



Research article

The effects of digital financial inclusion on innovation and entrepreneurship: A network perspective

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Abstract: The development of urban digital inclusive finance has a complex network connection, and the characteristics of this network affect urban innovation and entrepreneurship. By using 287 cities from 2015 to 2019 in China, this paper constructs the network of Chinese digital inclusive finance, extracting two typical network characteristics. And it further studies the impact of the two network characteristics on innovation and entrepreneurship in various cities. The empirical results show that: first, the network centrality characteristics of digital inclusive finance have a significant promoting effect on urban innovation and entrepreneurship; second, the impact of the network centrality characteristics of digital inclusive finance is related to the speed of industrial structure transformation, but the impact mechanism is related to the node number instead of the node strength; third, the impact of the network centrality characteristics on innovation and entrepreneurship exists heterogeneity among cities and the moderately developed cities have the largest impact.

Keywords: digital financial inclusion; social network analysis; innovation and entrepreneurship; degree centrality

1. Introduction

With the embedding of digital technologies into various fields, the paradigm of urban innovation and entrepreneurship has changed significantly. On the one hand, the demand on digitalization for various factors in the innovation and entrepreneurship process is increasing. In the process of economic development, traditional innovation activities focus on the improvement of production efficiency and

reduction of costs, and the input and output of innovation focus on the technical level and obey the mainstream economic analysis paradigm. After the integration of digital inclusive financial technologies, the technology of innovation revolves around digital inclusive financial to maintain the compatibility between the innovation subject and the whole chain [1]. On the other hand, the innovation process requires a corresponding change in the quality of the entrepreneurial personnel. In traditional innovation and entrepreneurial activities, labor force and technology can be separated to a certain extent, but with the full integration of digital inclusive financial technologies, the difference in the mastery of digital technologies by the entrepreneurial staff can lead to a digital divide [2]. Therefore, in the context of the digital economy, entrepreneurs require full integration of their labor force and technology elements. Although scholars have found that technological innovation, human capital, and entrepreneurial investment can effectively contribute to the development of urban innovation and entrepreneurship [3–6]. However, the full integration between technological innovation, human capital, and industrial investment is an inevitable requirement for the development of the digital economy, and the higher the degree of integration among the three, the more obvious the promotion effect.

Finance is an inevitable element in the process of innovation and entrepreneurship, but the changing characteristics of finance networks have a more prominent impact on innovation and entrepreneurship in the context of the digital economy [7]. On the one hand, digital finance presents prominent network characteristics. Digital inclusive finance developed in recent years based on artificial intelligence, big data, mobile payment, blockchain, and other information technologies effectively break geographical restrictions, making the coverage of financial services more extensive, inter-city financial business and financial activities become closer, and digital inclusive finance presents a complex network structure [8]. On the other hand, innovative and entrepreneurial actors will choose to cluster activities according to the characteristics of digital financial networks. The process of innovation and entrepreneurship needs sufficient financial support, and its actors are on the demand side. The behavior of innovation and entrepreneurship actors of digital finance needs to adapt to this complex network structure feature, so the actors of innovation and entrepreneurship will choose to have a digital financial virtual network for agglomeration activities.

The purpose of this paper is to investigate how the structural features of the digital inclusion finance network affect innovation and entrepreneurship. Based on existing studies, the digital inclusive finance correlations among cities form a complex network, and the roles and positions of these cities in the network constitute the diverse characteristics of the network. Analyzing the impact of digital inclusive finance network characteristics on urban innovation and entrepreneurship is conducive to a deeper understanding of the social network relationships of digital finance and provides targeted and holistic suggestions for the development of urban innovation and entrepreneurship from the perspective of digital finance networks.

Our study mainly relates to two strands of literature. First, it relates to the empirical literature on the impact of digital finance by using the social network analysis method. As the financial industry continues to innovate, the network relationships between financial institutions are becoming more and more complex. The social network analysis method takes subjects (including cities, regions or actors, etc.) as nodes and analyzes the behavior among them and their composition. According to the social network analysis method, the whole network has two basic elements: points and relationships. Social network analysis can analyze social structures and social phenomena from the perspective of relatedness [9]. Arthur et al. [10] argue that the economic system already has the basic characteristics of a social network. In the economic system, independent individuals and their multiple relationships with each other, such as division, cooperation, and trade, together constitute the basic characteristics of social networks. Pierrakis et al. [11] argue that internet lending can break

the limitation of spatial distance and solve the shortage of funds for the demand side of funds to a certain extent, in which the supplier and demander form a complex network. Moenninghoff et al. [12] argue that it is the network connection feature of digital finance that effectively alleviates the information asymmetry of small businesses, helps small businesses to obtain financing, and promotes entrepreneurship. As a product of digital technology and financial innovation, digital inclusive finance has the unique feature of information sharing, which can well solve the problem of information asymmetry existing between enterprises and financial institutions and alleviate financing constraints, as well as deepen the digitalization of enterprises and generate spillover effects on their innovation [13]. Jiang et al. [14] argue that financial elements between regions are more closely linked, and the market integration is more thorough, making significant spatial correlation and spillover effects in the development of digital inclusive finance. Guo et al. [15] compiled a digital inclusive finance index for 337 prefecture-level cities in China and analyzed the development characteristics and spatial trends of digital inclusive finance, which reflect regional clustering and have complex network characteristics.

