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Research article

Measuring China's urban digital finance

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Abstract: With the full integration of digital information technology and financial services, digital finance has developed rapidly. As there are significant differences in the development level of FinTech and traditional financial sectors in different cities, it is important to evaluate the development level of urban digital finance. This study aimed to compile an index of urban digital finance to present an accurate and in-depth depiction of how urban digital finance has developed in China. Our sample covers 278 cities in China, over the period 2010–2020. This paper firstly constructs the urban digital financial index system from the three dimensions of digital financial services, digital financial technology, and digital financial operating environment, and then adopts a combination of subjective and objective methods to measure the urban digital financial index. This paper study revealed that China's urban digital finance has been on an upward trend from 2010 to 2020, and the digital finance operating environment is an important driving force for the growth of the urban digital finance index. The convergence of China's urban digital finance is decreasing, indicating that the gap in digital financial development between cities is increasing. Urban digital finance has positive spatial agglomeration, but this spatial agglomeration is decreasing.

Keywords: city; digital finance; index compilation; development; spatial

JEL Codes: G20, G10, O16

1. Introduction

With the in-depth development of the Internet and information technology and the government's strong support for technological innovation, the emerging industry of digital finance has risen strongly. Digital financial technology is widely used in financial fields such as payment and settlement, loan financing, wealth management, retail banking, and transaction settlement. The financial industry has a disruptive, comprehensive and sustainable impact on its core business and profitability. Mobile banking and online banking supported by Internet technology have led to a decrease in the types and frequency of businesses handled by outlets year by year, and basic businesses such as deposits, account opening, and transfers handled by outlets have declined rapidly. In 2013, the number and amount of China's electronic payment business transactions were 25.783 billion and 1075.16 trillion yuan respectively, while in 2020, the number and amount of China's electronic payment business transactions reached 235.225 billion and 2711.81 trillion yuan, respectively. increased by 9.12 times and 2.52 times; the e-commerce transaction volume increased from 10.2834 trillion yuan in 2013 to 37.21 trillion yuan in 2020, an increase of 3.62 times; the proportion of online retail sales of physical goods in the total retail sales of social consumer goods continued to rise. In 2015 From 10.8% at the time, it has risen to 24.9% in 2020.

According to the development process of digital finance, it can be divided into four stages. The first stage is the penetration of Internet technology into the financial field. In the early 1990s, driven by capital, Internet technology quickly penetrated into the financial field. In 1992, the first Internet broker in the United States was established, which promoted the continuous growth of online securities trading, gradually replaced the traditional trading model, and triggered the second commission price war in the United States. In 1995, the first Internet bank was established, which within three years was the sixth largest bank in the United States and promoted the onlineization of major commercial banking businesses (Liao et al., 1999). At this stage, because the United States has not formed an independent financial format, there is no ‘‘Internet" term, but is called "electronic finance", "electronic banking", "online banking" and so on (Aladwani, 2001; Claessens et al., 2002; Yousafzai et al., 2003). China was also in this stage before 2013, mainly because traditional financial institutions used Internet technology to improve service efficiency and quality. Online banking, mobile banking, online securities trading, and short message services have become very common business models.

The second stage is the formation of the Internet financial format. In the late 1990s, Paypal completed the connection between electronic payment and monetary funds, marking the completion of the connection between electronic payment and monetary funds under the Internet technology, and a new transaction method was born. Since then, "Internet" has become an industry, and an industrial chain around Internet finance has gradually formed. At this stage, Internet finance has developed vigorously, forming a relatively complete industrial chain, and the main body of a single link of the industrial chain has gradually expanded vertically and integrated business, and Internet financial groups with businesses involving multiple links in the industrial chain have emerged. In the first and second stages, Internet technology has greatly reduced transaction costs, reduced information asymmetry, expanded the scale of the financial market, improved market liquidity, reduced residents' demand for deposits, and accelerated financial disintermediation (Berger and Gleisner, 2009; Raza and Hanif, 2013).

The third stage is the rise of financial technology. After 2007, the P2P model represented by Prosper and Lending Club has driven the rapid development of Internet finance. This peer-to-peer network direct financing model has almost realized financial disintermediation in a true sense,

providing an external environment for the birth of financial technology companies (Morse, 2015). After 2010, a large number of financial technology companies were established, and the financial technology industry emerged.

