatial Spillover Effects in China

Jia Di, Chunhui Yuan * and Xiaolong Li

School of Economics and Management, Beijing University of Posts and Telecommunications, Beijing 100876, China; xddijia@bupt.edu.cn (J.D.); xiaolongli@bupt.edu.cn (X.L.)

* Correspondence: yuanchunhui@bupt.edu.cn; Tel.: +86-18800162371

Abstract

This study examines how digital technology development affects entrepreneurial activity from a spatial perspective. Existing studies have mainly emphasized the local entrepreneurial effects of digital technology, while paying relatively limited attention to whether such effects extend across cities through spatial linkages. Using manually compiled large-scale business registration data, this study constructs a balanced panel dataset covering 281 prefecture-level and above cities in China from 2006 to 2020. Spatial autocorrelation tests and spatial econometric models are applied to identify the local and spatial spillover effects of digital technology. The findings suggest that urban entrepreneurial activity exhibits significant spatial dependence. After controlling for spatial correlation, digital technology development significantly promotes local entrepreneurial activity and generates positive spillover effects on surrounding cities. Effect decomposition results show that the indirect effect of digital technology is stronger than its direct effect, suggesting that spatial spillover is an important channel through which digital technology affects entrepreneurial activity. Further analysis finds that this effect differs across technology types, city size, urban hierarchy, and geographical location. Distance-band tests indicate that the positive spillover effect weakens as geographical distance increases. Overall, digital technology can promote entrepreneurial activity through regional linkages, but its spatial influence depends on actual intercity connections.

Keywords: digital technology; entrepreneurial activity; spatial spillover; spatial Durbin model; distance decay

1. Introduction

The economic benefits of digital technology are reflected not only in improvements in production efficiency but also in its role in accelerating data and information flows and reshaping the spatial allocation of resources. Based on the digital representation of information, digital technology can substantially lower data storage barriers, computation, and transmission, while further lowering economic costs related to search, replication, transportation, tracking, and verification [1]. Therefore, digital technology can be regarded as an important force that weakens spatial frictions and reduces the cost of cross-regional information flows. On the one hand, the dependence of economic activities on geographical proximity has been weakened. For example, under e-commerce and platform-based transactions, consumers can more easily access information about products from other regions and enter external markets. Existing research also shows that the expansion of



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e-commerce can improve market access and welfare for consumers in some remote areas [2]. This suggests that digital technology, to some extent, reduces market segmentation caused by physical distance. However, the spatial distribution of online transactions is not completely free from geographical constraints. Studies based on online transaction data from eBay and Mercado Libre find that distance still inhibits interregional transactions and that online transactions continue to exhibit a certain degree of local bias [3]. Research on firms' broadband adoption and trade relationships also reveals that while information and communication technologies alleviate information frictions, they do not necessarily eliminate the role of distance; rather, they may reshape the relationships among distance, market size, and trade connections [4]. Therefore, the weakening of spatial frictions by digital technology does not occur uniformly across all regions. Instead, it is more likely to manifest as the coexistence of weakened distance constraints and localized agglomeration diffusion.

On the other hand, the establishment of data trading platforms, the opening of public data, and the improvement of digital infrastructure further release the advantages of data elements, such as low replication costs and high shareability. These developments endow digital technology with the capacity for low-cost cross-regional transmission and diffusion. Unlike traditional industrial agglomeration, which relies heavily on geographical proximity, digital technology can expand the spatial boundaries of resource allocation through digital platforms, information networks, and data flows, thereby facilitating the wider circulation of entrepreneurial opportunities, knowledge resources, and market information. Autio et al. [5] point out that a key feature distinguishing digital entrepreneurial ecosystems from traditional regional clusters lies in their use of digital affordances, horizontal knowledge spillovers, and the identification and integration of external entrepreneurial opportunities. Accordingly, when a region develops advantages in digital resources, such advantages are often not confined to the local area. Instead, they may diffuse outward through data flows, information flows, and knowledge networks, forming spatial transmission channels with positive externalities and displaying more complex spatial linkages than traditional production factors such as labor and land. In this sense, examining the effects of digital technology only from the perspective of cities or industries within a region makes it difficult to fully explain the regional linkages and externalities emerging in the process of digitalization. Therefore, investigating the cross-regional impacts and spatial effects of digital technology from a spatial perspective constitutes an important prerequisite for further research in this field [1,4,5].

As an economic activity that is highly dependent on access to dynamic market information and resource matching, entrepreneurship is constrained not only by local resource endowments and institutional environments but also closely associated with knowledge spillovers from non-local markets and cross-regional factor interactions. The knowledge spillover theory of entrepreneurship argues that knowledge not fully absorbed or commercialized by existing organizations can generate entrepreneurial opportunities and be transformed into new firm entry and economic growth through entrepreneurial activity [6]. Tsvetkova and Partridge [7], from the perspective of the relationship between the knowledge-intensive service economy and firm entry, also emphasize the importance of regional knowledge bases and external interactions for firm entry. Following this logic, the impact of digital technology on entrepreneurial activity is also likely to transcend the boundaries of a single region and exhibit clear spatial effects. In particular, digital technology can reduce the costs for entrepreneurs to obtain external market information, identify business opportunities, and connect with non-local resources, thereby making entrepreneurial activity less constrained by local resource conditions. Nambisan [8] notes that digital technology is making entrepreneurial processes and outcomes less bounded and more open in terms of action space. Belitski et al. [9], based on regional data from

Europe, further show that digital affordances influence entrepreneurial dynamics such as new firm formation, firm survival, and high-growth employment. Therefore, when examining the impact of digital technology on entrepreneurial activity, it is necessary not only to focus on its direct effects within a region, but also to further analyze whether it generates spillover effects on entrepreneurial activity in neighboring regions through spatial linkage mechanisms [5,8,9].

Regarding the relationship between digital technology and entrepreneurial activity, existing studies have begun to examine the effects of digital platforms, digital infrastructure, and digital finance on entrepreneurial activity. For example, Kim and Orazem [10] find that broadband Internet significantly affects the location choices of new firms in rural areas, suggesting that digital infrastructure can alter the spatial conditions for entrepreneurial entry. Belitski et al. [9] further suggest that the complementarity between digital affordances and regional human capital and cultural environments affects new firm formation and entrepreneurial performance. It should be noted that although these studies provide an important foundation for understanding the relationship between digital technology and entrepreneurial activity, their analyses are mainly based on intra-regional or non-spatial perspectives and often implicitly assume that different regions are independent of one another. In reality, however, cities, especially neighboring cities and cities within urban agglomerations, are often closely connected through industrial linkages, factor mobility, and information transmission. The effects of digital technology may therefore not be limited to the local region, but may be transmitted to surrounding areas through channels such as information diffusion, knowledge spillovers, and demonstration effects. Accordingly, it is necessary to further examine the impact of digital technology on entrepreneurial activity from a spatial perspective.

Against this background, this study introduces spatial econometric methods and systematically examines the spatial spillover effects of digital technology on entrepreneurial activity from the perspective of spatial linkages. Specifically, this study constructs a spatial Durbin model to identify whether digital technology affects other cities through spatial associations while controlling for the spatial dependence structure of entrepreneurial activity, and further distinguishes its direct and indirect effects through effect decomposition. The spatial Durbin model can simultaneously incorporate the spatial dependence of the dependent variable and the spatial lag terms of explanatory variables, making it suitable for identifying interregional interactions and spillover effects. Meanwhile, the decomposition of direct, indirect, and total effects helps avoid the bias that may arise from a simple interpretation based solely on regression coefficients [11,12]. On this basis, this study further analyzes the heterogeneous manifestations of the spatial spillover effects of digital technology across city size, city hierarchy, and geographical location, and identifies the scope and attenuation path of these effects using a distance-band approach.

This study contributes to a systems-based understanding of the relationship between digital technology development and entrepreneurial activity. First, it moves beyond the conventional local-effect perspective by conceptualizing digital technology development as a systemic force embedded in an interregional entrepreneurial system. In this framework, digital technology shapes entrepreneurship through both local effects and cross-city flows of information, resources, markets, and opportunities. Second, this study provides empirical evidence on the spatial spillover effects of digital technology development by applying a spatial Durbin model, which enables the decomposition of direct and indirect effects. This approach helps reveal whether digital technology development in one city can generate entrepreneurial externalities for surrounding cities. Third, the study uncovers the differentiated transmission mechanism of these spillovers by examining heterogeneity across city size, city hierarchy, and geographical location, and by identifying the distance-

decay pattern of spatial effects. These results indicate that the impact of digital technology on entrepreneurship is shaped by spatial dependence and regional system structure rather than operating uniformly across locations. In this sense, the study enriches the literature by linking digital technology, entrepreneurial activity, and spatial spillovers within a unified systems-oriented analytical framework.

The remainder of this paper is organized as follows. Section 2 develops the hypotheses. Section 3 describes the research design. Section 4 reports the empirical results and robustness checks. Section 5 presents additional analyses. Section 6 discusses the implications, limitations, and conclusions.