Second, our study provides some empirical evidence for theories on the impact of digital inclusive finance on innovation and entrepreneurship. Financial support is a crucial factor for innovation and entrepreneurship, and the willingness of financial institutions about financing small businesses directly affects the effect of innovation and entrepreneurship [16]. China's digital inclusive financial system can effectively compensate for the shortcomings of traditional financial models and alleviate the financing constraints arising from innovative entrepreneurship. As a supplement to the traditional financial system, digital inclusive finance provides important support to innovation and entrepreneurship in the following three aspects: 1) Digital inclusive finance can break the limitation of geographical distance so that those cities that are not in the core nodes on the network nodes can enjoy convenient financial services and improve the level of innovation and entrepreneurship in these areas. Under the traditional financial system, financial institutions at the edge of the network have a relatively low level of access to financial support, and these actors can enjoy a low quantity and poor quality of financial services, making innovation and entrepreneurship also limited [17–20]. The financial services available to these actors are low in quantity and quality, which limits innovation and entrepreneurship. Digital inclusive finance provides basic financial services through digital technology, big data, and other emerging technologies, which can solve the problem of financing constraints for innovation and entrepreneurship in cities with low development levels and unremarkable network locations. 2) Relying on big data technology, digital inclusive finance significantly reduces the financing cost of the Small and Medium-sized Enterprises (SMEs). In China, the main obstacle for SMEs to innovate is the difficulty in financing. Due to the single financing channel and severe information asymmetry, traditional financial institutions are unable to discern the integrity of SMEs [21]. This leads to relatively high financing costs for enterprises. Hall et al. [22] studied the reasons for the reluctance of traditional financial markets to invest capital. They argue that the level of risk of innovation is too high to guarantee visible benefits for investors. However, digital inclusive finance can effectively address such challenges. Financial institutions use big data technologies to evaluate the risk of SMEs, alleviate information asymmetries and financing constraints, and thus promote innovation and entrepreneurship. Shahrokhi [23] believes that digital finance reduces the cost of financing and provides diversified financial services to businesses. It gives SMEs access to a wider range of financial institutions, thereby increasing the likelihood of innovative entrepreneurship. 3) Digital inclusive finance, as a product of innovation, provides a constant impetus for innovative entrepreneurship. The digital inclusion of finance is a core product of current financial innovation, giving a stronger impetus to economic growth and providing a wider space for innovation and entrepreneurship [24–27].

In summary, the existing literature reveals the impact of digital inclusive finance on urban innovation and entrepreneurship to a certain extent, including the respective spatial effects of urban digital inclusive finance and urban entrepreneurship. However, the study about the impact of digital inclusive finance on innovation and entrepreneurship from a network perspective has not been considered in the research process. Studying the impact of digital inclusion on innovation and entrepreneurship from a network perspective effectively makes up for the shortcomings of conventional statistical methods, better determines and measures the degree of digital inclusion among cities, and provides a deeper understanding of the intricate connection between the digital finance and the innovation and entrepreneurship. the digital finance and

To sum up, this paper intends to study in depth the impact of digital inclusive finance on urban innovation and entrepreneurship from the characteristics of digital inclusive finance networks. The marginal contributions of this paper can be concluded in the following aspects: first, carving out the network characteristics of digital inclusive finance. Digital inclusive finance has a complex network structure. By constructing a weighted digital inclusive finance network, the article uses social network analysis to comprehensively portray the digital inclusive finance network characteristics of each city. Second, this paper analyzes the heterogeneity of the impact of digital inclusive financial network features on urban innovation and entrepreneurship. In the digital inclusive financial network, the impact of digital inclusive finance network characteristics on innovation and entrepreneurship is different among different economic regions. Third, the article also analyzes the mechanism of the impact of digital inclusive financial network features on urban innovation and entrepreneurship by using the mediating effect model. The impact of digital financial inclusion network characteristics on innovation and entrepreneurship is realized through the speed of industrial structure transformation, but the impacts are different with the different characteristics.

The rest of this paper is structured as follows (see Figure 1 for the logical framework):

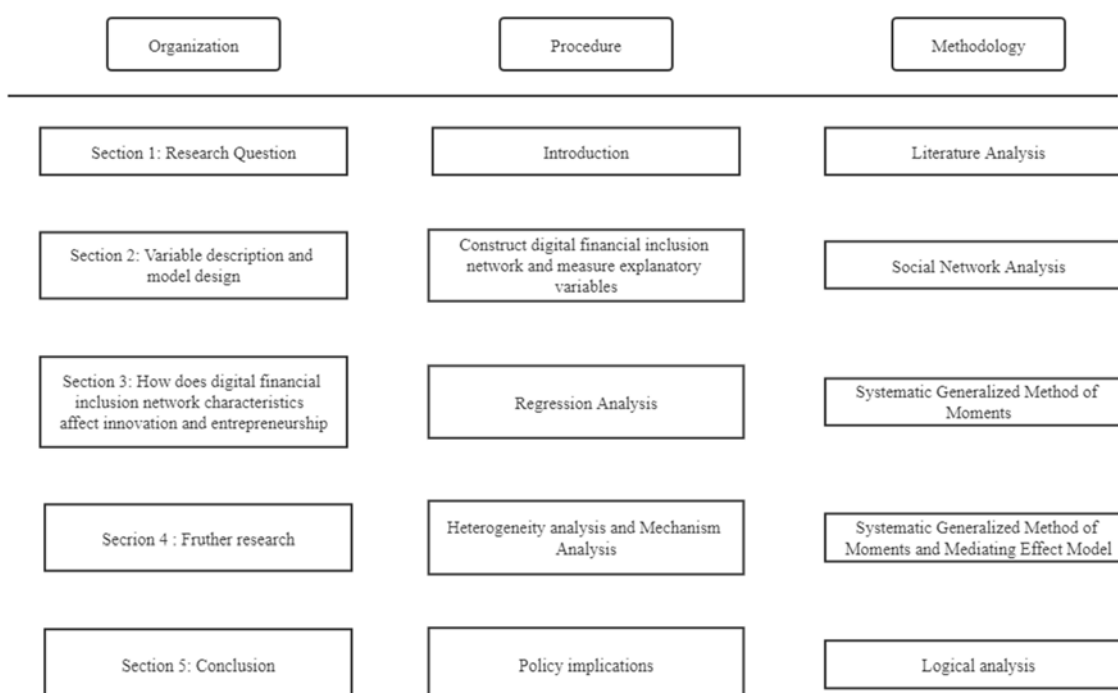


Figure 1. The logical framework.