The fourth stage is the internet finance develops into digital finance. The innovation of Internet finance is more at the product level, which improves the scale and efficiency of traditional financial business (Begenau et al., 2018; Fuster et al., 2019; Chen et al., 2019; Chiu and Koeppl, 2019). Digital finance is an innovation at the technical level, which is more reflected in the subversion of financial activities such as credit intermediation, information collection, risk pricing, and investment decision-making. For example, big data analysis can accurately describe users' risk preferences, and artificial intelligence can realize asset allocation, etc. Internet finance is an important part of digital, and it is also the primary stage of digital finance development. Internet finance is a major change to the channel level of the traditional financial industry, while digital finance is a comprehensive upgrade from the channel level to core business capabilities.

Digital finance refers to a new financial model in which traditional financial institutions and Internet companies use digital technology to realize payment, credit, investment, insurance and other financial services, including traditional financial institutions such as banks, securities, insurance, and Internet companies. There are many types of digital finance business, covering payment, credit, investment, insurance and other fields, usually including Internet payment, Internet fund sales, Internet trust, Internet consumer finance, Internet credit assessment, Internet lending, Internet crowdfunding, etc. Compared with traditional financial services, digital finance can not only reduce costs, improve efficiency, and optimize resource allocation, but also better meet the financial needs of the majority of groups, improve the availability of financial services, and help improve financial inclusion and and improve the quality of financial services to the real economy (Li et al., 2021; Ozili, 2018; Zhong and Jiang, 2021).

As the geographic space distance of digital finance application shrinks, the traditional financial industry breaks through the limitation of geographic space scope, making it possible for long-distance and low-cost cross-regional transactions. Most cross-regional financial activities can be completed quickly with low transaction costs, making financial services fast and efficient. However, a typical fact of financial services is that most financial activity is still clustered in certain geographic locations (Knight and Wójcik, 2017). The problem of information asymmetry in the financial industry cannot be solved by transaction forms such as electronic banking. In order to promote the formation of transaction networks and the efficient flow of financial information, close-range or face-to-face communication is indispensable. The phenomenon that financial elements such as various financial institutions, talents, and information continue to gather in space has made financial agglomeration become the basic spatial distribution feature of the modern financial service industry (Cao et al., 2021; Su et al., 2021). Geographical location factors play an important role in financial development and the layout of the financial industry.

There are two research results about digital finance: the measurement method of digital finance and the space-time characteristics of the development of digital finance. The first type of research results are mainly about the measurement methods of digital finance. Digital finance has the characteristics of natural universality and network, so it needs to consider the construction of its index system from various aspects. Firstly, digital finance is studied from a micro perspective. Southwestern University of Finance and Economics collated and released Chinese Household Finance Survey data (CHFS) based on household survey (Lu and Zhang, 2018)，and China Agricultural University released Chinese rural inclusive finance survey data based on inclusive research (He et al., 2017; He and Li,

2019). Secondly, Sarma and Pais (2011) used HDI method to measure the financial inclusion development index of some countries. With the deepening of the research on the indicator system, indicators related to financial development such as digital support factors, innovative digital finance and digital payment have been included in the measurement framework (Ambarkhane et al., 2016; Jiao et al., 2015; Liu, 2017). Then, the Digital Finance Research Center of Peking University constructed an index system and measured the digital inclusive finance index from the three dimensions of coverage, depth of use and degree of digitalization to comprehensively investigate the development of digital finance (Guo et al., 2020). In addition, fintech index can also be constructed through baidu search index and other channels, which has made corresponding contributions to the development analysis and empirical research of digital finance (Shen and Guo, 2015; Li et al., 2021).

