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Spatial-temporal Evolution and Influencing Factors of Digital Financial Inclusion: County-level Evidence from China

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Abstract: The vigorous development of information and communications technology has accelerated reshaping of the financial industry. The COVID-19 pandemic has further catalyzed the demand for digital financial services. Digital financial inclusion relies on information technology to overcome spatial limitations. In this case, the research question is whether it adheres to the spatial laws governing conventional financial activities. This study uses exploratory spatial data analysis and a geographical detector to elucidate the spatiotemporal characteristics and factors influencing digital financial inclusion at the county level in China (Data don't include that of Hong Kong, Macao and Taiwan of China) from 2014 to 2020. The research findings indicate: first, China's county-level digital financial inclusion is generally increasing and exhibits significant spatial autocorrelation. Second, population density, level of traditional financial development, government regulation, and education level are key determinants of China's county-level digital financial inclusion. Third, policies should be differentiated by region to narrow the spatial gap in digital financial inclusion. The results provide a reference for other developing countries on using digital technology to develop financial inclusion.

Keywords: digital financial inclusion; spatiotemporal characteristics; influencing factors; geographical detector; China

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1 Introduction

Financial inclusion is critical for promoting economic growth (Kim et al., 2018; Ozili, 2018; Duvendack and Mader, 2019), reducing poverty (Han and Melecky, 2013), promoting financial stability (Khan, 2011), increasing employment (Prasad, 2010), and improving household income (Zhang and Posso, 2019). With the rapid development of new-generation information technologies, such as 5G, artificial intelligence, big data, and cloud computing, digital technology to expand financial services as a component of the modern economy is now crucial for promoting the digital transformation of cities. Furthermore, during the COVID-19 pandemic, contactless transactions, a component of digital finance with numerous benefits, are viewed as a lifeline for addressing the pandemic crisis. In digital finance, big data can be used to collect information accurately, identify risks, and expand transaction boundaries. Due to the law's effect of reducing the marginal cost of the Internet, digital finance can effectively reduce the cost of financial services and contribute to their expansion. With the aid of digital technologies, financial institutions can transcend spatiotemporal limitations and integrate 'frag-

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mented funds' to form a 'long tail market', thereby lowering the financial service threshold (Johnson and Arnold, 2012). Digital finance enables leveraging the advantages of big data in payment, asset allocation, and risk management to effectively balance efficiency and fairness and make finance more accessible (Gabor and Brooks, 2017; Jin, 2017). Upon reducing transaction costs and expanding transaction boundaries, digital technology improves the quality of financial services through demonstrations, liquidity, and competition effects (Gomber et al., 2017; Ozili, 2018). In the post-epidemic era, many countries have investigated ways to improve their use of digital technology to achieve financial inclusion and foster economic recovery. For example, the Alliance for Financial Inclusion, the international organization for financial inclusion policies with the largest number of member states (75), is continually advancing the practice of digital financial inclusion, and a growing number of member states have formulated national financial inclusion strategies (John , 2019).

Different countries, regions, or communities have differences in the application and innovation capabilities of digital technologies, causing a 'digital divide' and widening the gap between the rich and the poor (Geach, 2007; Yartey, 2008). Against the background of the global consensus on the need to develop digital finance, scholars have investigated how best to use digital technology (with its convenience, efficiency, and sharing features) to make financial services more accessible and to expand the boundaries of financial products and services to the 'long-tail market' in accordance with the principles of efficiency and fairness. The concept of digital financial inclusion focuses on making financial products and services universally beneficial to all groups and locations in accordance with the principles of efficiency and fairness to promote social equity and advance equitable regional economic development (Huang and Huang, 2018). Digital financial inclusion integrates digital technology into financial services and reduces financial costs. The reduction in costs incurred from allocating financial resources helps expand the coverage of financial services, especially in underdeveloped regions. This highlights the 'inclusiveness' and 'precision' of financial services, narrows the gap between developing and developed regions, helps achieve a balance between fairness and efficiency, and promotes economic growth (Huang and Shen, 2019).

The literature has analyzed financial inclusion from a spatial perspective, reporting that financial inclusion exhibits global spatial agglomeration, with higher levels of financial inclusion in developed countries in Europe and North America than in the majority of developing Asian and African countries (Wang and Guan, 2017). A spatial autocorrelation analysis of 120 countries reported that financial inclusion showed significant spatial heterogeneity and spillover effects (Bozkurt et al., 2018). Research on spatial differences in China's financial inclusion has reported that eastern and western China have a negative spatial spillover effect on central China (Zhu et al., 2019).

In-depth research has also been conducted on the factors influencing digital financial inclusion from three perspectives: financial demand, supply, and the macroeconomic environment. From the demand perspective, income level, education level, gender, and other microeconomic characteristics significantly affect inclusive finance development (Fungáčová and Weill, 2015; Zins and Weill, 2016; Park and Mercado, 2018). Meanwhile, from the supply perspective, factors such as the financial environment, financial infrastructure, financial sector structure, and financial risks influence the supply of financial products and services of financial institutions, thereby influencing the level of financial inclusion development (Allen et al., 2016; Wang and Guan, 2017). From a macroeconomic environmental perspective, population density, infrastructure, industrialization level, and the legal environment influence the level of financial inclusion development (Allen et al., 2014; Park and Mercado, 2018).