The second part is the research proposal, i.e., the basic hypothesis of the impact of digital inclusive finance network characteristics on urban innovation and entrepreneurship, the design of the econometric test model, the measurement of the variables in the model, and the source of the data used. The third part is the econometric test of the impact of digital inclusive finance network characteristics on urban innovation and entrepreneurship, i.e., the econometric test of the relationship between the network centrality characteristics of digital inclusive finance and innovation and entrepreneurship through the benchmark regression model and the robustness tests. The fourth part is further analysis, the impact of digital inclusive finance network characteristics on urban innovation and entrepreneurship is analyzed in terms of both heterogeneity and mechanism. The fifth part is the conclusion and policy implications of the article.

2. Variable description and model design

2.1. Measurement of core variables in digital inclusive finance networks

The core variables of the digital financial inclusion network to be measured in this paper are degree centrality and eigenvector centrality, and these two core variables are the explanatory variables in the model. The article measures the degree centrality and eigenvector centrality of each city by methods of social network analysis. In the construction of the social network structure, the importance and centrality of each city in the digital inclusive finance network structure can be measured by the degree centrality and eigenvector centrality of each city in the network node. The nodes in the social network structure are confirmed by cities, and the edges in the network need to be measured by the connection strength of each city in digital inclusive finance, and this paper measures the connection strength of each city in digital inclusive finance through an improved gravity model. The basic form of the improved gravity model is as follows:

$$DF_{ij} = \frac{GM_iM_j}{D_{ij}^2} \quad (1)$$

In Eq (1), DF_{ij} represents the strength of the linkage of digital inclusive finance between city i and city j . M_i, M_j represents city i and city j 's the digital financial inclusion index respectively D_{ij} represents the economic distance between city i and city j ; G is the gravitational constant, usually taken as 1. This paper draws on Peltrault et al.'s study, the following economic distance index is constructed [28].

$$D_{ij} = \frac{\max(GDP_i, GDP_j)}{\min(GDP_i, GDP_j)} \quad (2)$$

In Eq (2), GDP_i, GDP_j represents the GDP per capita of city i and city j . Subsequently, the mean value of each row in the gravity matrix is used as the threshold value of that row and is replaced by 1 if it is greater than or equal to the threshold value, and by 0 if it is less than the threshold value, and is converted into a 0-1 unpaired matrix. The measure of degree centrality is an important variable based on the number of other nodes directly connected to a node to determine its position in the network. In a digital financial inclusion network, the degree centrality of each city represents the number of cities in which the city has digital financial inclusion connections with other cities. A city with a high degree of degree centrality means that its position in the digital financial inclusion network is more important.

Therefore, degree centrality is chosen as an explanatory variable in this paper. The formula for calculating the degree of centrality is shown below:

$$degree_cen_i = \frac{\sum_{j=1} a_{ij}}{n-1} \quad (3)$$

In Eq (3), i is a single city; j is a city other than city i . a_{ij} indicates whether there is a digital financial inclusion link between city i and city j . If $a_{ij} = 1$, it indicates the existence of a link between two cities, otherwise the $a_{ij} = 0$; n is the total number of cities, and $(n-1)$ is used to eliminate the size difference.

In digital financial inclusion networks, the degree centrality of a city indicates the number of cities in the network that are directly connected to the city, and it accurately portrays the location of the city in the network. The network characteristics can be described not only by the direct connection between cities but also by the “bridging role” of cities, i.e., measuring the centrality of the city’s eigenvector in the network. Therefore, this paper also measures the eigenvector centrality of all cities in the network as an alternative explanatory variable. Eigenvector centrality represents the importance of a node depending on the number of its neighbors (i.e., the degree of the node) and also depends on the importance of its neighbors. A city with higher eigenvector centrality means that it has more importance in the digital financial inclusion network. The eigenvector centrality is calculated as follows:

$$eigenvector_cen_i = \frac{\sum_j a_{ij} E_j}{\lambda} \quad (4)$$

In Eq (4), the λ is the maximum eigenvalue of the adjacency matrix a_{ij} ; and E_j is the eigenvalue of the centrality of city j .

2.2. Variable selection and data source

The explained variable in this paper is the level of innovation and entrepreneurship (Innovation) in cities, and the China Regional Innovation and Entrepreneurship Index published by Peking University Open Research Data [29]. The index measures the level of the region’s innovation and entrepreneurship of enterprises from the perspective of output, uses the “full” data from the enterprise database, and also combines data from several scattered fields to unify the classification from the perspective of “enterprises”. Therefore, it includes multiple dimensions of evaluation indicators, forming a more objective and realistic innovation and entrepreneurship index from different levels.

The following indicators are also selected as control variables in this paper.

Industrial structure level ($C2$): the proportion of the value added of secondary industry to the city’s GDP. The level of the industrial structure reflects the environment of innovation and entrepreneurship in the city. The improvement of industrial structure level helps to make up for the defects of traditional industries, develop the advantages of new industries, and provide a good development environment for innovation and entrepreneurship.