The development of urban digital finance has a spatial and temporal pattern. On the one hand, the paper analyzes the spatial and temporal evolution of digital finance in China. Most literatures use Moran's I index and Kernel density estimation to analyze the global or local correlation effect of digital finance, so as to identify the evolution law and development trend of digital finance's spatial distribution (Wang, 2021; Jiao, 2021). In addition, Dagum Gini coefficient and other convergence models are used to describe the spatial and temporal differences of urban digital finance (Chen et al., 2015; Zhang and Zhu, 2020), exploratory data analysis method is used to investigate the spatial agglomeration and convergence characteristics of urban digital financial index (Guo et al., 2020; Liang and Zhang, 2019). On the other hand, the spatial heterogeneity of China's digital finance is analyzed. Previous studies have investigated the spatial differences, causes and dynamic evolution of digital finance from urban agglomeration and specific regions (Zhang and Zhu, 2020). There are regional differences in the spatial distribution of digital finance development (Ge and Zhu, 2018), and the spatial spillover effect and heterogeneity of digital finance deserve in-depth study. Therefore, there is room for research on regional differences of digital finance.

In the past few years, China's digital finance has made great progress and has exerted great influence in the world, but it has always lacked an indicator system to measure its overall development level. Different from the commonly used Peking University Digital Financial Inclusion Index. The goal of this paper is to compile a digital financial index from the perspective of the whole city, which comprehensively reflects the development of urban digital finance. The "Peking University Digital Financial Inclusion Index" released by the Digital Finance Research Center of Peking University is mainly based on the perspective of users. Although the index is highly related to digital finance, the research focus basically focuses on the reflection of digital finance at the service level, which is still different from the complete concept of digital finance. This paper aims to measure China's urban digital finance. By combing the development history of digital finance and related research on its measurement, combined with the actual situation of urban digital finance development, this paper constructs a set of urban digital finance index system, which reflects the development status and urban differences of urban digital finance in China, which is conducive in-depth research to digital finance.

The rest of the paper is organized as follows: section 2 lay out the urban digital finance indicator system and index compilation method. Section 3 analyze the development trend of urban digital finance and its sub-indices. In section 4, we analyze the spatial characteristics of urban digital finance. Section 5 provides the main conclusions.

2. Indicator system and method

2.1. Urban digital financial indicator system

Digital finance is a new type of financial service format. With the development of information technology, financial services exist in various formats. The traditional financial service formats include core businesses such as credit and payment. With the development of information technology, information technology and traditional related businesses are combined to form a new financial service format. For example, in the credit business, in traditional business, assets, etc., need to be used as credit collateral, and related assets need to be evaluated in the loan business process; however, after the digitization of credit business, artificial intelligence technology is integrated into the credit risk assessment and approval process. Unsecured credit business for financial consumption and other situations. Another example is the payment business. Through blockchain and other technologies, the payment can be decentralized in the local area, and the efficiency can be improved through digital technology, thereby forming a new business form.

Digital finance must be integrated into modern information technology, especially digital technology. The continuous integration of digital technologies such as information and traditional financial services has greatly promoted the emergence and continuous iteration of digital finance. The integration of digital technology into the financial system can greatly reduce transaction costs, improve the effectiveness of risk control, and expand the scope of financial service supply for all parties involved in financial transactions, and accordingly promote the emergence of new financial formats. At the same time, the integration of digital technology has also significantly changed the cost, risk control and coverage of digital finance. Digital financial technology has transformed many financial services from offline to online, and improved transaction efficiency, thereby reducing transaction costs. Digital finance has changed in the form of risks. For example, the digital currency based on blockchain technology has effectively controlled moral risks such as forged bills in financial transactions; however, the dependence of digital technology on the network presents risks in terms of network security. Changes in the form of digital financial risks require changes in risk control strategies. Many transactions in digital finance are conducted online, so digital finance makes the coverage of transaction subjects and transaction scope more extensive, and the breadth and depth of participation are developed.

Diversified participants in digital finance. With the development of digital technology, the transaction methods have changed significantly, especially the characteristics of online transactions and partial decentralization, and the subjects involved in digital financial transactions have become more diversified. Originally, the main players participating in the market were financial institutions and investors. However, with the development of digital finance, the coverage of financial transactions is wider, so ordinary residents also participate more. The transaction method has changed the payment method. For example, the original cash transaction or bank transaction is now transaction through WeChat and other methods. At this time, financial transactions are not completely dependent on traditional financial transaction methods.

Digital financial services are fundamental to the realization of urban digital finance. Digital financial services mainly comprehensively reflect the degree to which cities can provide digital financial services. From the perspective of index selection, theoretical indicators that can explain urban digital financial services can be selected from how to achieve the goal of digital financial services.