2. Literature Review and Research Hypothesis

2.1. Spatial Spillover Effects of Digital Technology on Entrepreneurial Activity

The development of digital technology can influence entrepreneurial activity by reducing information acquisition costs, expanding the scope of market connections, and improving the efficiency of resource matching. For entrepreneurial entry, whether entrepreneurs can identify opportunities largely depends on their timely access to information about changes in market demand, technological application scenarios, and viable business models. Based on datafication, networking, and platforms, digital technology can reduce the costs of information search and transaction matching, while expanding entrepreneurs' access to external markets and non-local resources [1,8,9]. Within urban systems, digital technology can also improve the efficiency of cross-regional information diffusion, making entrepreneurial experience, digital business practices, and market demand signals among neighboring cities easier to observe, learn from, and imitate. As a result, the development of digital technology in surrounding cities may generate external driving effects on local entrepreneurial activity [5,13,14]. Meanwhile, entrepreneurial entry itself is characterized by strong imitation and diffusion. When the development of digital technology in one region promotes an increase in entrepreneurial activity, entrepreneurs in neighboring regions are more likely to perceive changes in opportunities through spatial linkages and enter related fields accordingly [15–17]. Therefore, digital technology can not only enhance local entrepreneurial activity but may also generate positive spatial spillover effects through intercity information flows, market linkages, and opportunity diffusion. Accordingly, the following hypothesis is proposed:

H1. *The development of digital technology significantly enhances entrepreneurial activity and generates positive spatial spillover effects.*

2.2. Spillover Effects of Digital Technology on Entrepreneurial Activity from the Perspective of Urban Heterogeneity

The spatial spillover effects of digital technology on entrepreneurial activity do not necessarily manifest uniformly across all cities. Whether spatial spillovers occur depends on whether the development of digital technology in surrounding cities can be observed, absorbed, and transformed into entrepreneurial opportunities by local entrepreneurs. Cities differ in terms of digital foundations, market size, industrial structure, innovation resources, and the intensity of spatial linkages; therefore, the external effects of digital technology may display significant urban heterogeneity [13,15,18]. From a systems perspective, cities are not independent economic units, but nodes embedded in regional entrepreneurial systems and digital networks. The diffusion effects of digital technology are jointly shaped by the position of urban nodes, the strength of system connections, and resource absorption capacity [5,19,20]. Therefore, after identifying the overall spatial spillover effects of digital

technology on entrepreneurial activity, it is necessary to further analyze in which types of cities such spillover effects are stronger or weaker.

First, city size may influence the capacity to absorb the spatial spillover effects of digital technology. Large cities generally already possess higher levels of digitalization, more developed entrepreneurial ecosystems, and more active entrepreneurial activities; thus, the additional impact brought by digital technology development in surrounding cities may be relatively limited. By contrast, small and medium-sized cities often have more limited local markets and weaker digital foundations, making them more dependent on external information, platform connections, and cross-city market opportunities. When the level of digital technology in surrounding cities improves, entrepreneurs in small and medium-sized cities are more likely to identify new entrepreneurial opportunities through external information diffusion and digital business experience. Consequently, their entrepreneurial activity may respond more strongly to the development of digital technologies in neighboring cities [9,16,21]. Existing studies also show that the effects of the digital economy are often moderated by city size, market environment, and stage of development, and may therefore differ across cities of different scales [18,22,23]. Thus, differences in city size may lead to variations in the spatial spillover effects of digital technology.

Second, urban hierarchy may also influence the spatial spillover effects of digital technology. Central cities and peripheral cities occupy different positions within regional linkages, and the relationship between their entrepreneurial activity and the digital conditions of surrounding cities may also differ. Central cities usually maintain more frequent economic connections with surrounding cities and possess stronger capacities for information agglomeration, resource integration, and market radiation. Therefore, improvements in neighboring cities' digital capacity may be more easily reflected in changes in entrepreneurial activity in central cities. Although peripheral cities may also be affected by external digital conditions, their entrepreneurial activity may be more constrained by local industrial foundations, talent supply, and institutional environments; consequently, their response to changes in neighboring cities' digital development may not be the same as that of central cities [15,22,24]. Therefore, the spatial spillover effects of digital technology on entrepreneurial activity may differ between central and peripheral cities. It should be noted that this difference emphasizes variations in the spatial responses of cities at different hierarchical levels to digital technology development in surrounding cities, rather than directly implying that central cities necessarily have stronger diffusion capacity toward peripheral cities.

Finally, geographical location may affect the stability of the spatial spillover effects of digital technology. Cities in different regions vary in the density of economic linkages, degree of market integration, conditions for digital technology diffusion, and maturity of entrepreneurial ecosystems. These differences may influence whether the digital capacity of surrounding cities can be effectively transformed into an increase in local entrepreneurial activity. In regions with closer intercity connections, more developed industrial division of labor, and higher levels of market integration, such development is more likely to generate positive spillovers through information transmission, knowledge spillovers, and market linkages. In contrast, in regions with weaker intercity connections or greater internal development disparities, the driving effect of neighboring cities' digital technology development on local entrepreneurial activity may be weaker, or may even become unstable due to resource attraction, opportunity relocation, or the digital divide [24–26]. Therefore, the spatial spillover effects of digital technology may also vary among eastern, central, western, and northeastern regions. Accordingly, the following hypotheses are proposed:

H2. *The spatial spillover effects of digital technology on entrepreneurial activity differ significantly across cities of different sizes.*

H3. *The spatial spillover effects of digital technology on entrepreneurial activity differ significantly between central and peripheral cities.*

H4. *The spatial spillover effects of digital technology on entrepreneurial activity differ significantly across geographical regions.*

2.3. Attenuation of the Spatial Spillover Effects of Digital Technology

Digital technology can reduce the cost of information transmission and facilitate the diffusion of entrepreneurial opportunities, digital business experience, and market demand signals across cities. However, this does not mean that its spatial spillover effects can extend without limit. Although entrepreneurial activity can overcome some geographical constraints with the support of digital technology, entrepreneurs' understanding, learning, and transformation of external information still depend on actual intercity connections. Cities located closer to one another usually have more frequent market interactions, more similar business environments, and closer industrial linkages. As a result, the market signals and entrepreneurial experience generated by digital technology development in surrounding cities are more likely to be identified and absorbed by local entrepreneurs, thereby forming stronger external driving effects [3,4,27,28].

As geographical distance increases, the efficiency of information transmission, the intensity of market linkages, and the capacity for resource coordination among cities usually decline. Even though digital technology enhances long-distance connectivity, entrepreneurial activity still relies on demand assessment, business imitation, trust formation, and resource matching, all of which may be affected by communication costs, coordination costs, and institutional differences associated with distance. Spatial econometric research also indicates that spillover effects often exhibit distance decay and spatial boundaries; thus, external effects cannot simply be assumed to diffuse uniformly across all distance ranges [11,29,30]. Therefore, the impact of digital technology development in surrounding cities on local entrepreneurial activity may gradually weaken as distance increases and may become insignificant beyond a certain spatial range. This indicates that the spatial spillover effects of digital technology on entrepreneurial activity are characterized by both cross-city diffusion and geographical boundaries, and their intensity does not remain constant across all distance ranges. Based on the above analysis, this study proposes the following hypothesis:

H5. *The spatial spillover effects of digital technology on entrepreneurial activity exhibit significant geographical attenuation and have certain spatial boundaries.*

3. Research Design

3.1. Sample and Data Sources

This study constructs a balanced panel dataset covering 281 prefecture-level and above cities in China from 2006 to 2020. The dataset includes manually compiled indicators of digital technology development and entrepreneurial activity, as well as city-level control variables obtained from official statistical yearbooks and databases. The sample period is set as 2006–2020 because the construction of a consistent city-level balanced panel is constrained by the availability and comparability of firm registration data and socioeconomic variables. In addition, ending the sample in 2020 helps reduce potential disturbances from the COVID-19 pandemic, which may have affected entrepreneurial activity and the spatial diffusion of digital technology. Although this period provides a relatively stable

window for empirical analysis, it may not fully capture post-pandemic changes in digital transformation and entrepreneurship. This represents a limitation of this study and a direction for future research. The data processing procedures are described as follows.

For digital technology data, this study uses patent data directly obtained from the China National Intellectual Property Administration. The data cover patent application and grant records during the sample period and include basic information such as patent applicants, patent types, and International Patent Classification codes. Based on these records, this study systematically identifies and aggregates patenting activities related to digital technology across different cities, providing a reliable data foundation for constructing city-level indicators of digital technology development.

For entrepreneurial activity data, the original data on business registrations are obtained from the National Enterprise Credit Information Publicity System. The raw dataset contains more than 200 million business registration records in China. It covers registered market entities nationwide and records key information such as firm name, establishment date, enterprise type, industry category, registered capital, and the administrative division corresponding to the registered address. These records provide a comprehensive basis for measuring firm entry into the market. Considering that the raw business registration data contain missing information and irregular records, this study conducts a strict data cleaning procedure. First, observations with unidentifiable registration dates, obviously abnormal registration information, or records that cannot be matched with corresponding fields are removed. Second, firms with missing registered address information or addresses that can only be located at the provincial level are excluded, ensuring that all observations can be accurately matched to the city level. Third, observations with incomplete industry information, especially those that can only be identified at a broad industry-category level but cannot be further classified, are removed. After these procedures, the cleaned data are used to construct indicators of city-level entrepreneurial activity.

In addition to digital technology and entrepreneurial activity data, the city-level control variables used in this study are mainly obtained from the China Statistical Yearbook, the China City Statistical Yearbook, the China Stock Market & Accounting Research Database, the EPS Database, and the Chinese Research Data Services Platform. During the data integration process, variables from different sources are standardized to ensure consistency and comparability in variable definitions.