Previous studies have focused on the spatial characteristics, influencing factors, and impact of digital financial inclusion. However, only a few studies have focused on the spatiotemporal evolution characteristics and spatial heterogeneity of the factors influencing digital financial inclusion from a geographical perspective. As a new financial model, digital financial inclusion relies on the Internet to overcome spatial limitations. Whether digital financial inclusion still follows the basic laws governing the spatial characteristics of traditional financial activities and whether the factors influencing digital financing are spatially heterogeneous have become a significant research value. China's Internet and digital finance industries have attracted global attention because of their rapid development. Accord-

ing to the Statistical Report on Internet Development in China released by the China Internet Network Information Center (CNNIC) (http://www.cnnic.net.cn/NMediaFile/old_attach/P020210915523670981527.pdf), as of June 2021, China's number of Internet users reached 1.01 billion. The Internet penetration rate reached 71.6% and the urban-rural digital gap narrowed significantly. The Internet penetration rate difference between urban and rural areas is 36.2% in June 2018 and 19.1% in June 2021. Moreover, the number of online wealth management users in China reached 166.23 million, accounting for 16.4% of the country's Internet population. The number of online payment users in China has reached 871.21 million, representing 86.3% of the country's Internet users. Given the current rapid development of digital finance in China, this study analyzes the 'digital divide' in China's financial inclusion from a geographic perspective. The study examines the spatial and temporal characteristics and influencing factors of digital financial inclusion at the county level in China. First, exploratory spatial data analysis is conducted to elucidate the spatiotemporal characteristics of digital financial inclusion in China and to examine whether its spatial agglomeration characteristics continue to exhibit significant autocorrelation and adhere to the fundamental spatial laws governing traditional financial activities. Second, a geographical detector model is developed to identify the factors influencing digital financial inclusion, including population density, traditional finance, local fiscal spending and education level. Third, suggestions are made to narrow the spatial gap in digital financial inclusion development, which provide a reference for other developing countries on using digital technology to develop financial inclusion.

2 Materials and Methods

2.1 Index system

The construction of the digital financial inclusion indicator system is based on three dimensions: coverage breadth, usage depth, and digitalization level. This surpasses traditional financial inclusion indicators, which are primarily concerned with the conduct of banking services (Guo et al., 2020). The data for this study are obtained from the Peking University Digital Financial Inclusion Index of China, which were compiled by the Institute of Digital Finance at Peking University (https://en.idf.pku.edu.cn). Based on the literature (Guo et al., 2020) and traditional financial inclusion indicators proposed by international organizations, the index reflects the new situation and characteristics of digital financial services using data that are readily available and reliable. The digital financial inclusion indicator system comprises three dimensions of digital financial inclusion (Table 1). The digital financial inclusion index and three-dimensional indices from 2014 to 2020 of 2836 counties (the maximum number of samples in a single year is 2836, with different data defects in different years) across the country were analyzed due to data acquisition process limitations.

2.2 Research methods

2.2.1 Global spatial autocorrelation

Global spatial autocorrelation reflects the level of aggregation of different unit attribute values from global spatial units (Méndez-Ortega and Arauzo-Carod, 2019). It measures whether spatial attribute values exhibit agglomeration, scattered, or random patterns. In this study, global spatial autocorrelation is utilized to describe the county-level spatial characteristics of digital financial inclusion in China as measured by global Moran's I. The formula for calculating I is as follows:

$$I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(X_i - \overline{X})(X_j - \overline{X})}{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\sum_{i=1}^{n}(X_i - \overline{X})^2}$$

where W_{ij} is the spatial weight between counties i and j (if counties i and j are adjacent and not adjacent, W_{ij} is 1 and 0, respectively) and X_i and X_j are the values of the county-level digital financial inclusion index in the corresponding counties i and j, respectively. $\overline{X}$ is the mean of the county-level digital financial inclusion index values, and n is the total number of counties. The range of I is [−1, 1]. If I is significantly positive, significantly negative, and zero, the spatial distribution of county-level digital financial inclusion is agglomerated, scattered, and random, respectively. In other words, the farther I is from 0, the greater the difference in spatial distribution.