Specifically, the total telecom service volume is selected to illustrate the amount of data provided by digital finance, because digital finance needs to be realized through the Internet, and the total telecom service volume reflects the degree to which telecom sector provide digital financial telecom services to the society. Selecting the total postal service volume and the total retail sales of social consumer goods to illustrate the transportation and consumption provided by digital finance, because payment and settlement is one of the main services provided by digital finance, and the transportation of goods requires postal services. Financial consumption reflects the extent to which digital finance provides services to the society at the consumer end. Selecting the number of financial industry practitioners and fintech companies indicates the number of service personnel and companies provided by digital finance, because financial industry practitioners and fintech companies directly reflect the number of service personnel and companies related to digital finance.

Digital financial technology is the driving force behind the development of urban digital finance. Digital financial technology mainly reflects the city's ability to continuously promote the development of digital finance. From the perspective of index selection, theoretical indicators that can explain the city's digital financial technology can be selected from the perspective of how to promote digital financial innovation. Specifically, select the market value of listed financial and technology companies and the number of employees in the information and financial industry to measure the labor force of digital financial technology in a city. Because labor is the main body that promotes the formation of digital financial technology, major digital financial innovation activities in the city require the participation and collaboration of various entities. The financial technology expenditure is selected to measure the funds of urban digital financial technology, because the development of urban digital financial technology is inseparable from the support of funds, and the government's financial technology is one of the main sources of urban digital financial technology. The number of patent applications and patent authorizations related to digital finance are selected to measure the innovation activities of urban digital financial technology, because innovation activities are the main performance of urban digital financial technology, the number of patent applications reflects the city's innovation vitality, and the number of patent authorizations reflects the city's innovation achievements.

The digital financial environment is the guarantee for the operation of urban digital finance. The digital financial environment mainly reflects the basis of the city's ability to effectively support the operation and development of digital finance. From the perspective of index selection, theoretical indicators that can explain the urban digital financial environment can be selected from the perspective of how to ensure the operation of digital finance. Specifically, the mobile phone users and the Internet user are selected to illustrate the network operating environment of digital finance, because the operation of digital finance is inseparable from the effective support of the Internet, and mobile phones increase the convenience of digital finance services. The degree of attention to digital finance is selected to illustrate the operating environment of digital finance. Because digital finance is an emerging thing, most people lack understanding of it. The higher the attention paid to digital finance, the easier it will be to popularize digital finance. The policy support for digital finance is selected to illustrate the policy support environment for digital finance, because government support can effectively promote the development of digital finance. The greater the government support, the better the development environment for digital finance. The urban light index is selected to describe the infrastructure environment of digital finance cities, because urban lights can directly and objectively reflect the construction of urban roads and houses.

Table 1. Evaluation indicator system of urban digital finance.

Target	Dimension	Indicator	Calculation method
Urban Digital Finance Index	Digital financial services	Total telecom service volume	Total telecom service volume
		Total postal service volume	Total postal service volume
		Digital financial consumption	The total retail sales of social consumer goods*Internet penetration
		Number of digital financial services staff	Financial industry practitioners
		Number of FinTech companies	Number of FinTech-related companies
	Digital financial technology	Number of patent applications	Number of patent applications related to urban digital finance
		Number of patents granted	Number of urban patents granted related to urban digital finance
		R&D spending	public finance technology spending
		Number of R&D staff	Computer Services and Software Industry Practitioners
		The scale of digital financial enterprises	Market value of listed digital financial companies
	Digital financial environment	Total mobile phone users	Number of mobile phone users
		Total Internet users	Number of Internet broadband users
		Digital finance concerns	Web Crawler from Baidu Index
		Digital financial policy support	Text Analysis
		Urban light index	Urban light image

2.2. Indicator weight method

This paper takes 278 cities above the prefecture level in China (regions, autonomous prefectures, leagues, etc., referred to as "cities") as research samples to examine the characteristics of urban digital finance, over the period 2010–2020.