Because the spatial Durbin model imposes strict requirements on the data structure and requires a balanced panel dataset, this study further screens the original sample. City-year observations with severe missing values are removed, while a small number of missing values are supplemented using interpolation methods. After these data processing steps, the final sample consists of a balanced panel dataset covering 281 prefecture-level and above cities from 2006 to 2020.

3.2. Variable Measurement

Level of digital technology development. Existing studies generally measure the level of digital technology development in three ways. The first group of studies uses digital economic activities, information and communication technology inputs, digital industry outputs, or Internet infrastructure as proxy variables for digital technology development. These indicators can characterize the development of the digital economy at the macro level, but they focus more on the digital economy sector or digital infrastructure construction and therefore cannot directly reflect the actual level of digital technology innovation and technological accumulation at the regional level [1,31]. The second group of studies constructs comprehensive evaluation index systems to measure digital economy or digitalization development indices, usually from dimensions such as digital infrastructure,

digital industrialization, industrial digitalization, digital finance, and digital governance. Although such methods can comprehensively reflect the digital development environment, they may still involve a certain degree of subjectivity in indicator selection, weight assignment, and cross-regional comparability, which may affect the stability of measurement results [24,32,33]. The third group of studies focuses on firm-level digital transformation and often uses the frequency of digital technology terms in annual reports of listed companies, digitalization-related keywords, or survey data to measure firms' degree of digitalization. While these methods can better reflect firms' digital practices, their samples are usually concentrated among listed firms or specific survey respondents, making it difficult to comprehensively capture the overall level of digital technology development at the city level [34–36].

In general, patent data can objectively reflect technology formation, technological accumulation, and technology application, and thus serve as an important indicator for measuring regional technological innovation and technological development. Griliches [37] pointed out early on that patent statistics are an important data source for measuring technological change and innovation output in economic research; Haupt et al. [38] also showed that patent indicators can be used to identify technology life cycles and technological evolution. Compared with macro-output indicators, comprehensive evaluation indices, or survey-based indicators, patent data have several advantages, including strong technological specificity, long time series, broad coverage, and high traceability. They can therefore systematically capture the dynamic changes in digital technology across different regions. In recent years, an increasing number of studies have also used digital technology-related patents or digital innovation patents to identify the technological basis and spatial evolution of digital economy development [39,40]. Therefore, this study selects patents related to key digital technologies as the core variable reflecting the level of regional digital technology development.

It should be noted that patent-based indicators mainly capture the innovation, formation, and accumulation of digital technologies, rather than the full process of digital technology adoption, diffusion, or actual use. A city with fewer digital technology patents may still achieve a relatively high level of digital technology penetration through technology imports, platform applications, or the adoption of external digital solutions. Therefore, this study does not interpret digital technology patents as a comprehensive measure of all dimensions of digitalization. Instead, they are used to capture the regional technological foundation and innovation capacity underlying digital technology development. This choice is consistent with the focus of this study, which examines how locally accumulated digital technological capabilities affect entrepreneurial activity and generate spatial spillovers across cities. Compared with indicators of digital infrastructure or digital economy output, digital technology patents provide a more direct and traceable measure of regional digital technological capability, especially for identifying the spatial distribution and evolution of key digital technologies. To further alleviate potential measurement bias arising from the use of a single patent-based indicator, this study also uses Internet penetration as an alternative proxy for digital technology development in the subsequent robustness checks.

Specifically, based on the Classification System for Key Digital Technology Patents issued by the China National Intellectual Property Administration, this study uses the International Patent Classification codes corresponding to key digital technology patents as the identification criteria and screens patents in the field of key digital technologies from the patent database. This classification system focuses on emerging digital industries and frontier technologies, covering key digital technology categories such as artificial intelligence, high-end chips, quantum information, the Internet of Things, blockchain, industrial

Internet, and the metaverse. It also establishes correspondence between each technological branch and international patent classifications, providing a relatively clear classification basis for systematically identifying digital technology patents. In international research, identifying digital technology innovation based on patent classifications, keyword searches, and technology-field mapping has become a common practice, especially for analyzing the spatial distribution and technological evolution of digital technologies such as artificial intelligence, blockchain, cloud computing, the Internet of Things, and robotics [39,41]. This study uses the per capita number of digital technology patents as the core explanatory variable in the spatial econometric analysis and constructs the spatial Durbin model accordingly. Following the same classification system, this study further divides key digital technology patents into three functional categories: Digital Infrastructure Technology, Digital Intelligent Support Technology, and Digital Integration Application Technology. Digital Infrastructure Technology refers to foundational technologies that support computing, transmission, and sensing capabilities, such as high-end chips and quantum information. Digital Intelligent Support Technology refers to core technologies that support intelligent decision-making, trusted data processing, and value transmission, such as artificial intelligence and blockchain. Digital Integration Application Technology refers to scenario-based and platform-based technologies that promote industrial digitalization and integrated applications, such as the Internet of Things, the industrial Internet, and the metaverse.

Entrepreneurial activity. The number of firm registrations has been widely used to measure entrepreneurship at the regional level and has gradually become an important indicator for characterizing entrepreneurial activity and new firm entry. The World Bank Entrepreneurship Database uses the number of newly registered firms and its population-standardized indicators as important measures of entrepreneurial entry, emphasizing that firm registration data can reflect market entry and private-sector dynamics [42]. In the Chinese context, many recent studies have also used business registration data to identify new firm entry and entrepreneurial activity [14,43–45]. These studies indicate that business registration data can effectively reflect entrepreneurial entry at the city level in China.

Accordingly, in line with the common practice in existing studies and to maintain consistency with the city-level statistical scope of the core explanatory variable, this study uses Chinese business registration data to measure entrepreneurial activity. Specifically, based on firms' registration dates, this study identifies the number of firms newly entering the market in each city and each year. Then, using firms' registered address information, these firms are matched to the corresponding city level, thereby forming city-year-level firm registration data. Furthermore, considering differences in population size across cities, this study standardizes the number of firm registrations by population in the spatial econometric model to improve comparability across regions. The per capita number of firm registrations is ultimately used as the measure of entrepreneurial activity.

Control variables. To prevent other city-level factors during the sample period from interfering with the estimation of the impact of digital technology development on entrepreneurial activity, this study follows Cui and Li [43] and controls for the interaction terms between city characteristic variables in the year before the sample period, namely 2005, and time trends. This approach helps avoid the potential endogeneity problems that may arise from directly including contemporaneous city-level control variables in the regression. The city-level control variables include economic development level (Pgdp), measured by the logarithm of per capita GDP; population density (Pop), measured by the logarithm of population per square kilometer; fixed asset investment ratio (Fix), measured by the ratio of total fixed asset investment to regional GDP; industrial structure (Stru), measured by the share of secondary industry value added in regional GDP; and industrial

development level (Firmnum), measured by the logarithm of the number of above-scale industrial enterprises.

3.3. Spatial Weight Matrix

Considering that this study focuses on the spatial effects of digital technology on entrepreneurial activity, and that the diffusion of entrepreneurial activity, information transmission, and regional linkages usually decline as geographical distance increases, this study constructs a spatial weight matrix based on the inverse squared geographical distance between cities to characterize the intensity of spatial interactions among regions. Specifically, the elements of the spatial weight matrix W are defined as follows:

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

where d_{ij} denotes the geographical distance between city i and city j , calculated as the spherical distance based on the longitude and latitude coordinates of the two cities. On this basis, the spatial weight matrix is row-standardized so that the sum of the weights in each row equals 1. The standardized matrix W^* is obtained as follows:

$$w_{ij}^* = \frac{w_{ij}}{\sum_{j=1}^N w_{ij}} \quad (2)$$

This transformation allows the spatial lag term to be interpreted as the weighted average effect of relevant variables in other regions.

The use of the inverse-squared geographical distance matrix in this study is mainly based on two considerations. First, this matrix form can strengthen the distance-decay feature by assigning higher weights to linkages between nearby cities while allowing the influence of distant cities to decline rapidly. This is consistent with the basic patterns of entrepreneurial activity diffusion and digital technology diffusion. Second, compared with an adjacency matrix, which only captures whether regions are contiguous, a distance-based matrix preserves the continuity of spatial linkages and is more conducive to identifying differentiated spatial interactions across regions.

Within the framework of this study, the impact of digital technology on entrepreneurial activity is mainly realized through channels such as information diffusion and regional coordination, and these mechanisms generally weaken as geographical distance increases. Therefore, adopting a distance-decay spatial weight matrix has clear economic implications. Overall, the inverse squared geographical distance matrix can effectively characterize the spatial correlation structure examined in this study and provide a basis for identifying spatial spillover effects in the subsequent analysis. In addition, the results using alternative spatial weight matrices are also reported in the robustness checks.

3.4. Model Specification

The spatial Durbin model (SDM) can characterize the spatial correlation structure among regional variables within a unified framework. In particular, by introducing the spatial lag terms of explanatory variables, the SDM can directly identify cross-regional spillover effects. Therefore, it is well-suited for analyzing the spatial diffusion effects of digital technology on entrepreneurial activity. This study examines whether the impact of digital technology is transmitted through interregional linkages and whether it leads to differences in entrepreneurial activity. Based on this consideration, the following spatial Durbin model is constructed:

$$y_{it} = \delta \sum_{j=1}^N w_{ij} y_{jt} + \theta \text{DigiTech}_{it} + \rho \sum_{j=1}^N w_{ij} \text{DigiTech}_{jt} + \gamma X_{it} + \phi \sum_{j=1}^N w_{ij} X_{jt} + \mu_i + \lambda_t + \varepsilon_{it} \quad (3)$$

where i and j denote cities, t denotes year, and N denotes the number of cities. y_{it} represents entrepreneurial activity, and w_{ij} is the element of the spatial weight matrix, which is used to capture the intensity of spatial linkages between cities.