2.2.2 Local spatial autocorrelation

The global Moran's I can indicate the nationwide, but not regional, spatial agglomeration characteristics of di-

Table 1 Index system of digital financial inclusion

Level 1 dimension	Level 2 dimension		Indicator
Breadth of coverage	Account coverage rate		Number of Alipay accounts owned by per 10000 people
			Proportion of Alipay users who have bank cards bound to their Alipay accounts
			Average number of bank cards bound to each Alipay account
Depth of usage	Payment		Number of payments per capita
			Amount of payments per capita
			Proportion of number of high frequency active users (50 times or more each year) to number of users with frequency of once or more each year
	Money funds		Number of Yu'ebao purchases per capita Amount of Yu'ebao purchases per capita
			Number of people who have purchased Yu'ebao per 10000 Alipay users
	Credit	Individual user	Number of users with an Internet loan for con-sumption per 10000 adult Alipay users
			Number of loans per capita
			Total Amount of loan per capita
		Small & Micro Business	Number of users with an Internet loan for small & micro businesses per 10000 adult Alipay users
			Number of loans per small & micro business Average amount of loan among small & micro businesses
	Insurance		Number of insured users per 10000 Alipay users
			Number of insurance policies per capita
			Average insurance amount per capita
	Investment		Number of people engaged in Internet investment and money management per 10000 Alipay users
			Number of investments per capita
			Average investment amount per capita
	Credit Investigation		Number of credit investigations by natural persons per capita
			Number of users with access to credit-based livelihood services (including finance, accommodation, mobility, social contact, *etc*.) per 10000 Alipay users
Level of digitalization	Mobility		Proportion of the number of mobile payments
			Proportion of total amount of mobile payments
	Affordability		Average loan interest rate for small & micro businesses
			Average loan interest rate for Individuals
	Credit		Proportion of number of Ant Check Later payments
			Proportion of total amount Ant Check Later payment
			Proportion of number of 'Zhima Credit as deposit' case (to number of full-deposit cases)
			Proportion of total amount of 'Zhima Credit as deposit' (to amount of full-deposit)
	Convenience		Proportion of number of QR-code payments by users
			Proportion of as above, please clarify with 'average amount' or 'total amount' of QR-code payments by users

gital financial inclusion in China at the county level. Local analysis methods are required to determine the regional county-level spatial differences in digital financial inclusion. Local indicators of spatial association (LISA) are local spatial autocorrelation indicators used to determine the distribution characteristics concealed or inconsistent with the global spatial autocorrelation. The LISA describes the degree of spatial agglomeration between a spatial unit and its surrounding spatial units. We can calculate the local spatial autocorrelation as follows:

$$I_i = \frac{(X_i - \overline{X})}{S^2} \sum_{j=1}^{n} W_{ij}(X_j - \overline{X})^2 \quad (1)$$

where I_i is the local Moran's I and the other variables have the same notation as those in Formula (1).

2.2.3 Geographical detector

Geographical detection is a spatial statistical method used to reveal the spatial differentiation of geographic elements and driving forces (Wang and Xu, 2017). It has four modules: risk, factor, ecology, and interaction detectors. Using the factor detector module, this study clarified the independent variables with statistical significance and their explanatory power for the dependent variable. The interaction detector module was used to determine whether an interaction exists between the independent variables and the direction and type of action. The q-value measures the explanatory power of the independent variable.The calculation formula for the geographical detector is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \quad (2)$$

where L is the stratification of the dependent variable or independent variable, N_h and σ_h^2 are the numbers of units and variance of layer h, respectively, and N and σ^2 are the number of units and variance of the entire study area, respectively.

3 Spatial-temporal Evolution Analysis

3.1 Temporal characteristics

China's county-level (Data don't include that of Hong Kong, Macao and Taiwan of China) digital financial inclusion index shows an increasing trend on the whole from 2014 to 2020 (Fig. 1). The average value of the county-level digital financial inclusion index increased from 47.15 in 2014 to 113.74 in 2020, representing an average annual growth rate of 15.81%. In terms of dimensional development, from 2014 to 2020, the level of the digitalization index grew the fastest, with an average annual growth rate of 20.25%, followed by the depth of usage index, with an average annual growth rate of 18.62%. The breadth of coverage index had the slowest growth, with an average annual growth rate of 12.64%. The rapid development of China's digital financial inclusion is due to the rapid popularization of the

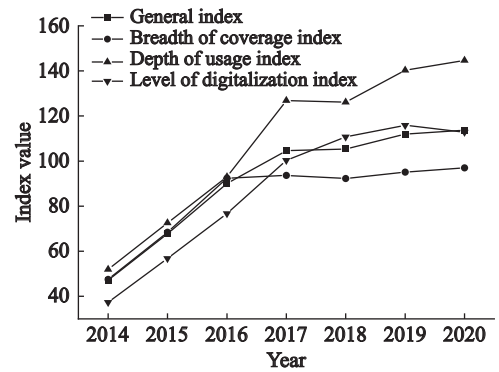

Fig. 1 China's county-level digital financial inclusion index from 2014 to 2020. Data don't include that of Hong Kong, Macao and Taiwan of China

Internet. First, the rapid expansion of netizens has greatly increased digital financial inclusion coverage. From 2014 to 2020, the number of Chinese Internet users increased from 649 million to 989 million, and the Internet penetration rate increased from 47.9% to 70.4%. The number of mobile Internet users reached 986 million in 2020, accounting for 99.7% of all Internet users. Second, the scale of online wealth management has expanded significantly, effectively enhancing the depth of usage of digital financial inclusion. From 2014 to 2020, the number of online wealth management service users in China increased from 78 million to 169 million, increasing from 12.1% to 17.2% of all Internet users. As of June 2020, the number of Internet wealth management users in China reached 149 million, accounting for 15.9% of the overall Internet population. Third, the number of users of online payment services continues to increase, effectively deepening the level of digitalization of financial inclusion. From 2014 to 2020, the number of users of online payment services in China increased from 304 to 854 million, of which the number of mobile online payment users increased from 217 to 853 million.