In order to make the weight calculation method of this paper more convincing, this paper adopts a combination of subjective and objective methods to measure the urban digital financial index. First, based on the grey target theory, calculate the secondary indicators of urban digital finance. The specific steps are as follows: (1) Establish an influence space. That is to determine the evaluation objects and evaluation indicators. The evaluation objects of this report are 278 cities at the prefecture level and above in China, and the evaluation indicators are all the indicators in Table 1. (2) Establish an index sequence. That is, the data sequence of evaluation objects and evaluation indicators is obtained in chronological order. The time span studied in this report is from 2010 to 2020. (3) Establish a standard model. That is, to determine whether the indicator is a positive indicator, a negative indicator or a moderate indicator. The indicators for measuring digital finance in this paper are all positive indicators, so they have the polarity of the maximum value, and the maximum value of each indicator sequence is selected as the standard. (4) Perform gray target conversion. That is, the index data is compared with the standard value, and the pattern sequence after the polarity change is obtained. (5) Establish grey

relational difference information space. That is to calculate the information difference between the corresponding elements of the gray target converted pattern sequence and the standard pattern sequence. (6) Calculate the bullseye degree. That is, according to the principle of least information, calculate the bullseye degree of each indicator.

Then, the weight of the first-level indicators of urban digital finance is calculated based on the analytic hierarchy process. Analytic Hierarchy Process (AHP) first places the target object to be analyzed in a large system. There are many factors influencing each other in this system. These problems should be layered to form a multi-layer analysis structure model. Among them, the target layer is the core issue studied in this report, that is, the evaluation index system of urban digital finance; the element layer includes three dimensions that constitute urban digital finance, namely digital financial services, digital financial technology, and digital financial operating environment; the indicator layer is to reflect a representative basic indicator of urban digital finance.

When determining the weight of each indicator, it is necessary to sort the importance of each indicator relative to the indicator to which it belongs, and determine the importance scale value. Due to the strong subjectivity in the process of sorting and determining the importance scale value, the sorting and the importance scale value should be determined according to the suggestions of scholars and experts. This report solicited the opinions of many experts in the economic and financial industry to rank the importance of each indicator, and received valid opinions from 50 experts in total. The weight of each indicator determined by different experts is obtained by using the AHP, and then the final weight of each indicator is determined by arithmetic average of the weight determined by each expert. Since various experts have different rankings of the importance of different indicators, this report does not describe the weight calculation process, but only lists the final weights of each indicator. The weight of digital financial services is 0.464, the weight of digital financial technology is 0.305, and the weight of digital financial environment is 0.231.

3. Overall characteristics of urban digital finance

3.1. The development trend of urban digital finance

The overall results of China's urban digital finance index are shown in Figure 1. The mean of the urban digital finance index has risen from 103.65 in 2010 to 106.24 in 2020, with an average annual growth rate of 0.25%. The median of urban digital finance index has risen from 102.99 in 2010 to 104.16 in 2020, with an average annual growth rate of 0.11%. China's urban digital finance has achieved steady growth from 2010 to 2020. The mean value of urban digital finance is significantly larger than the median, and the gap is gradually widening. The development of urban digital finance is concentrated in developed cities. In 2020, all aspects of China's economy and society have been severely impacted by the COVID-19. The economic growth rate has dropped significantly compared with previous years, but the urban digital finance index still increased by 0.28% compared with 2019. From the above, we can see the steady development trend of urban digital finance. Please see Supplementary file for detailed results.