Among them, $\sum_{j=1}^N w_{ij} \text{DigiTech}_{jt}$ is the spatial lag term of digital technology. Its coefficient ρ captures the association between digital technology development in surrounding cities and local entrepreneurial activity, and thus provides an important basis for identifying spatial spillovers. However, because the SDM includes the spatially lagged dependent variable and therefore involves spatial feedback effects, the spatial spillover effect of digital technology cannot be inferred directly from ρ alone. It should instead be identified through the decomposition of direct, indirect, and total effects. By comparison, $\sum_{j=1}^N w_{ij} y_{jt}$ is mainly used to capture the spatial dependence structure of entrepreneurial outcomes themselves, so as to control for the mutual influence of entrepreneurial performance across regions and avoid mistakenly interpreting such endogenous spatial correlation as the spatial spillover effect of the explanatory variable. In addition, $\sum_{j=1}^N w_{ij} X_{jt}$ is used to control for the influence of other regional characteristics transmitted through spatial channels.

It should be further noted that, because the model includes the spatially lagged dependent variable, there is an explicit spatial feedback mechanism. As a result, the impact of explanatory variables on the dependent variable cannot be directly inferred from the estimated regression coefficients. Therefore, it is necessary to decompose the estimated effects into direct effects, indirect effects, and total effects. The direct effect represents the average impact of digital technology on local entrepreneurial outcomes. The indirect effect, namely the spatial spillover effect, represents the impact of digital technology on entrepreneurial outcomes in other cities transmitted through the spatial weight matrix, which is the core focus of this study. The total effect is the sum of the direct and indirect effects, reflecting the overall impact of digital technology.

In matrix form, the spatial Durbin model can be expressed as:

$$Y_t = (I - \delta W)^{-1} (\theta \text{Dige}_t + \rho W \text{Dige}_t + X_t \gamma + W X_t \phi + \mu + \lambda_t + \varepsilon_t) \quad (4)$$

Further, the partial derivative matrix can be written as:

$$\frac{\partial Y_t}{\partial \text{Dige}_t} = (I - \delta W)^{-1} (\theta I + \rho W) \quad (5)$$

The average of the diagonal elements of this matrix represents the direct effect, while the average row sum represents the total effect. The indirect effect, namely the spatial spillover effect, is obtained by subtracting the direct effect from the total effect. Based on the above specification, this study focuses on the indirect effect of digital technology and compares its spatial impact on entrepreneurial activity. If digital technology influences entrepreneurial activity mainly through mechanisms such as information diffusion and demonstration effects, it is more likely to exhibit significant spatial spillover effects on entrepreneurial activity.

4. Empirical Results and Analysis

4.1. Spatial Correlation Analysis

Based on the geographical distance weight matrix, this study uses Moran's I index to test the spatial autocorrelation of entrepreneurial activity and digital technology de-

velopment. The results are reported in Table 1. Overall, from 2006 to 2020, Moran's I values of both variables are positive and significant at the 1% level, indicating that both entrepreneurial activity and digital technology exhibit significant positive spatial autocorrelation at the city level. Specifically, Moran's I values of entrepreneurial activity range from 0.1368 to 0.3955 and are significantly positive in all years. The Moran's I values of digital technology development range from 0.0104 to 0.3147 and also pass the significance test in all years. This indicates that neither entrepreneurial entry nor digital technology development follows a completely random spatial distribution; instead, both exhibit a certain degree of spatial agglomeration.

Table 1. Moran's I test results for entrepreneurial activity and digital technology.

Year	Entrepreneurial Activity: Moran's I	Z-Value	Digital Technology: Moran's I	Z-Value
2006	0.3198 ***	18.7050	0.0104 ***	3.4237
2007	0.2871 ***	17.5705	0.0147 ***	3.9213
2008	0.2210 ***	14.3744	0.0250 ***	4.7307
2009	0.2315 ***	14.9309	0.0344 ***	5.6334
2010	0.1924 ***	11.7792	0.0753 ***	9.5160
2011	0.1776 ***	14.1388	0.0650 ***	7.3367
2012	0.1368 ***	11.4943	0.1315 ***	11.9004
2013	0.1516 ***	12.2243	0.1498 ***	11.3665
2014	0.1608 ***	13.5990	0.1777 ***	12.2152
2015	0.1986 ***	14.9351	0.2480 ***	16.0886
2016	0.2377 ***	17.8023	0.2820 ***	18.2020
2017	0.3733 ***	22.0591	0.3147 ***	19.6732
2018	0.3668 ***	20.6313	0.3000 ***	18.2170
2019	0.2561 ***	14.1813	0.2489 ***	15.3389
2020	0.3955 ***	21.8570	0.2400 ***	14.5380

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

A further comparison shows that Moran's I values of entrepreneurial activity are generally higher than those of digital technology in the early sample period, suggesting that the spatial correlation of entrepreneurial activity was relatively stronger in the initial stage. Meanwhile, Moran's I values of digital technology are significantly higher in the later sample period than in the earlier period, indicating that its degree of spatial agglomeration has strengthened over time. It should be noted that Moran's I test reflects the spatial correlation of the variables themselves and is mainly used to determine whether it is necessary to introduce a spatial econometric model. However, it cannot directly indicate that there must be a spatial spillover relationship between variables. Therefore, whether digital technology has a spatial spillover effect on entrepreneurial activity still needs to be further identified using spatial econometric models.

4.2. Spatial Econometric Tests and Estimation Results

4.2.1. Specification and Tests of the Baseline Spatial Econometric Model

Following the general logic of spatial econometric model selection and drawing on the treatment methods in existing studies, this study adopts a combination of the "general-to-specific" and "specific-to-general" approaches to gradually test and select the model. The relevant results are shown in Table 2. From the results of the spatial correlation tests, the LM_Error, RLM_Error, LM_Lag, and RLM_Lag statistics for entrepreneurial activity are all significant at the 1% level. This indicates that both spatial lag effects and spatial error effects exist in the model, and that both the SAR model and the SEM model have certain explanatory power. Further tests of the model specification indicate that the LR statistics for

individual effects and time effects are both significant, indicating that both unobservable heterogeneity across cities and common shocks over time have systematic impacts on the dependent variable. Therefore, a model specification including both city and year fixed effects should be adopted. Meanwhile, the Hausman test results generally support the fixed-effects model over the random-effects model, suggesting that individual effects may be correlated with the explanatory variables and that the fixed-effects specification is more robust. After determining the use of the spatial Durbin model, this study further tests whether the SDM can be simplified into the SAR or SEM model. The results show that both the LR statistic for SAR and the LR statistic for SEM are significant at the 1% level, rejecting the null hypothesis that the model can be simplified. This implies that the spatial lag terms of the explanatory variables play a non-negligible role in the model, and excluding them would lead to model specification bias. Therefore, from the perspective of model nesting relationships and statistical test results, the complete SDM specification should be retained for estimation. Based on the above test results, this study ultimately selects the spatial Durbin model with city and year fixed effects as the baseline model to characterize the spatial mechanism through which digital technology development affects entrepreneurial activity at the city level. At the same time, to facilitate comparison of estimation results under different spatial specifications and to test model robustness, this study also reports the corresponding SAR and SEM estimation results as comparative analyses.

Table 2. Spatial econometric model test results.

Indicator	Entrepreneurial Activity
LM_Error	1391.949 ***
RLM_Error	344.432 ***
LM_Lag	1301.014 ***
RLM_Lag	253.496 ***
Hausman χ^2	61.761 ***
LR, individual effects χ^2	67.470 ***
LR, time effects χ^2	1268.299 ***
LR, SAR χ^2	100.528 ***
LR, SEM χ^2	211.650 ***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The LM tests include both standard LM tests and robust LM tests. The Hausman test is used to determine the choice between fixed-effects and random-effects models. In the LR tests, individual effects and time effects are used to test whether two-way fixed effects should be adopted, while SAR and SEM are used to test whether the SDM can be simplified.

After completing the spatial correlation tests and determining the model specification, this study further estimates the spatial effects of digital technology development on entrepreneurial activity based on Model (3), which incorporates both city and year fixed effects.

The empirical results in Table 3 suggest that, for entrepreneurial activity, the spatial correlation terms are significantly positive regardless of whether the SAR, SEM, or SDM model is used. Specifically, the spatial lag coefficient ρ in the SAR model and the spatial error coefficient λ in the SEM model are both significant at the 1% level. This indicates that entrepreneurial entry across cities exhibits clear spatial dependence; that is, changes in entrepreneurial activity in one region are linked to those in surrounding regions. This result confirms the necessity of incorporating spatial factors into the analysis. It should be noted that the relatively low Within R^2 in the SDM specification should be interpreted in light of the model structure. Unlike the SAR and SEM specifications, the SDM includes both the spatially lagged dependent variable and the spatially lagged explanatory variables. Part of the explanatory power is therefore captured through spatial feedback and spillover channels rather than through the non-spatial within-city fitted component used to compute

the reported Within R^2 . Thus, the low Within R^2 in the SDM does not imply that the model lacks explanatory relevance; rather, it reflects how the spatial panel estimator decomposes within-city variation after accounting for spatial dependence and spatially lagged covariates. For this reason, the interpretation of the SDM results relies mainly on the significance of the spatial parameters and the decomposition of direct, spillover, and total effects.