Fiscal expenditure level ($Spend$): measured by the general public budget expenditure of each city as a percentage of regional GDP. Government intervention can significantly affect the level of innovation and entrepreneurship. The increase in government transfer payments will encourage enterprises to carry out innovative and entrepreneurial activities, thus improving their level of innovation and entrepreneurship.

Economic development level ($Pergdp$): measured by the logarithmic GDP of a city. The improvement of the economic development level can provide favorable support to innovation and entrepreneurship. At the same time, economic development can effectively integrate social resources,

and the integrated resources can be used to participate in innovation and entrepreneurship, increase the opportunities for innovation and entrepreneurship, and promote the development of innovation and entrepreneurship.

Financial development level (*Finance*): measured by the proportion of the balance of RMB loans of financial institutions in each city on its GDP. An increase in the level of financial development can provide more financing channels for enterprises in a city. Especially for small and medium-sized enterprises, financial development effectively reduces the degree of information asymmetry between them and financial institutions and alleviates financing constraints. This helps to provide them with sufficient financial support, which in turn promotes innovation and entrepreneurship among SMEs.

The level of science and technology development (*Science*): measured by the share of science and technology in the general public budget expenditure of each city. Local government's science and technology investment can effectively encourage innovation and entrepreneurship. Science and technology investment also provides financial support and reward for innovation and entrepreneurship, significantly increasing the incentive for innovation and entrepreneurship of enterprises.

This paper uses all the data of China's prefecture-level cities (287 in total) from 2015 to 2019 from public databases such as the China Statistical Yearbook, China City Statistical Yearbook, EPSdata Database, CEInet Statistics Database, and so on. The variables were aggregated to obtain descriptive statistics as shown in Table 1.

Table 1. Descriptive statistics.

VarName	Obs	Mean	SD	Min	Median	Max
Innovation	1420	52.000	28.120	1.365	52.136	100.000
Degree_cen	1420	0.432	0.051	0.003	0.441	0.514
Eigenvec_cen	1420	0.057	0.015	0.008	0.061	0.090
C2	1420	43.734	10.846	11.040	44.370	75.970
Lnpergdp	1420	11.027	0.536	9.210	11.032	15.675
Science	1420	0.019	0.020	0.000	0.012	0.182
Finance	1420	3.011	30.107	0.001	1.186	5.305
Spend	1420	0.592	7.086	0.010	0.165	2.702

In Table 1, the variables are free of singular values and satisfy the basic requirements of the empirical evidence.

2.3. Econometric specifications

Burt et al. [30,31] measured the importance of each node in the network and the degree of access and utilization of resources through the degree of network centrality, so the cities in the central position of the digital inclusive finance network can fully access and utilize the resources, and the resources are easy to be clustered in this type of cities. The measure of centrality in social network analysis can be selected from a variety of centrality characteristics, and Freeman [32] proposes that the measures of network centrality can be divided into degree centrality, intermediate centrality, proximity centrality, etc. Through the analysis of these characteristic indicators, the role and status of each node in the social network can be studied, and the centrality of cities corresponding to digital inclusive finance can also be measured by using the corresponding characteristic values. In the digital inclusive finance network, the higher the centrality of a city in the network, the stronger the city's aggregation of financial

resources, and the more capable of meeting the city's capital demand for innovation and entrepreneurship. At the same time, the higher level of the digital inclusive finance center, the faster the transmission of financial information in the city, which in turn enhances the demand for information for urban innovation and entrepreneurship and effectively solves the problem of information asymmetry. For innovative enterprises, cities with a higher degree of being at the center of network nodes, the full circulation of network information are conducive to alleviating the financing constraints in the process of innovation and entrepreneurship. Therefore, it is reasonable for this paper to argue that the stronger the degree of city centrality in the digital inclusive finance network, the more innovative entrepreneurship is promoted.

Since this paper uses the panel data for 287 prefecture-level cities in China from 2015 to 2019, they can be considered as a panel data structure. From the dimension of time, the position of each city in the digital inclusive financial network changes, and the impact on innovation and entrepreneurship shows differences over time; from the dimension of space, each city has a different position in the digital inclusive financial network, and the impact on innovation and entrepreneurship shows significant variability [33,34]. Therefore, this paper adopts a panel data model to test the impact of digital inclusive finance network characteristics on innovation and entrepreneurship. The specific form of the model is shown below:

$$Innovation_{it} = \alpha_0 + \alpha_1 * degree_cen_{it} + \sum_{j=2}^6 \alpha_j * (Control_{it})_j + \varepsilon_{it} + \gamma_t + \theta_i \quad (5)$$

In Eq (5), i represents the city; t represents the year. $Innovation_{it}$ represents the level of innovation and entrepreneurship in the city. $degree_cen_{it}$ represents the degree of centrality of the city in the digital financial inclusion network. $Control_{it}$ represents the control variables. j represents the number of the control variable. ε_{it} represents the random disturbance term. γ_t and θ_i represent the time effect and individual effect of cities. In this paper, we also select the eigenvector network centrality to study the impact of digital inclusive finance networks on innovation and entrepreneurship.

3. Benchmark results

In this paper, the fixed effects regression (FE) method is used to estimate Eq (5) using data from 287 cities from 2015 to 2019. Since the sample selected in this paper has the characteristic of having a large number of cities with few years (i.e., N is large and T is small), parameter estimation using the ordinary least squares (OLS) method is biased [35,36]. The parameter estimation process also needs to consider whether there is an endogeneity between the structural characteristics of city networks and innovation and entrepreneurship.