3.2 Spatial characteristics

3.2.1 Spatial autocorrelation analysis

The calculation results of Moran's I index reveal that from 2014 to 2020, the Moran's I index of China's county-level digital financial inclusion general index increased from 0.271 in 2014 to 0.565 in 2020, all of which had positive values and passed the 5% significance test. This indicates that China's county-level digital financial inclusion from 2014 to 2020 shows significant spatial autocorrelation and a positive correlation

with the spatial distribution. Temporally, the Moran's *I* value slightly increased from 2014 to 2015. From 2016 to 2020, Moran's *I* value continued to escalate, indicating a significant increase in the spatial aggregation of China's County Digital Inclusion Index.

According to the local Moran's *I* of China's county-level digital financial inclusion index in 2014 and 2020, combined with the LISA agglomeration map (Fig. 2), the local spatial distribution agglomeration types were divided into high-high (HH), low-low (LL), high-low (HL), and low-high (LH) agglomerations. China's county-level digital financial inclusion index exhibits apparent local spatial agglomeration, which includes HH and LL agglomerations. In 2014, the high-value agglomeration areas of county-level digital inclusive finance were primarily distributed in the Shandong Peninsula, Yangtze River Delta, Fujian, and the junction area between Xinjiang and Gansu. Meanwhile, the low-value agglomeration areas were mainly distributed in Yunnan; Guizhou; Guangxi; western Hunan; the junction area of Shaanxi, Gansu, Ningxia, and Qinghai; the junction area of Sichuan, Chongqing, and Hubei; and northeastern China. By 2020, China's county-level digital financial inclusion agglomerations had strengthened, and high-value agglomeration areas had expanded to most areas in Shandong, Henan, Hubei, Jiangxi, and the Pearl River Delta. Moreover, the low-value agglomerations had spread to most regions of southwestern, northwestern and northeastern China. Overall, low-value agglomerations expanded in western and northeastern China, whereas high-value agglomerations spread from the eastern coast of China to central China.

3.2.2 Spatial distribution characteristics

To facilitate the comparison of the development level and spatial distribution characteristics of county-level digital financial inclusion, combined the ArcGIS natural breakpoint delineation with the actual situation, this study divided the county-level digital financial inclusion index and its three-dimensional index into five categories: low-, medium-low-, medium-, medium-high-, and high-value areas (Fig. 3). In 2014–2020, the development level of China's county-level digital financial inclusion demonstrates that the spatial differences have been decreasing on two sides of the Hu Huanyong Line. On the east side of the Hu Huanyong Line, the development level of digital financial inclusion demonstrates a spatial differentiation pattern with the higher value areas in the eastern coast of China as the core and gradually decreasing to the periphery. On the west side of the Hu Huanyong Line, it roughly shows a spatial differentiation pattern with the higher value areas at the borders of Gansu, Xinjiang, Qinghai, and Inner Mongolia as the