Table 3. Spatial model regression results of the impact of digital technology development on entrepreneurial activity.

Variables	SAR	SEM	SDM	SAR	SEM	SDM
ρ	0.697 *** (0.0242)		0.591 *** (0.0308)	0.608 *** (0.0259)		0.519 *** (0.0337)
λ		0.745 *** (0.0277)			0.680 *** (0.0305)	
<i>DigiTech</i>	5.158 *** (0.1848)	5.257 *** (0.2146)	4.639 *** (0.2035)	3.680 *** (0.2128)	3.371 *** (0.2382)	2.997 *** (0.2293)
$W \times \text{DigiTech}$			3.247 *** (0.5203)			4.809 *** (0.6000)
Control variables	No	No	No	Yes	Yes	Yes
Direct effect	5.365 *** (0.1884)		4.902 *** (0.2025)	3.788 *** (0.2218)		3.229 *** (0.2306)
Spillover effect	11.676 *** (1.2004)		14.528 *** (1.1198)	5.695 *** (0.6417)		13.096 *** (1.1712)
Total effect	17.041 *** (1.1981)		19.429 *** (1.0800)	9.483 *** (0.7436)		16.325 *** (1.1538)
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4215	4215	4215	4215	4215	4215
Within R^2	0.605	0.360	0.610	0.499	0.515	0.017

Notes: This table reports the spatial econometric estimation results. SAR, SEM, and SDM refer to the spatial autoregressive model, spatial error model, and spatial Durbin model, respectively. Direct, spillover, and total effects are calculated based on spatial effect decomposition. City fixed effects and year fixed effects are controlled as indicated in the table. Standard errors are reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The reported R^2 is the within R^2 generated by the spatial panel estimator; because different spatial models differ in their spatial structures and treatment of spatial feedback effects, these R^2 values should not be interpreted as directly comparable measures of overall model fit across models. The same applies below.

On this basis, the estimated coefficients of the digital technology variable are significantly positive across all models and remain robust after introducing control variables. This suggests that digital technology development significantly promotes entrepreneurial entry. Furthermore, in the spatial Durbin model, the spatial lag term of digital technology, $W \times \text{DigiTech}$, is also significantly positive, indicating that digital technology not only affects local entrepreneurial activity but also drives entrepreneurial activity in other cities through spatial linkages. The effect decomposition results further confirm this pattern. Both the direct and indirect effects of digital technology are significantly positive at the 1% level. The indirect effect, namely the spatial spillover effect, is clearly larger than the direct effect, indicating that the influence of digital technology on entrepreneurial activity is not limited to the local city. Instead, its diffusion effect through spatial channels occupies a more important position in the overall impact. In other words, as the level of digital technology increases, not only is local entrepreneurial activity promoted, but entrepreneurial entry in surrounding cities is also significantly stimulated, reflecting strong regional linkage characteristics. These findings are broadly consistent with prior studies showing that digital technologies can reshape entrepreneurial processes, reduce uncertainty, and expand

entrepreneurial opportunities [5,8,13]. They also complement the literature on knowledge spillovers and regional innovation diffusion by showing that the entrepreneurial effect of digital technology is not confined to local cities, but can extend across space through intercity linkages [25,46].

4.2.2. Spatial Spillover Effects of Different Types of Digital Technology on Entrepreneurial Activity

After verifying that digital technology has a significant positive spatial spillover effect on entrepreneurial activity, this study further divides digital technology into digital infrastructure technology, digital intelligent support technology, and digital integration application technology. This classification helps identify the specific roles played by different types of digital technology in the stage of entrepreneurial entry. Since different digital technologies have different functional positions in the economic system, their effects on entrepreneurial activity may also vary. Therefore, it is necessary to further examine the spatial spillover effects of digital technology from a classification perspective.

Table 4 reports the results. Overall, the spatial autoregressive coefficient ρ is significantly positive across all three model specifications, indicating that entrepreneurial activity is not only affected by local factors but also exhibits clear spatial dependence. In other words, entrepreneurial entry in one region can generate linkage effects on surrounding cities through regional connections. On this basis, the estimated coefficients of the three types of digital technology variables are all significantly positive, and their spatial lag terms are also significant. This indicates that different types of digital technology can not only promote local entrepreneurial activity but also stimulate entrepreneurial entry in other cities through spatial channels. The effect decomposition results further show that the direct and indirect effects of all three types of digital technology are significantly positive, suggesting that digital technology can both promote local entrepreneurial entry and generate positive driving effects on surrounding cities through spatial linkages. A further comparison indicates that the indirect effects are generally larger than the direct effects, indicating that the impact of digital technology on entrepreneurial activity is realized more through spatial spillover channels. That is, regional interaction and connectivity play a more important role in the process through which digital technology exerts its effects.

Table 4. Spatial spillover effects of different digital technology types on entrepreneurial activity.

Variables	Digital Infrastructure Technology	Digital Intelligent Support Technology	Digital Integration Application Technology
ρ	0.571 *** (0.0323)	0.578 *** (0.0324)	0.539 *** (0.0333)
<i>DigiTech</i>	0.169 *** (0.0151)		
$W \times DigiTech$	0.552 *** (0.0469)		
<i>DigiTech</i>		0.220 *** (0.0217)	
$W \times DigiTech$		0.781 *** (0.0677)	
<i>DigiTech</i>			0.109 *** (0.0073)
$W \times DigiTech$			0.271 *** (0.0226)
Control variables	Yes	Yes	Yes

Table 4. Cont.

Variables	Digital Infrastructure Technology	Digital Intelligent Support Technology	Digital Integration Application Technology
Direct effect	0.196 *** (0.0159)	0.258 *** (0.0229)	0.121 *** (0.0076)
Spillover effect	1.498 *** (0.1252)	2.133 *** (0.1821)	0.708 *** (0.0552)
Total effect	1.694 *** (0.1301)	2.391 *** (0.1901)	0.829 *** (0.0576)
City fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	4215	4215	4215
Within R ²	0.172	0.365	0.162

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively. The classification of digital technology is based on the Classification System of Key Digital Technology Patents (2023) issued by the China National Intellectual Property Administration. Digital Infrastructure Technology includes high-end chips and quantum information. Digital Intelligent Support Technology includes artificial intelligence and blockchain. Digital Integration Application Technology includes the Internet of Things, the industrial Internet, and the metaverse.

Comparing different types of digital technology, digital intelligent support technology has the most prominent effect, followed by digital infrastructure technology, while digital integration application technology has a relatively weaker effect. This result suggests that, compared with integration-oriented technologies that depend on specific application scenarios, intelligent support technologies that provide algorithmic support, data processing, and resource allocation capabilities, as well as infrastructure technologies that provide underlying computing power and hardware support for digital activities, are more likely to break through regional boundaries and form stable spatial diffusion effects. This finding is consistent with the formation mechanism of entrepreneurial activity. Entrepreneurial entry essentially depends on opportunity identification and resource matching. The improvement of digital infrastructure lowers the technical threshold for entrepreneurship, while digital intelligent support technology further improves information processing efficiency and factor allocation efficiency, making entrepreneurial opportunities more likely to diffuse across regions. By contrast, integration application technologies rely more on specific industrial environments and application scenarios, and their spatial spillover effects are relatively limited. Therefore, the classification analysis results show that the spatial spillover effects of digital technology on entrepreneurial activity have internal differences related to technological characteristics, mainly reflected in the diffusion capacity of different technology types. The closer digital technology is to underlying support and intelligent decision-making functions, the stronger its cross-regional radiation and driving effects; conversely, the closer it is to specific application scenarios, the weaker its spatial diffusion effect tends to be.

4.2.3. Robustness Checks

To examine the reliability of the baseline results, this study conducts robustness analyses by changing the specification of the spatial weight matrix. In the baseline regression, the spatial weight matrix is constructed using the inverse squared geographical distance between cities, so as to capture the basic feature that spatial interactions decline with distance. On this basis, this study further introduces an adjacency matrix and an economic-geographical matrix for alternative estimations [26,47–49], in order to test the sensitivity of the results to the specification of the spatial weight matrix. Table 5 reports the robustness check results based on alternative spatial weight matrices.

Table 5. Robustness checks based on alternative spatial weight matrices.

Variables	Adjacency Matrix			Economic-Geographical Matrix		
	SAR	SEM	SDM	SAR	SEM	SDM
ρ	0.359 *** (0.0179)		0.295 *** (0.0206)	0.377 *** (0.0531)		0.300 *** (0.0867)
λ		0.364 *** (0.0212)			0.795 *** (0.0422)	
<i>DigiTech</i>	4.023 *** (0.2139)	3.821 *** (0.2364)	3.375 *** (0.2252)	4.690 *** (0.2238)	4.304 *** (0.2247)	3.957 *** (0.2269)
$W \times DigiTech$			3.879 *** (0.4013)			14.000 *** (1.5584)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Direct effect	4.162 *** (0.2238)		3.725 *** (0.2257)	4.706 *** (0.2296)		4.008 *** (0.2306)
Spillover effect	2.090 *** (0.1748)		6.430 *** (0.4665)	2.942 *** (0.6658)		21.922 *** (2.8057)
Total effect	6.252 *** (0.3459)		10.155 *** (0.4946)	7.648 *** (0.7068)		25.930 *** (2.7676)
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4215	4215	4215	4215	4215	4215
<i>Within R</i> ²	0.511	0.523	0.555	0.517	0.528	0.377

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The adjacency matrix W^{adj} is constructed based on whether two cities share a common boundary. Its elements are defined as follows:

$$w_{ij}^{adj} = \begin{cases} 1, & \text{If city } i \text{ and city } j \text{ are adjacent} \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

The matrix is also row-standardized. This matrix mainly captures direct spatial adjacency relationships and helps identify local spillover effects formed through geographical contiguity.