First, the development of innovative entrepreneurship could better increase the importance of cities in the digital inclusive finance network, i.e., there is an inverse causal relationship between the improvement of the structural characteristics of city networks on innovative entrepreneurship. Second, there may be omitted variables that affect both urban network structural characteristics and innovation entrepreneurship, i.e., they may cause errors in the empirical results.

Either of the above-mentioned relationships will give rise to endogeneity problems and estimation bias, while parameter estimation methods such as OLS require strict exogeneity among variables, so this paper uses a SYS-GMM approach to set instrumental variables for parameter estimation to obtain parameter estimation results with unbiased results. The instrumental variables selected in this paper are the lagged first order of the explanatory variables, and the parameter estimation results of the benchmark regression are obtained as shown in Table 2.

Table 2. The impact of structural features of digital inclusive finance networks on innovation and entrepreneurship.

	Fe (1) Innovation	GMM (2) Innovation	Fe (3) Innovation	GMM (4) Innovation
Degree_cen	14.878* (1.695)	21.140** (2.207)		
Eigenvec_cen			63.889* (1.991)	77.923* (2.016)
C2	-0.044 (-0.986)	-0.140** (-1.970)	-0.048 (-1.087)	-0.208*** (-2.896)
Lnpergdp	4.234*** (4.964)	1.706 (1.064)	4.041*** (4.750)	3.091* (1.658)
Science	27.916 (1.611)	25.749 (0.922)	26.998 (1.564)	30.082 (0.990)
Finance	0.125** (2.367)	0.189*** (15.590)	0.125** (2.383)	0.188*** (17.464)
Spend	-0.500** (-2.180)	-0.590*** (-12.112)	-0.502** (-2.188)	-0.586*** (-17.643)
L.innovation		0.795*** (13.077)		0.790*** (13.624)
Time effect	Yes	Yes	Yes	Yes
Individual effect	Yes		Yes	
_cons	0.869 (0.085)	-12.695 (-0.689)	5.994 (0.085)	-20.764 (-1.056)
N	1420	1136	1420	1136

Notes: *, **, *** stand for significant levels of 10, 5, and 1%, respectively, and the values in brackets are T-values.

The results in Table 2 show that the digital inclusion financial centrality features have a significant contribution to the level of innovation and entrepreneurship. Comparing the parameter estimation results in columns (2) and (4) with the corresponding results in columns (1) and (3), it is found that the parameter estimation significance level, the direction of coefficients, and the degree of influence are robust, therefore, it is fully indicated by the econometric test that degree centrality and eigenvector centrality have a significant and robust promotion effect on innovation and entrepreneurship. Columns (1)–(4) in Table 2 show that digital inclusive finance degree centrality and eigenvector centrality have significant effects on innovation and entrepreneurship, and from the direction of influence, both are positive, so both centrality effects on innovation and entrepreneurship are promoting effects. In terms of the degree of influence of the two centrality degrees on innovation and entrepreneurship, the degree of influence of both innovation and entrepreneurship is somewhat different; based on controlling other variables, for every 1% increase in the degree centrality degree of cities in the digital inclusive finance network, urban innovation and entrepreneurship will increase by 21.140%; for every 1 percentage point increase in the eigenvector centrality degree of cities in the digital inclusive finance network, urban innovation and entrepreneurship will increase by 77.923%.

The regression results test that digital inclusive finance network centrality has a significant contribution to urban innovation and entrepreneurship, which is strongly correlated with digital

inclusive finance agglomeration characteristics. On the one hand, the digital inclusive finance degree centrality makes the number of financial resources clustered in the city. In the digital inclusive finance network structure, a large centrality indicates that the more cities are connected to other cities, and accordingly, the more financial information-gathering elements in those cities. As the larger the centrality, the more city network nodes can be connected, economic entities of innovation and entrepreneurship can obtain a wider range of financial resources and information through the city, and they are more inclined to engage in economic activities in cities with larger centrality to maximize their benefits. In addition, the point-centeredness of digital inclusive finance makes cities have a strong influence on the level of digital inclusive finance network, and the development of digital inclusive finance is far superior to other cities.

Such cities can improve digitally inclusive financial services for remote areas and small and medium-sized enterprises to make up for the shortage of traditional financial services and promote innovation and entrepreneurship; at the same time, when providing financial services for other cities, they constantly improve their financial infrastructure, enhance the availability of financial services, vigorously develop advanced digital technologies and provide a better environment for innovation and entrepreneurship. On the other hand, the eigenvector centrality of digital inclusive finance makes the concentration of financial resources in cities stronger and the flow of information smoother. In the digital financial inclusion network, a city with a high eigenvector centrality means that it has a high central position and plays the role of a “bridge”. Eigenvector centrality plays a key role in the digital financial inclusion network as an intermediary that connects the other two cities. It shows the importance of cities in the network from another perspective. When two cities need to be connected through a “bridge city” for digital inclusion, it also has a positive effect on the development of digital inclusion in the “bridge city”.

4. Further research

4.1. Heterogeneity analysis

In digital inclusive finance networks, differences in resource endowment, geographic location, and financial development among cities lead to differences in the impact of digital inclusive finance on innovation and entrepreneurship [37]. The development of digital inclusive finance is more beneficial to the development of periphery cities and small and medium-sized enterprises in the digital inclusive finance network [38]. It can provide them with a good environment for innovation and entrepreneurship and more opportunities for innovation and entrepreneurship. However, for the central cities in the digital inclusive finance network, the marginal effect of digital inclusive finance is relatively small, or even the impact is insignificant or suppressed. This is related to the fact that the size of digital inclusive finance empowerment shows a marginal decrease. For remote areas and small and medium-sized enterprises implemented for their development, the marginal effect of digital inclusive finance in marginal cities in the digital inclusive finance network will be much larger than that in central cities. The differences in resource endowment, geographic location, and financial development of Chinese cities are directly related to the location of individual cities [39]. Based on this, this paper divides the heterogeneous sample according to the geographic location of China, i.e., the 287 sample cities are divided into three subsamples: east, central and west, according to the regional division criteria commonly used in many kinds of literature.