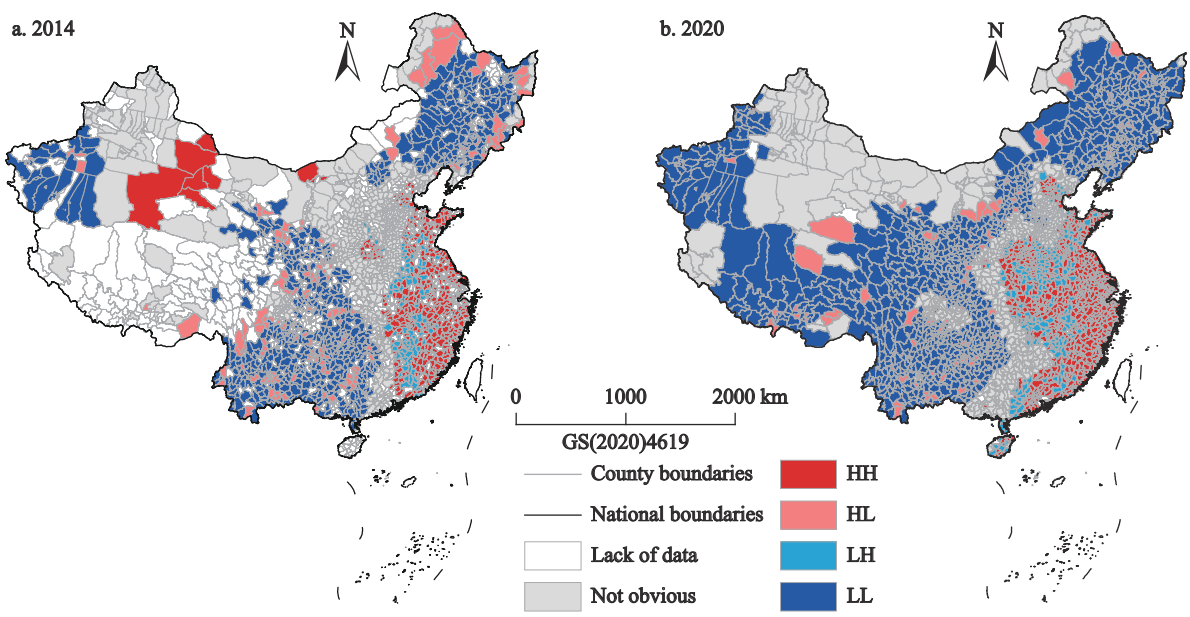

Fig. 2 Local indicators of Spatial association (LISA) agglomeration map of China's county-level digital financial inclusion index in 2014 and 2020. HH: high-high agglomerations; LL: low-low agglomerations; HL: high-low agglomerations; LH: low-high agglomerations. Data don't include that of Hong Kong, Macao and Taiwan of China

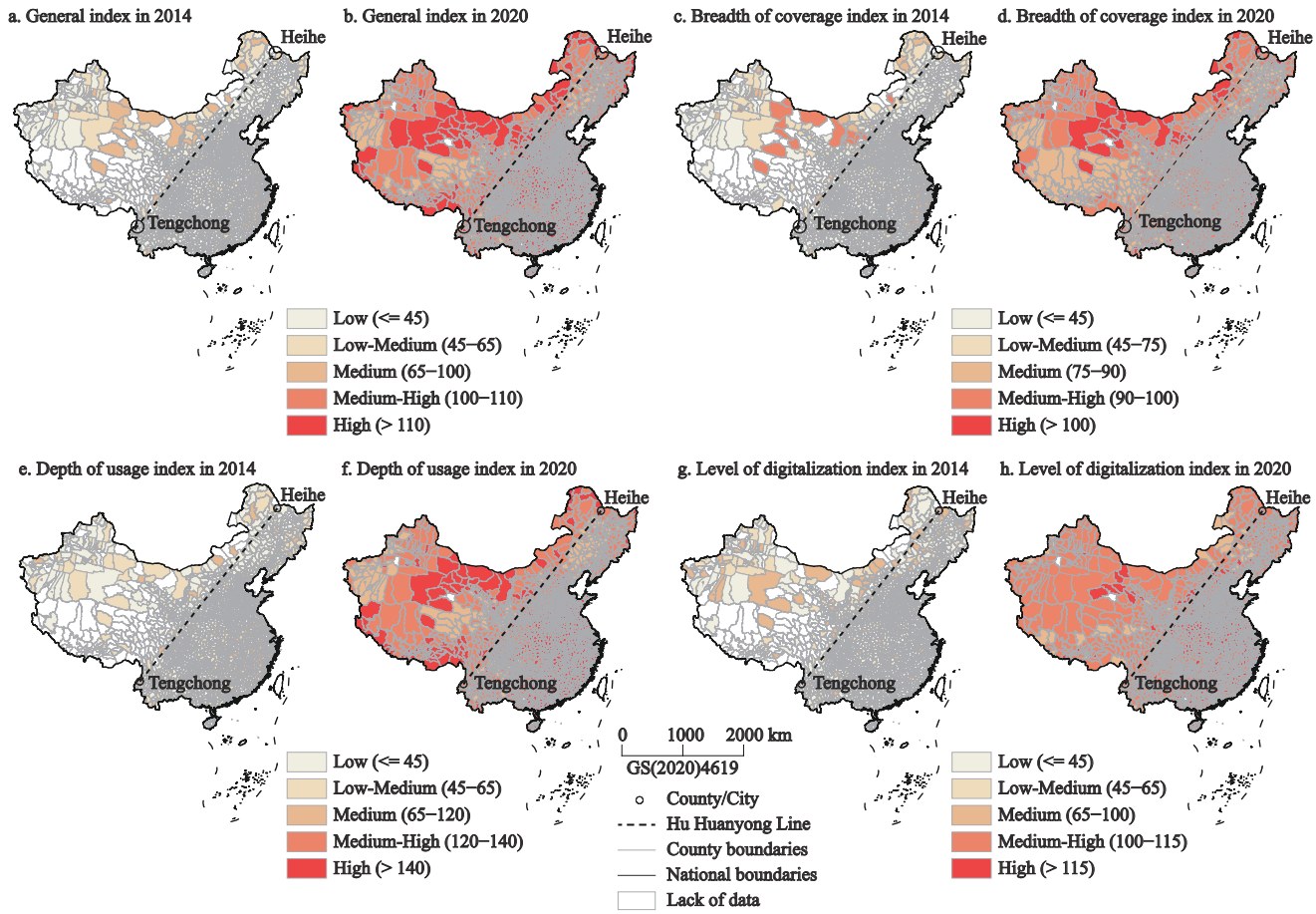

Fig. 3 Spatial pattern of China's county-level digital financial inclusion index in 2014 and 2020. Data don't include that of Hong Kong, Macao and Taiwan of China