Meanwhile, to further consider the influence of economic linkages between cities on spatial interactions, this study constructs an economic-geographical matrix W^{eco} , which introduces economic scale into the geographical distance matrix. Its elements are defined as follows:

$$w_{ij}^{eco} = \begin{cases} \frac{GDP_i}{d_{ij}}, & i \neq j \\ 0, & i = j \end{cases} \quad (7)$$

The matrix is also row-standardized. By assigning higher weights to cities with larger economic scale, this matrix allows spatial linkages to depend not only on geographical proximity but also on the potential strength of economic connections between cities. Re-estimating the model under these different spatial weight matrix specifications can, to some extent, avoid bias caused by the choice of the weight matrix and thus more robustly identify the spatial spillover effects of digital technology on entrepreneurial activity.

The evidence reveals that, regardless of the spatial weight matrix used, the spatial autoregressive coefficients are significantly positive, indicating that entrepreneurial activity consistently exhibits stable spatial correlation across cities. At the same time, the spatial lag terms of digital technology in the spatial Durbin model remain significantly positive, suggesting that the spatial spillover effect of digital technology on entrepreneurial activity

does not depend on a specific spatial weight matrix specification. The effect decomposition results show that, under different spatial weight matrices, both the direct and indirect effects of digital technology are significantly positive, and the indirect effects are generally larger than the direct effects. This indicates that the impact of digital technology on entrepreneurial activity is reflected not only in its local promotional effect, but also in its significant driving effect on surrounding cities through spatial linkages. In particular, under the economic-geographical matrix specification, the spillover effect becomes even stronger, suggesting that the diffusion effect of digital technology is more pronounced among cities with closer economic connections. This result is consistent with the baseline regression results.

To further examine whether the baseline results are sensitive to the measurement of digital technology development, this study replaces the patent-based indicator with Internet penetration and re-estimates the spatial Durbin model. The results are shown in Table 6. The spatial autoregressive coefficient remains significantly positive, indicating that entrepreneurial activity continues to exhibit strong spatial dependence. More importantly, both the coefficient of *DigiTech* and its spatially lagged term are significantly positive, suggesting that Internet penetration not only promotes local entrepreneurial activity but also generates positive spillover effects on surrounding cities. The spatial effect decomposition further shows that the direct effect, spillover effect, and total effect are all significantly positive. These results are consistent with the baseline findings based on digital technology patents, indicating that the positive spatial spillover effect of digital technology development on entrepreneurial activity is robust to the use of an alternative proxy variable.

Table 6. Robustness check using internet penetration as an alternative proxy.

Variables	Entrepreneurial Activity
ρ	0.719 *** (0.028)
<i>DigiTech</i>	0.003 *** (0.001)
$W \times DigiTech$	0.006 *** (0.002)
Control variables	Yes
Direct effect	0.004 *** (0.001)
Spillover effect	0.029 *** (0.007)
Total effect	0.033 *** (0.007)
City fixed effects	Yes
Year fixed effects	Yes
Observations	4215
Within R^2	0.460

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

To further alleviate potential endogeneity concerns, this study conducts an IV-based robustness check. The instrumental variable is constructed as the interaction between the number of post offices per 10,000 people in 1984 and a linear time trend. The rationale is as follows. On the one hand, the development of digital technology is closely related

to earlier communication infrastructure. As an important component of traditional communication infrastructure, the historical distribution of post offices reflects a city's early information transmission capacity, communication network foundation, and long-term familiarity with information exchange. These historical conditions may affect the subsequent development of information and communication technologies, as well as the accumulation and diffusion of digital technological capabilities. Therefore, the instrument satisfies the relevance requirement. On the other hand, the number of post offices per 10,000 people in 1984 predates the sample period by more than two decades. With the rapid development of modern communication technologies, banking systems, express delivery networks, and transportation infrastructure, the traditional functions of post offices in financial services, logistics, and market access had been largely replaced during the sample period. Moreover, the time-invariant direct effect of historical postal infrastructure is absorbed by city fixed effects, while common temporal shocks are absorbed by year fixed effects. After controlling for city-level socioeconomic characteristics, historical postal infrastructure is less likely to directly affect contemporary entrepreneurial activity except through its influence on digital technology development. Therefore, this instrumental variable basically satisfies the exclusion restriction.

As shown in Table 7, the first-stage coefficient of the instrumental variable is significantly positive, and the Kleibergen-Paap rk Wald F-statistic is 45.48, which is higher than the Stock-Yogo 10% maximal IV size critical value of 16.38. In the second-stage regression, the coefficient of DigiTech remains significantly positive, indicating that digital technology development continues to promote entrepreneurial activity after addressing potential endogeneity. In addition, the spatial model based on the first-stage fitted value shows that both Fitted DigiTech and its spatially lagged term are significantly positive, and the decomposed direct, spillover, and total effects are also significantly positive. These results further support the robustness of the baseline findings.

Table 7. IV Robustness check.

Variables	First Stage: DigiTech	Second Stage: Entrepreneurial Activity	Spatial Model: Entrepreneurial Activity
IV	0.145 *** (0.021)		
<i>DigiTech</i>		12.044 *** (2.074)	
ρ			0.705 *** (0.028)
<i>Fitted DigiTech</i>			5.499 *** (1.425)
$W \times \text{Fitted } DigiTech$			26.605 *** (5.479)
First-stage F-statistic	45.48		
Control variables	Yes	Yes	Yes
Direct effect			7.315 *** (1.504)
Spillover effect			103.789 *** (18.998)
Total effect			111.104 *** (19.392)

Table 7. *Cont.*

Variables	First Stage: DigiTech	Second Stage: Entrepreneurial Activity	Spatial Model: Entrepreneurial Activity
City fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Observations	4215	4215	4215
Within R ²			0.460

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5. Additional Analysis

5.1. Urban Size Heterogeneity: Large Cities and Small and Medium-Sized Cities

Urban size is an important dimension for examining the heterogeneity of the spatial spillover effects of digital technology. The development of digital technology not only affects local entrepreneurial activity but may also influence surrounding regions through intercity information linkages, market connections, and the diffusion of entrepreneurial activity. Cities of different sizes occupy different positions in regional networks, and their ability to absorb external digital technology spillovers may therefore vary. Large cities are usually major agglomeration centers of digital technology and entrepreneurial activity. Although their surrounding areas may benefit from certain spillover effects, large cities themselves have a strong capacity to attract resources and entrepreneurial opportunities, which may weaken the conversion of external spillovers into local entrepreneurial activity. By contrast, the connections between small and medium-sized cities and surrounding cities rely more heavily on external technology diffusion and market linkages. The cross-regional information flows and reductions in transaction costs brought by digital technology development are more likely to break through local market-size constraints and be transformed into new entrepreneurial opportunities. Therefore, analyzing heterogeneity from the perspective of city size helps identify differences in the spatial spillover effects of digital technology across cities of different scales.

Following the *Notice on Adjusting the Standards for City Size Classification* issued by the State Council of China, this study uses a resident population of one million in municipal districts as the threshold and divides the sample cities into large cities and small and medium-sized cities. The grouped regression results show that digital technology development has significant spatial spillover effects on entrepreneurial activity in both types of cities, but the external driving effect is more pronounced in small and medium-sized cities. According to the spatial effect decomposition results in Table 8, the indirect effect for small and medium-sized cities is significantly higher than that for large cities, indicating that digital technology development in surrounding regions has a stronger promotional effect on entrepreneurial activity in small and medium-sized cities. This suggests that the spatial spillover effects of digital technology do not occur uniformly across cities of different sizes, but are more likely to be transformed into increased entrepreneurial activity in small and medium-sized cities. A possible reason is that small and medium-sized cities have relatively limited local entrepreneurial conditions and depend more heavily on external information, market connections, and the diffusion of digital applications. Therefore, the spillover effects generated by digital technology development in surrounding regions can more easily compensate for their local resource constraints and promote the growth of entrepreneurial activity. Overall, differences in city size affect the intensity of digital technology spillovers, and small and medium-sized cities constitute a more sensitive receiving space for the entrepreneurial spillover effects of digital technology. These findings are

consistent with H2, indicating that the spatial spillover effects of digital technology on entrepreneurial activity differ across cities of different sizes.

Table 8. Heterogeneity analysis of the spatial spillover effects of digital technology.