Using the model identical to the aforementioned econometric tests, the subsamples were tested separately to investigate the heterogeneity of the impact of urban centrality on innovation and entrepreneurship in the digital inclusive finance network, and the results of parameter estimation for each subsample were obtained as shown in Table 3.

Table 3. Evaluating the impacts on a different region.

	Eastern Region Innovation	Central Region innovation	Western Region innovation
Degree_cen	13.463 (0.772)	30.401*** (2.676)	24.446 (1.135)
C2	-0.068 (-0.588)	-0.066 (-0.946)	-0.127 (-1.250)
Lnpergdp	4.594*** (2.734)	8.025*** (4.167)	2.389 (1.453)
Science	21.535 (0.720)	49.915 (1.366)	26.557 (1.071)
Finance	-4.149*** (-2.949)	0.125** (-0.622)	0.134*** (2.797)
Spend	5.555 (0.602)	3.128 (-1.564)	-0.553*** (-2.685)
Time effect	YES	YES	YES
Individual effect	YES	YES	YES
_cons	-16.547 (-0.770)	-88.959*** (-4.265)	-89.242 (-0.323)
N	565	545	310

Notes: *, **, *** stand for significant levels of 10, 5, and 1%, respectively, and the values in brackets are T-values.

The results in Table 3 show that the network structure characteristics of cities have a heterogeneous impact on innovation and entrepreneurship, and the heterogeneity is mainly reflected in the degree of significance of the impact. As can be seen from Table 3, for the central subsample, the degree of urban digital inclusive financial center can significantly enhance innovation entrepreneurship, but for the western and eastern subsamples, the increase of urban network centrality does not significantly promote urban innovation entrepreneurship. A 1% increase in centrality in central cities is associated with a 30.401% increase in urban innovation and entrepreneurship.

Based on the results of the above empirical evidence, this paper concludes that the reason for the differential impact of network structural characteristics in digital inclusive finance networks is that digital inclusive finance provides different marginal effects to regions with different levels of economic development. This has a greater correlation with the development of digital inclusive finance in cities themselves [40]. For remote and underdeveloped areas, the development of digital inclusive finance can provide these cities with perfect financial services, reduce the gap with developed areas, and enable economic agents to obtain enhanced benefits, but the financial resource-gathering capacity is not necessarily enhanced; after all, the comparative advantages of remote and underdeveloped areas are relatively weak, thus making them relatively less attractive to innovative and entrepreneurial agents. Cities with greater resource endowment and higher economic levels have better quality financial

services. According to the economic law of diminishing marginal effect, digital inclusive finance has already reached a certain degree to enhance innovation and entrepreneurship, and its attractiveness to innovation and entrepreneurship subjects has gradually weakened. Especially in the eastern region, most cities are in the central region of the digital inclusive finance network, and the degree of centrality is larger, and the position of cities in the network is very important. The cities in this region have greater influence in the digital inclusive finance network, but their economic strength is stronger and the level of innovation and entrepreneurship has reached a peak, so it is difficult to play a significant role in promoting innovation and entrepreneurship in the cities. Cities in the central region and cities in the eastern region show significant differences in the empirical results. Cities in the central region have a relatively low level of economic development and receive less financial services in terms of quantity and quality than those in the eastern region. Digital financial inclusion has a greater impact on cities in the region, and it provides strong support for financial services in cities in the central region, making these cities more important in the network, which in turn promotes the development of innovation and entrepreneurship. The western region is the weaker region in terms of economic strength and development level among the three regions, and digital inclusion finance should support it the most obvious. However, cities in the western region have a lower status in the digital inclusion finance network, are very vulnerable to the influence of other cities, and have poorer economic strength and resource endowment, resulting in an inability to effectively promote innovation and entrepreneurship. Although digital inclusion finance has supplemented a large number of financial services for cities in these regions to promote innovation and entrepreneurship. However, the increase in the importance of these cities in the network may have a lag and good results cannot be seen in a short period. Therefore, the impact on urban innovation and entrepreneurship is insignificant.

4.2. Mechanism analysis

4.2.1. Model design

The impact of structural features of digital inclusive finance networks on innovation and entrepreneurship is achieved through certain mechanisms, which are mainly through the upgrading of urban industrial structure. The enhancement of urban innovation and entrepreneurship relies on the upgrading of industrial structure, which needs to be supported through digital finance [41]. The higher the degree of the city network center, the stronger the correlation between the leading industrial chain and other cities, and the stronger the resilience of the industrial structure, so it can attract more innovation and entrepreneurship entities. From a micro perspective, cities in the center of a digital inclusive finance network need to accelerate the industrial transformation to expand market demand; due to the high level of development of the city itself, innovative individuals carry out industrial transformation to gain the market share by increasing R&D investment and other innovative activities, which makes innovation and entrepreneurship increase significantly. From a macro perspective, the accelerated rate of industrial transformation is accompanied by the enhancement of inter-city connections and the aggregation of resources in the digital financial network. In particular, the aggregation of financial resources, which is the backbone of accelerating the speed of industrial transformation in cities, can promote competition and cooperation in urban innovation in digital financial inclusion networks by upgrading the industrial structure [42]. Therefore, the impact of increasing the city centrality of digital inclusive financial network on innovation and entrepreneurship can be realized by upgrading the speed of industrial transformation.