core and gradually decreasing to the periphery. The number of counties in the core area on the right side is much larger than that on the left side (Figs. 3a, 3b). Specifically, in 2014, the digital financial inclusion index of China's counties belonged to the low-, medium-low-, and medium-value areas, but neither the medium-high- nor high-value areas were represented. There were 247 counties in the medium-value area, which accounted for 14.09%, mainly in the Yangtze River Delta region and Fujian. Moreover, there were 651 counties in the medium-low-value area and 855 in the low-value area, which accounted for 37.14% and 48.77%, respectively, with no discernible distribution characteristics. In 2020, there was a significant increase in the digital financial inclusion index of counties in China, all of which belonged to the medium-, medium-high-, and high-value areas. There were 1765 counties in the high-value area, accounting for 62.23%, mainly distributed in the southeastern coast of China, central provinces of China, and the junction area of Gansu, Xinjiang, Qinghai, and Inner Mongolia. Moreover, 916 counties belonged to the medium-high-value area, accounting for 32.30%, mainly in western and northeastern China, and 155 counties in the medium-value area, accounting for 5.47%, mainly in western Xinjiang, southern Qinghai, and the junction area of Jilin, Liaoning, and Heilongjiang. During the study period, the spatial pattern of China's county-level digital financial inclusion index has changed to a certain extent, that is to say, most of the counties with a high level of digital financial inclusion development are located in the east of the Hu Huanyong Line, in the meantime, the development level of the counties in the west of the Hu Huanyong Line has improved rapidly, which reflects that the trend of the spatial distribution of the development level of digital financial inclusion breaking through the Hu Huanyong Line has been strengthening by relying on Internet technology.

3.2.3 Spatial stratified heterogeneity of the breadth of coverage

During the research period, the overall spatial pattern of

the breadth of coverage of digital financial inclusion is relatively consistent with the spatial pattern of the overall index (Figs. 3c, 3d). In 2014, the coverage breadth of the digital financial inclusion index of counties in China varied widely, with 892, 622, 128, and 111 counties belonging to low-, medium-low-, medium-, and medium-high-value areas, accounting for 50.89%, 35.48%, 7.30%, and 6.33%, respectively. Moreover, there were no counties in the high-value areas. Among them, counties in the medium-high- and medium-value areas are mainly concentrated in the Yangtze River Delta, Fujian, and so on. In 2020, the gap in the coverage breadth index of digital financial inclusion of counties across China narrowed significantly, and the digital financial inclusion index of counties in central and western China generally increased. The coverage breadth index of digital financial inclusion in counties nationwide fell into the medium-, medium-high-, and high-value areas. Among them, there were 860 and 1578 counties in the high- and medium-high-value areas, accounting for 30.33% and 55.64%, respectively, mainly located in the southeastern coast of China and central cities in central and western China. Meanwhile, 398 counties belong to the medium-value areas, accounting for 14.03%, mainly located in counties far away from central cities and urban agglomerations in central and western China. The spatially stratified heterogeneity of county coverage breadth is shrinking, indicating that the use of digital technology has greatly contributed to enhancing the coverage breadth of financial inclusion and helped narrow regional differences.

3.2.4 Spatially stratified heterogeneity of the depth of usage

The spatially stratified heterogeneity of the depth of usage of county-level digital financial inclusion is consistent with the overall spatial pattern of county-level digital financial inclusion, except for some counties in Gansu and Tibet, where most of the high values are mainly concentrated in the eastern coastal regions (Figs. 3e, 3f). In 2014, the depth of usage index of digital financial inclusion of counties nationwide belonged to the low-, medium-low-, and medium-value areas. There were 388 counties in the medium-value area, accounting for 22.13%, mainly located in the southeastern coast of China and the middle-lower reaches of the Yangtze River regions. Meanwhile, 746 counties were in the medium-low-value area, accounting for 42.56%, mainly distributed in the central and southwestern China ; and 619 counties in the low-value area, accounting for 35.31%, mainly distributed in northern and western China. In 2020, the usage depth indexes of digital financial inclusion of counties nationwide increased significantly, all of which belong to the medium-, medium-high-, and high-value areas. Among them, 1623 counties are in the high-value area, accounting for 57.23%, mainly distributed along the southeast coast of China, central provinces of China, the junction area of Gansu, Xinjiang, Qinghai, and Inner Mongolia, and eastern and western Tibet. Meanwhile, 987 counties are in the medium-high-value area, accounting for 34.80%, mainly distributed in the western and northeastern provinces of China; 226 counties in the medium-value area, accounting for 7.97%, mainly distributed in western Xinjiang, southern Qinghai, and the junction area of Heilongjiang, Jilin, and Liaoning. In 2020, compared with 2014, the index of the depth of usage of digital financial inclusion generally increased faster, and the trend of breaking through the Hu Huanyong Line in space distribution was more obvious.