Variables	Urban Size		Urban Hierarchy			Geographical Location		
	Large	Small and Medium-Sized	Central	Peripheral	Eastern	Central	Western	Northeastern
ρ	0.159 *** (0.0462)	0.466 *** (0.0407)	0.635 *** (0.0462)	0.602 *** (0.0326)	0.427 *** (0.0471)	0.112 * (0.0636)	0.157 *** (0.0567)	−0.015 (0.0903)
<i>DigiTech</i>	3.482 *** (0.3434)	4.219 *** (0.9814)	0.145 (0.5910)	6.797 *** (0.2157)	2.722 *** (0.3952)	6.457 *** (0.6316)	14.044 *** (0.9371)	4.085 *** (1.4434)
$W \times DigiTech$	5.531 *** (0.8121)	12.349 *** (2.6845)	5.404 *** (1.2184)	−3.086 *** (0.5086)	4.402 *** (0.9600)	−4.361 ** (2.0399)	−3.126 (3.1841)	−15.518 *** (5.7490)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Direct effect	3.597 *** (0.3477)	4.917 *** (0.9775)	1.143 * (0.6229)	6.853 *** (0.2237)	3.015 *** (0.4064)	6.447 *** (0.6485)	14.066 *** (0.9639)	4.164 *** (1.4832)
Spillover effect	7.211 *** (0.8571)	26.525 *** (4.7048)	14.420 *** (3.1093)	2.565 ** (1.1021)	9.594 *** (1.6308)	−3.909 * (2.3475)	−0.771 (3.7143)	−14.697 ** (5.7162)
Total effect	10.808 *** (0.8883)	31.442 *** (4.6102)	15.563 *** (3.3155)	9.418 *** (1.1575)	12.609 *** (1.7213)	2.538 (2.4792)	13.295 *** (3.8956)	−10.533 * (5.9769)
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1500	2715	525	3690	1290	1200	1215	510
Within R^2	0.015	0.273	0.381	0.364	0.300	0.033	0.492	0.742

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5.2. Urban Hierarchy Heterogeneity: Central Cities and Peripheral Cities

Urban hierarchy is a necessary dimension for examining the heterogeneity of the spatial spillover effects of digital technology. Unlike city size, which mainly focuses on population scale, urban hierarchy emphasizes differences in cities' positions within regional linkages. Central cities usually maintain more frequent economic connections with surrounding cities, and their entrepreneurial activity is not only affected by local digital technology development, but is also more likely to be influenced by digital technology development in neighboring cities. Peripheral cities are also embedded in regional linkages, but their entrepreneurial activity may depend more on improvements in local digital technology conditions, and their response to digital technology development in surrounding cities may not be the same. Therefore, grouping cities into central and peripheral cities helps determine whether the spatial spillover effects of digital technology on entrepreneurial activity differ across urban hierarchies.

Consistent with prior studies on China's urban administrative hierarchy, this study defines municipalities directly under the central government, provincial capitals, and sub-provincial cities as central cities, while the remaining prefecture-level cities are defined as peripheral cities [50,51]. As shown in Table 6, digital technology development affects entrepreneurial activity in both types of cities, but the structure of its effects differs markedly. The local effect is stronger in peripheral cities, indicating that digital technology development more directly promotes local entrepreneurial activity in peripheral cities. By contrast, the indirect effect is significantly higher in central cities than in peripheral cities, suggesting that entrepreneurial activity in central cities is more likely to be influenced by digital technology development in surrounding cities, and that the spatial linkage between digital technology and entrepreneurial activity is more pronounced in central cities. It should be noted that this result does not directly prove that central cities diffuse the entrepreneurial effects of digital technology to external cities. Rather, under the current spatial

effect decomposition framework, it indicates that central cities show a stronger response to the spillover effects of digital technology development in surrounding cities. Overall, differences in urban hierarchy shape how the spatial spillover effects of digital technology are manifested: peripheral cities mainly exhibit stronger local direct effects, whereas central cities show stronger responses to digital technology development in surrounding cities. This pattern is consistent with H3, which predicts that the spatial spillover effects of digital technology on entrepreneurial activity differ between central and peripheral cities.

5.3. Geographical Location Heterogeneity: Eastern, Central, Western, and Northeastern Regions

Geographical location is an important dimension for examining the heterogeneity of the spatial spillover effects of digital technology. The impact of digital technology on entrepreneurial activity involves cross-regional linkages, but such linkages do not occur uniformly across different regions. Cities in different geographical locations differ in the intensity of regional connections, conditions for digital technology diffusion, and the extent of external linkages in entrepreneurial activity. These differences affect whether digital technology development in surrounding cities can be effectively transformed into an increase in local entrepreneurial activity. In general, the closer the interregional connections, the more likely digital technology development is to generate positive external effects through information flows and market linkages. Conversely, if intercity connections within a region are relatively weak, or if digital development in surrounding cities mainly functions as a competitive attraction force, spatial spillover effects may weaken or even become negative. Therefore, grouping cities into the eastern, central, western, and northeastern regions helps identify spatial differences in the entrepreneurial effects of digital technology across geographical locations.

Based on the *Several Opinions of the State Council on Promoting the Rise of the Central Region*, the *Implementation Opinions of the State Council on Several Policies and Measures for the Development of the Western Region*, and the relevant regional classification standards of the *National Bureau of Statistics of China*, this study divides the sample cities into the eastern, central, western, and northeastern regions. The grouped regression results in Table 6 suggest that digital technology development generally promotes entrepreneurial activity in the eastern, central, and western regions, but its spatial spillover effects differ significantly across regions. The indirect effect in the eastern region is significantly positive, indicating that digital technology development in surrounding cities can effectively promote local entrepreneurial activity. This suggests that the spatial spillover effect of digital technology is most stable in the eastern region. Although the central and western regions reveal relatively strong local promotional effects, their indirect effects do not form stable positive spillovers. This indicates that digital technology development in the central and western regions mainly promotes local entrepreneurial activity through direct local effects, whereas cross-city external driving effects remain relatively insufficient.

In the regional analysis, the northeastern region presents a particularly noteworthy pattern, as digital technology development exhibits a negative spatial spillover effect in this region. Specifically, in the northeastern region, the local promotional effect of digital technology is unstable, and the indirect effect is significantly negative. This counterintuitive result may be related to the structural characteristics of Northeast China. As a traditional old industrial base, this region has long faced challenges such as heavy-industry dependence, slower industrial restructuring, population outflow, and relatively weak entrepreneurial vitality [52–55]. Under these conditions, digital technology development in surrounding cities may not easily generate complementary entrepreneurial opportunities for local cities. Instead, it may intensify competition for limited entrepreneurial resources, skilled labor, market demand, and investment opportunities within the region. In addition,

because many northeastern cities share similar industrial structures and face relatively limited market expansion, digital technology development in neighboring cities may generate substitution effects rather than positive knowledge spillovers. Therefore, the negative indirect effect should not be interpreted as evidence that digital technology itself suppresses entrepreneurship, but rather as suggesting that, in regions with weaker entrepreneurial ecosystems and insufficient intercity complementarity, surrounding digital technology development may crowd out local entrepreneurial activity through competitive and substitution channels. However, this explanation should be interpreted as a plausible mechanism rather than direct empirical evidence of the underlying channel. Because the present study focuses on the spatial effect of digital technology development rather than the internal mechanism of regional decline, the competition and substitution explanation remains interpretive. Future research could further test this mechanism by incorporating mediating variables such as industrial structure change, talent outflow, labor mobility, or indicators of entrepreneurial ecosystem quality.

Taken together, these regional differences suggest that digital technology-enabled entrepreneurship depends not only on the level of local digital development but also on the formation of effective intercity linkages within a region. The positive external effects are concentrated mainly in the eastern region, while the northeastern region exhibits negative spillover effects, indicating that the spatial spillover effects of digital technology vary substantially across geographical regions; this finding is consistent with H4.

5.4. Spatial Spillover Boundary Test

Based on the previous confirmation that digital technology has a significant spatial spillover effect on entrepreneurial activity, it is still necessary to further identify the effective range of this effect. Spatial spillover does not mean that the influence of digital technology can diffuse across cities without limit; rather, its intensity may gradually decline as geographical distance increases. To test this, this study constructs distance-band variables based on the geographical distance between cities and adopts two step-size settings, namely 100 km and 80 km, to examine the impact of digital technology development in surrounding cities on local entrepreneurial activity within different spatial ranges. This also helps avoid being dependent on a single distance classification standard.

Following the approach of existing studies [56,57], this study first calculates the spherical distance between any two cities based on their longitude and latitude coordinates. Then, distance bands are constructed using 100 km and 80 km intervals, respectively. Under the 100 km interval setting, intercity distances are divided into bands of 0–100 km, 100–200 km, 200–300 km, and 300–400 km. Under the 80 km interval setting, intercity distances are divided into bands of 0–80 km, 80–160 km, 160–240 km, 240–320 km, and 320–400 km. Taking city i as the reference city, this study calculates the average level of digital technology development of other cities located within each distance band in each year and constructs distance-band variables to capture the external influence of digital technology development within different spatial ranges. These distance bands are mutually exclusive, so each neighboring city is assigned to only one distance interval according to its distance from city i . The corresponding fixed-effects model is specified as follows:

$$Entre_{it} = \alpha + \beta DigiTech_{it} + \sum_k \gamma_k NeighborDigiTech_{it}^k + \delta Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (8)$$

where $Entre_{it}$ denotes the entrepreneurial activity of city i in year t , and $Digital_{it}$ denotes the level of local digital technology development. $NeighborDigiTech_{it}^k$ represents the average level of digital technology development of other cities located within the k -th distance band around city i . The coefficient γ_k captures the spatial spillover effect of surrounding

digital technology development on local entrepreneurial activity within the corresponding distance range. If γ_k decreases as distance increases, or becomes insignificant in farther distance bands, indicating that the spatial spillover effect of digital technology exhibits distance decay and has an effective spatial boundary. $Controls_{it}$ denotes control variables, while μ_i and λ_t represent city fixed effects and year fixed effects, respectively. The model is estimated using a fixed-effects approach, with cluster-robust standard errors at the city level.