Through the above theoretical analysis, to study the mechanism of urban network centrality of digital inclusive finance network centers on innovation and entrepreneurship, the article sets up a mediating effect model to test it empirically. The mediating effect model considers that the influence of the independent variable X on the dependent variable Y is realized through the influencing variable M . This paper is to test the influence of the structural characteristics of digital inclusive finance on urban innovation and entrepreneurship precisely through the acceleration of industrial transformation, so it is based on Baron et al. [43]. The study of the mediating effect model is improved based on Eqs (6)–(9) for validation.

$$Med_{it} = \beta_0 + \beta_1 * lndeg_{it} + \sum_{j=2}^6 \beta_j * Control_{it} + \varepsilon_{it} + \gamma_t + \theta_i \quad (6)$$

$$Innovation_{it} = \beta'_0 + \beta'_1 * lndeg_{it} + \beta'_2 * Med_{it} + \sum_{j=3}^7 \beta'_j * Control_{it} + \varepsilon_{it} + \gamma_t + \theta_i \quad (7)$$

$$Med_{it} = \beta_0 + \beta_1 * eigenvec_{it} + \sum_{j=2}^6 \beta_j * Control_{it} + \varepsilon_{it} + \gamma_t + \theta_i \quad (8)$$

$$Innovation_{it} = \beta'_0 + \beta'_1 * eigenvec_{it} + \beta'_2 * Med_{it} + \sum_{j=3}^7 \beta'_j * Control_{it} + \varepsilon_{it} + \gamma_t + \theta_i \quad (9)$$

In Eqs (6)–(9), the Med_{it} represent the mediating variables and the rest of the variables are consistent with Eq (5).

Based on the aforementioned theoretical analysis, this paper selects the speed of industrial transformation (Ias) as a mediating variable. By drawing on the existing studies, we calculate the industrial structure hierarchy coefficient and use it to represent the speed of industrial transformation. The industrial structure hierarchy coefficient can better reflect the change in industrial structure, i.e., the development of the three major industries is described by the relative change of the share ratio. The overall trend is that the proportion of primary industry gradually decreases, the proportion of secondary industry rises and then decreases, and the proportion of tertiary industry gradually increases. Therefore, this paper assigns weights of 3, 2, and 1 to the third, secondary, and primary industries to measure the speed of industrial transformation. The calculation formula is as follows:

$$Ias_t = \frac{\sum_{i=1}^n \theta_{it} * q_{it} - \sum_{i=1}^n \theta_{i,t-1} * q_{i,t-1}}{\sum_{i=1}^n \theta_{i,t-1} * q_{i,t-1}} \quad (10)$$

In Eq (10), the Ias is the speed of industrial transformation, the θ is the weight of the corresponding industry, and q_i is the proportion of value added by industry i to GDP.

4.2.2. Model results

The results of estimating the parameters in Eqs (6)–(9) by systematic GMM estimation models according to the mediating effects model set up previously, using samples that are identical to the measurement tests, are shown in Table 4.

The results in Table 4 show that in the digital inclusive finance network, the increase in degree centrality promotes innovation and entrepreneurship by accelerating the speed of industrial transformation; the process of eigenvector centrality promoting innovation and entrepreneurship is independent of the speed of industrial transformation. Columns (1)–(4) show that controlling for other variables, each 1 percentage point increase in degree centrality accelerates the rate of industrial transformation by 0.749 percentage points and increases innovation and entrepreneurship by 23.460 percentage points; eigenvector centrality does not promote innovation and entrepreneurship by accelerating the rate of industrial transformation. This indicates that the increase in the importance of

cities in the network cannot directly affect entrepreneurship and innovation, and needs to promote innovation and entrepreneurship by accelerating the speed of industrial transformation.

Table 4. Mechanism test.

	(1) Ias	(2) Innovation	(3) Ias	(4) Innovation
L.innovation		0.789*** (13.138)		0.462*** (5.495)
L.ias	0.182** (2.248)		0.164*** (1.976)	
Degree_cen	0.749** (2.420)	23.460** (2.436)		
Eigenvec_cen			4.230** (2.816)	112.801*** (3.239)
Ias		1.718*** (2.446)		0.761 (1.184)
C2	-0.009** (-2.108)	-0.152** (-2.140)	-0.009** (-2.158)	-0.097 (-1.537)
Lnpergdp	0.058** (2.528)	1.996 (1.186)	0.059*** (2.909)	0.701 (0.450)
Science	0.775 (0.979)	25.028 (0.899)	0.948 (1.163)	15.525 (0.647)
Finance	0.135 (1.440)	-0.402 (-0.636)	0.137 (4.489)	-0.613 (-1.176)
Spend	0.263 (1.167)	2.952 (1.192)	0.254 (1.129)	1.072 (0.373)
Time effect	YES	YES	YES	YES
_cons	1.163** (2.434)	-20.397 (-1.035)	1.264*** (2.455)	16.130 (0.893)
N	1136	1136	1136	1136

Notes: *, **, *** stand for significant levels of 10, 5, and 1%, respectively, and the values in brackets are T-values.