3.2.5 Spatial stratified heterogeneity of the level of digitalization

The spatial gradient pattern of the digitalization level of county digital financial inclusion is more obvious; the high-value areas are mainly concentrated on the eastern coast of China. Moreover, the level of digitalization in central cities and urban agglomerations is significantly higher than that in other regions. In 2014, there was no obvious spatially stratified heterogeneity in the digitalization level of county digital financial inclusion. In 2020, the spatial gradient pattern became more pronounced, with high-value areas primarily concentrated in eastern and central China, Shaanxi, and the junction area between Gansu and Qinghai. Simultaneously, the level of digitalization in central cities and urban agglomerations was significantly higher than in the other regions (Figs. 3g, 3h). In 2014, there was little difference in the digitalization level index of digital financial inclusion of counties nationwide, with 1,142, 431, and 180 counties belonging to the low-, medium-low-, and medium-value areas, accounting for 65.14%, 24.59%, and 10.27%, respectively. The medium-value areas are concentrated in some central cities, and none of the counties belong to the medium-high and high-value areas. All of the medium-, medium-high, and high-value areas of digital finance inclusion experienced a significant increase in di-

gitalization in 2020. There were 1092 counties in the high value area, accounting for 38.50%, mainly distributed in eastern and central China, Shaanxi, and the junction area between Gansu and Qinghai; 1672 counties in the medium-high value area, accounting for 58.96%, mainly distributed in vast counties far from the central cities; and 72 counties in the medium-value area, accounting for 2.54%, dispersed throughout the northeast and western China. In 2014–2020, the improvement in the digitalization level of county digital finance inclusion is the greatest of the three dimensions, indicating that the rise in the digitalization level of the county has substantially increased the overall level of county digital finance inclusion. However, the level of counties in western and northwestern China must be further strengthened in terms of mobile payments, loan rates, digital credit loans, and QR code payments to narrow the spatial differences.

4 Influencing Factors of Digital Financial Inclusion

With the development of digital technology, serving 'agriculture, rural areas, and farmers' and financing small and micro enterprises, new services and products continue to emerge in the digital financial inclusion. Digital finance inclusion has been fully integrated into all economic and social development areas. This study combines the existing literature (Song et al., 2017; Fungáová and Weill, 2015; Allen et al., 2016; Zins and Weill, 2016; Wang and Guan, 2017; Park and Mercado, 2018; Li et al., 2021) to reveal the direction and extent of economic and social factors on the development of digital finance inclusion. It also considers the availability of data, selects population density, traditional financial development level, government regulation, and education level as independent variables. Moreover, it uses geographic detectors to analyze the influencing factors of digital financial inclusion in China's county areas. Population density (X_1) reflects population concentration, and to a certain extent, the increase in population density is conducive to raising the demand for financial products and services. The level of traditional financial development (X_2) is an important basis for digital financial inclusion and is measured by the ratio of total deposits and loans to regional GDP. Government regulation (X_3) is represented by the proportion of fiscal expenditure in the GDP, and the government's macro-control can promote the development of digital financial inclusion. The improvement in education level (X_4) helps increase the usage depth of digital financial products. In this study, the education level is expressed by the ratio of the number of the primary and secondary school students to the population.

4.1 *q*-value detection results

The results of the Geographical Detectors indicate that population density, traditional financial development, government regulation, and education levels all passed the significance test at the 1% level. Moreover, the analysis of the *q*-values of the explanatory power of the factors indicates that, throughout the study period, these four factors consistently had a significant impact on the level of county-level digital financial inclusion development, and that this impact is generally increasing (Table 2). Among them, the *q*-value of government regulation is the largest, and its influence is the strongest. The population density factor had the largest increase in the *q*-value and the fastest rise in influence, followed by the impact of education level. The influence of the traditional financial development level has declined, and its influence on the development level of digital financial inclusion has gradually weakened. The higher the population density, the greater is the demand for digital financial inclusion products and services, which can increase the depth of usage of financial products to a certain extent. An increase in education level helps the understanding and usage of digital financial products, which can effectively increase the usage depth and digital financial inclusion digitalization. The influence of traditional financial development level on China county-level digital financial inclusion shows a weaker trend, probably because of the development of digital technology. Furthermore, inclusive finance has shifted from the popularization of basic services to the deepening of products and business, enhancing digitalization, and breaking through reliance on the scale of traditional finance. The government supports financial institutions to increase loans to agriculture and micro and small enterprises by establishing a special fund for the development of digital financial inclusion and invests heavily in infrastructure, which is conducive to expanding the breadth of financial services and digitalization coverage. Government regulation has been influential throughout

the study period, indicating that coordinated regional development of China's digital financial inclusion cannot be achieved without government macro-control. This is consistent with China's promotion of inclusive development and its 'people-centered' philosophy of governance.