As shown in Figure 1, under different distance-band settings, the spatial impact of digital technology on entrepreneurial activity exhibits a clear distance-decay pattern. Local digital technology development has a positive effect on entrepreneurial activity, and digital technology development in neighboring cities can also generate certain external driving effects. However, as spatial distance expands, this positive effect gradually weakens and tends toward zero or fluctuates after reaching a medium distance, while the confidence intervals gradually cover zero. This indicates that the spatial spillover effect of digital technology on entrepreneurial activity does not extend indefinitely, but is mainly concentrated within adjacent or relatively short-distance ranges.

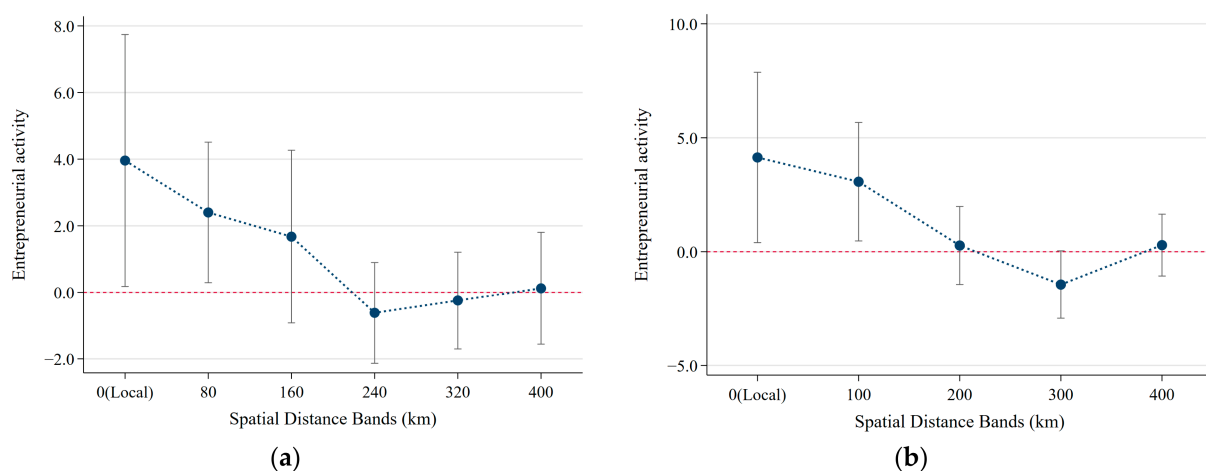


Figure 1. Spatial spillover boundary test of digital technology on entrepreneurial activity. (a) Results based on 80 km distance bands; (b) Results based on 100 km distance bands. The dots denote coefficient estimates, the capped vertical lines denote confidence intervals, and the red dashed line represents the zero-effect benchmark. The figure shows that the spillover effect of digital technology on entrepreneurial activity declines with distance and becomes unstable beyond a certain spatial range.

This result is generally consistent with the mechanism through which digital technology affects entrepreneurial activity. Digital technology development in surrounding cities can influence local entrepreneurial activity through information transmission, market connections, and entrepreneurial demonstration effects, but these channels remain constrained by geographical distance. Cities located closer to each other usually have more frequent interactions, and entrepreneurs are more likely to obtain digital application experience and market information from nearby cities. Therefore, digital technology spillovers are more likely to be transformed into increased entrepreneurial activity. As distance increases, the intensity of intercity connections declines, and the costs of information transmission and market interaction rise, thereby weakening the driving effect of surrounding digital technology development on local entrepreneurial activity. Combined with the overall estimation results of the SDM model above, the boundary test further indicates that digital technology development indeed has spatial spillover effects, but these spillover effects have clear geographical boundaries. The impact of digital technology on entrepreneurial

activity mainly occurs within short- and medium-distance ranges. Beyond a certain spatial distance, its external driving effect is no longer stable. This suggests that digital technology can promote entrepreneurial activity through regional linkages, but its spatial diffusion still depends on the actual strength of intercity connections, rather than naturally spreading with digital development alone.

6. Implications and Conclusions

6.1. Conclusions

This study uses spatial econometric methods to examine the spatial effects of digital technology development on entrepreneurial activity. The results show that entrepreneurial activity exhibits significant spatial dependence across cities. After controlling for spatial correlation, digital technology development still significantly promotes entrepreneurial activity, and its indirect effect is stronger than its direct effect, indicating that spatial spillover is an important channel through which digital technology affects entrepreneurial activity. These findings are consistent with prior research on digital entrepreneurship, knowledge spillovers, and regional innovation diffusion [5,8,13,46], while extending this literature by highlighting the spatial and heterogeneous nature of digital technology's entrepreneurial effects. Further analyses indicate that the spillover effects of digital technology differ across technology types, city size, urban hierarchy, and geographical location. The heterogeneous results also resonate with recent studies emphasizing that knowledge spillovers and entrepreneurial outcomes depend on regional absorptive capacity and entrepreneurial ecosystems [58]. The spatial boundary test further shows that positive spillover effects mainly occur within adjacent or relatively short-distance ranges and weaken as distance increases. Overall, digital technology can promote entrepreneurial activity through regional linkages, but its spatial influence depends on actual intercity connections.

6.2. Theoretical Implications

This study provides a spatial perspective for understanding the relationship between digital technology development and entrepreneurial activity. Existing studies often focus on the impact of digital technology on local entrepreneurial activity, while this study further examines whether such effects extend across cities through spatial linkages. The findings suggest that entrepreneurial activity exhibits significant spatial dependence. Digital technology development not only promotes local entrepreneurial entry but also stimulates entrepreneurial entry in surrounding cities through spatial associations. This finding suggests that digital technology not only functions as a development condition within a single city but may also affect entrepreneurial activity through interregional information diffusion, market connections, and opportunity transmission. Accordingly, this study extends the relationship between digital technology and entrepreneurial activity from local effects to spatial spillover effects, which helps further understand the role of digital technology in regional entrepreneurial systems. In addition, by analyzing technology types, city characteristics, geographical locations, and distance boundaries, this study shows that the entrepreneurial effects of digital technology do not occur uniformly, but are shaped by intercity spatial linkages and regional structural differences.

6.3. Practical Implications

The findings suggest that policies promoting digital technology and entrepreneurship should not focus only on individual cities, but should also pay attention to regional linkages. Since digital technology can generate spatial spillover effects on entrepreneurial activity, local governments may strengthen intercity cooperation, digital infrastructure connectivity, and information-sharing mechanisms. For small and medium-sized cities, improving

the ability to absorb external digital resources may help transform surrounding digital technology development into local entrepreneurial opportunities. For central cities, policy efforts may focus on enhancing their functions in regional coordination and resource matching. Regional differences should also be considered. The eastern region indicates more stable positive spillover effects, while the central, western, and northeastern regions may need to further strengthen market integration and digital resource sharing. In addition, because spillover effects decline as distance increases, entrepreneurship policies should place greater emphasis on neighboring-city cooperation and regional cluster development.

Beyond the Chinese context, these findings also provide useful implications for other countries, particularly emerging economies and countries with pronounced regional disparities. The results suggest that digital technology policies may generate broader entrepreneurial effects when they are embedded in regional networks rather than confined to individual urban centers. For countries seeking to promote digital entrepreneurship, policy attention should therefore be given not only to strengthening leading cities, but also to improving the digital absorptive capacity of smaller, peripheral, or less-developed cities so that they can benefit from nearby digital technology spillovers. At the same time, the applicability of these findings should be interpreted with caution, as the strength and direction of spatial spillovers may depend on country-specific conditions, including institutional arrangements, digital infrastructure, market integration, and the maturity of entrepreneurial ecosystems.

6.4. Limitations and Future Research

This study has several limitations. First, digital technology development is mainly measured using digital technology patents. Although patent data can reflect technological accumulation, they may not fully capture the actual application and commercialization of digital technologies. Future research could combine patent data with indicators such as digital infrastructure, digital platforms, and firm-level digital transformation to construct a more comprehensive measure. Second, this study uses city-level data, which is suitable for examining spatial spillover effects but cannot fully reveal micro-level entrepreneurial decisions. Future studies could use firm-level or entrepreneur-level data to further examine specific mechanisms such as opportunity recognition, financing, and digital technology adoption. Third, although this study analyzes heterogeneity across technology types, city characteristics, regions, and distance bands, the mechanisms behind these differences still require further testing. Future research could further examine channels such as digital finance, digital platforms, and talent mobility to more clearly explain the formation conditions of digital technology's spatial spillover effects. Finally, because the sample period ends in 2020, the findings may not fully capture the accelerated digital transformation and changes in entrepreneurial behavior after the COVID-19 pandemic. Post-2020 changes in remote work, platform-based entrepreneurship, and digital infrastructure may have further influenced the mechanisms through which digital technology affects entrepreneurial activity. Future research could extend the sample to the post-2020 period to examine whether the spatial spillover effects of digital technology remain consistent under these new digital transformation trajectories.

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