The empirical results show that the role of digital inclusive finance is crucial to industrial transformation and upgrading. Financial development encourages the transformation of savings into investment, which leads to the inflow of capital to new types of industries, eliminates backward industries, and promotes industrial upgrading. The development of digital technology can accelerate this process, as industries are differentiated and integrated by the influence of digital inclusive finance, and the speed of industrial transformation is continuously accelerated. This is manifested in two aspects: on the one hand, digital inclusive finance makes up for the shortcomings of traditional financial services; on the other hand, digital inclusive finance is also promoting the formation and development of new industries. At the same time, it is also prompting the rational allocation of resources, improving the efficiency of resource utilization, and significantly raising the level of innovation and entrepreneurship. This is because the accelerated industrial transformation makes

enterprises form competitive advantages and enterprises innovate to seize the market; the accelerated industrial transformation of a city makes that city obtain sufficient elements such as capital and technology from other cities and absorb and digest them as well as reinvent. This effectively enhances the ability of innovation and entrepreneurship; industrial transformation and upgrading make the old and new industries alternate, and new industries become the main force of development, giving more opportunities for innovation and entrepreneurship. In the digital financial inclusion network, the more important a city is, the greater the influence of digital financial inclusion in that city. The higher the network “status” of a city, the more frequently other cities will be connected with its digital inclusive finance, which will have a positive effect on the industrial transformation of the city. At the same time, the accelerated industrial transformation will generate new consumer demand, breed new consumer industries, and other innovation opportunities, and attract active participation of enterprises to increase innovation and entrepreneurship. In addition, this paper argues that inconsistent measures of network structure characteristics of cities lead to differences in empirical results. In the digital inclusion network, degree centrality measures the number of cities that have direct digital inclusion connections to the city; eigenvector centrality measures the “bridging” role of the city. The direct increase in the importance of a city in the network indicates a high level of digital inclusion in the city, which is conducive to the industrial transformation and upgrading of the city, and thus has a positive impact on innovation and entrepreneurship. Indirectly, it only indicates that the city can effectively transmit the digital financial inclusion linkage in the network, but not the high level of digital financial inclusion in the city, which can accelerate the industrial transformation.

5. Conclusions

In this paper, we construct a panel data model and use data from Chinese prefecture-level cities from 2015 to 2019 to conduct an econometric test of the impact of digital inclusive finance network characteristics on urban innovation and entrepreneurship by using fixed effects model and systematic GMM estimation method. We further investigate the mechanisms and heterogeneity of the impact on this basis, and the basic conclusions obtained are as follows.

First, digital inclusion financial centrality features have a significant promoting effect on the level of innovation and entrepreneurship, but the effect has some differences. Both digital inclusive finance degree centrality and eigenvector centrality promote the level of innovation and entrepreneurship, but the significant degree of degree centrality to enhance the level of innovation and entrepreneurship is stronger, while the eigenvector centrality to promote innovation and entrepreneurship only passes the test at 90% significance level.

Second, there is heterogeneity in the impact of network structure characteristics of cities on innovation and entrepreneurship. In terms of the significant degree of the impact of city network structure characteristics on innovation and entrepreneurship, there is a significant impact of city network structure characteristics on innovation and entrepreneurship in the central city subsample, but there is no significant impact in the western and eastern cities. The absence of significant effects in western cities is strongly associated with the digital inclusion finance city catch-up target, while the absence of significant relationships in eastern cities is associated with the diminishing marginal effects of digital inclusion finance empowerment.

Third, the impact of digital financial inclusion network degree centrality features on innovation and entrepreneurship is realized through the speed of industrial structure transformation, but the speed of industrial structure transformation is not significant in the impact of eigenvector centrality on innovation and entrepreneurship, i.e., the centrality impact mechanism is related to the number of

nodes and not to the node strength. The empirical analysis through the mediating effect model shows that the impact of cities with a high degree of degree centrality on innovation and entrepreneurship is realized through the speed of industrial transformation, while the degree of centrality reflects more the number of nodes in the network structure. The eigenvector centrality does not affect the level of innovation and entrepreneurship through the speed of industrial transformation. This is related to the difference in significance degree in conclusion 1.

Based on the above findings, the following policy insights are obtained in this paper: First, cities strengthen the degree of digital inclusive finance linkages with other cities to create favorable conditions for innovation and entrepreneurship and improve the status of cities in the digital inclusive finance network [44–46]. The more frequent the digital inclusion financial connections between cities, the higher the degree of digital inclusion financial development. This not only provides enterprises and regions with sufficient funds and alleviates the problem of financing constraints, enabling them to carry out innovative and entrepreneurial activities; it also leads enterprises and regions to collaborate, adhering to the concept of mutually beneficial and win-win development, further deepening the digital inclusive finance linkages with other cities and jointly solving the difficulties in the process of innovation and entrepreneurship [47]. Second, focus on the role of digital inclusive finance in industrial structure upgrading, so that the acceleration of industrial transformation can strongly improve innovation and entrepreneurship. From the study, it is clear that the development of digital inclusive finance provides strong support for the upgrading of industrial structures in cities. It is because of the development of digital technologies like digital inclusive finance that the speed of industrial transformation has increased and more new industries have been created [48,49]. The emergence of new industries means the emergence of new opportunities, and regions and enterprises should seize the current “dividend” of digital inclusive finance to further innovate and seize business opportunities. Especially in cities with “higher” status in the digital inclusive finance network, they should give full play to the driving role of digital inclusive finance to guide industrial transformation and promote innovation and entrepreneurship. Thirdly, we should pay attention to the development of digital inclusive finance in the western region and strive to increase the importance of cities in this region in the network. Cities in the western region are unable to receive comprehensive financial services due to the limitations of their geographical location. Moreover, digital inclusive finance has been developed for a relatively short time, and there are fewer digital inclusive finance links with other cities [50,51]. In this regard, it is important to strengthen the degree of digital inclusion in the western region to improve the network “status” of the peripheral cities, and thus promote innovation and entrepreneurship in the cities of the region.

Conflict of interest

The authors declare there is no conflict of interest.

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