4.2 Interaction detection results

As the effects of different factors on China's county-level digital financial inclusion may not be independent, this study further explored the interactions of the influencing factors. The results indicate that the type of interaction is a two-factor enhancement, meaning that the explanatory power of the interaction between the independent variables is significantly greater than that of the respective variables individually (Table 3). This indicates that the interactions between these factors influence the spatial distribution of county-level digital financial inclusion development. During the study period, the strongest explanatory power was consistently found in the interaction between government regulation and education level, which increased from 0.975 in 2014 to 0.993 in 2020. This indicates that the coordinated regional development of county-level digital financial inclusion should focus on both government regulations and improving education levels. Moreover, the 'talent strategy' and the 'rural revitalization strategy' proposed by the 20th Party Congress are conducive to further improving the level of China county-level digital financial inclusion, promoting economic development in the direction of higher efficiency, fairer, higher quality, and more sustainable growth, and promoting finance to assist in achieving the goal of Common Prosperity.

Table 2 *q*-value detection results in 2014 and 2020

Year	X_1	X_2	X_3	X_4
2014	0.454	0.393	0.537	0.298
2020	0.461	0.294	0.630	0.373

Table 3 Interaction detection results in 2014 and 2020

Year	Influencing factors	X_1	X_2	X_3	X_4
2014	X_1				
2014	X_2	0.966			
2014	X_3	0.968	0.968		
2014	X_4	0.961	0.969	0.975	
2020	X_1				
2020	X_2	0.982			
2020	X_3	0.992	0.988		
2020	X_4	0.990	0.967	0.993	

5 Conclusions

This study analyzed the temporal and spatial characteristics and influencing factors of digital financial inclusion at the county level in China from 2014 to 2020. The main conclusions are as follows. First, overall, the digital financial inclusion index and in all three dimensions (breadth of coverage, depth of usage, and level of digitalization) increases over time. This is due to the rapid popularization of the Internet in China during the study period; more users used the Internet in general and online financial services. Second, significant spatial autocorrelation was noted at the level of digital financial inclusion. The pattern of local spatial agglomeration is dominated by HH and LL clusters, mainly distributed along the southeastern coast of China and western China, respectively. Third, population density, traditional financial development level, government regulations, and education level are core factors influencing digital financial inclusion at the county level in China.

In the context of the literature findings, this study reports the following. First, digital financial inclusion relying on digital technology is overcoming the spatial restrictions and the trend of breaking through the Hu Huanyong Line is strengthening. However, digital financial inclusion is still more developed in eastern than in western China. Second, improvements in digitalization can significantly increase digital financial inclusion at the county level in China. Policymakers should promote mobile payments and digital credit loans further and strengthen online payment capabilities, particularly in western China. Third, differences exist in digital financial inclusion and its influencing factors in different regions. This implies that government policies that enhance digital financial inclusion should adapt to local conditions to narrow the gap between eastern and western China.

6 Implications

Based on these findings, this study presents the following suggestions to reduce regional disparity in China's

county-level digital financial inclusion. 1) Among the three dimensions of China's county-level digital financial inclusion development, the digitalization level index shows the fastest growth. Advancing the digitalization of counties in China's central and western regions is conducive to enhancing the overall level of digital financial inclusion in China's counties. For example, increasing the financial support for small and micro-operators can improve the benefits, and expanding the QR code payment can improve the facilitation. 2) Government regulation and education level are key determinants of China's county-level digital financial inclusion, and their interaction can effectively increase the overall level of digital financial inclusion. The balanced development of digital financial inclusion must also be promoted by strengthening government regulation, allowing fiscal funds to play a guiding role, thus further improving education in less developed regions, increasing macrocontrol, and upgrading the governments of less developed regions to expand the coverage depth of digital financial inclusion. Local governments and financial institutions must also conduct extensive publicity on digital finance in rural areas, increase farmers' awareness and usage depth of digital finance, and promote the in-depth development of digital finance. 3) There are large spatial differences in the development of digital financial inclusion at the county level in China, necessitating the implementation of city-specific policies in the promotion of digital financial inclusion. On the one hand, policymakers continue to promote national strategies, such as 'Rise of Central China', 'Development of the West', and 'Revitalization of the Northeast' to advance digital financial inclusion in these regions. On the other hand, Midwest-targeted policies must further leverage digital technologies to increase the coverage of financial services and strengthen citizens' financial knowledge to increase the depth of usage and digitalization level of financial products and services, with a greater emphasis on the government's leadership role, thereby releasing the development potential of digital inclusion in the Midwest. By contrast, policies targeting the eastern region can encourage innovation in financial products and services, focusing on enhancing the depth of usage of digital financial services in the economy and the lives of residents, concentrating on market orientation, continuing the strengths of financial development in the east, and exploring models for digital financial inclusion.

Digital financial inclusion is still in its infancy on a global scale. For example, it is difficult in Africa for bank branches to reach places with low population density. Therefore, using digital technology is a more effective way to promote financial inclusion in Africa (Allen et al, 2014). This study examines the spatial determinants of digital financial inclusion at the county level in China from a geographical perspective, providing a reference for digital financial inclusion in other developing countries. As more data becomes available, it will be necessary to conduct additional research on the spatiotemporal evolution characteristics and spatial heterogeneity of digital financial inclusion across the globe and in various countries to inform policies pertaining to its development.

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