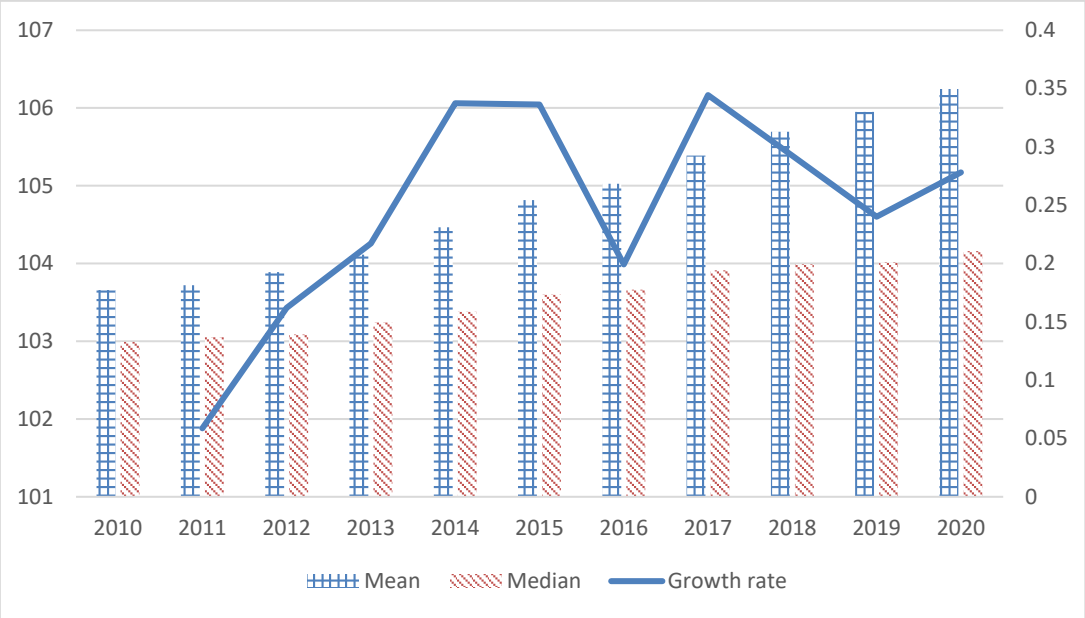

Figure 1. China's urban digital finance index.

Due to the large number of city samples included in this paper, it is difficult to analyze all cities one by one. Therefore, the analysis of urban digital finance is mainly analyzed from the perspective of 35 major cities in China. Major cities include: municipalities directly under the Central Government, provincial capitals and cities under separate state planning, excluding Hong Kong, Macao and Taiwan.

Table 2 shows the digital finance index of 35 major cities in China. Through the urban digital finance index in major cities, we can see that there are obvious regional differences in the development of urban digital finance. The urban digital finance index of Beijing, Shanghai, Shenzhen and Gauangzhou have been much higher than other cities, and have grown significantly. Especially in Beijing, the digital finance index increased from 132.75 to 214.94, making it the only city that exceeded 200. The digital finance level of eastern coastal cities is significantly higher than other cities. This shows that the regional imbalance in the development of urban digital finance in China is significant.

Table 2. Urban digital finance index of major cities.

Major cities	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Beijing	132.75	128.88	134.54	139.77	156.10	169.71	179.92	176.47	184.69	201.06	214.97
Shanghai	129.43	126.48	129.31	137.28	141.66	144.29	148.22	153.40	162.74	173.85	178.02
Shenzhen	126.54	118.27	121.13	123.51	128.75	128.67	135.47	141.25	155.14	161.43	167.07
Guangzhou	110.49	112.22	114.38	116.54	117.93	119.63	120.42	124.75	131.49	136.35	142.42
Chongqing	107.73	108.83	110.25	111.48	113.03	115.28	116.31	118.80	122.66	124.86	125.80
Hangzhou	107.82	108.81	109.57	110.62	112.49	114.45	116.40	119.26	121.16	123.14	124.83
Chengdu	109.24	108.39	109.15	110.48	111.76	114.96	116.92	119.37	119.96	119.82	120.58
Tianjin	109.96	108.73	109.35	110.29	110.87	113.83	116.83	118.23	117.86	117.52	117.36
Wuhan	106.43	107.00	107.89	108.87	110.08	111.71	112.13	114.25	114.88	116.07	115.49
Nanjing	106.03	106.75	107.42	108.75	109.94	110.61	111.50	113.86	115.36	115.90	115.33
Xiamen	105.79	105.65	105.88	106.40	107.09	107.66	108.24	109.54	111.46	113.28	114.84
Xi’an	106.74	107.11	107.97	109.85	109.86	109.92	110.75	112.69	112.83	114.16	113.22
Hefei	104.32	104.98	104.82	105.33	106.36	106.90	108.43	110.20	110.13	110.62	113.17
Changsha	105.15	105.47	105.85	106.42	107.18	107.83	108.40	110.27	110.66	110.59	112.35
Zhengzhou	105.11	105.37	105.79	106.43	107.75	108.86	109.51	110.41	111.37	111.33	111.80
Ningbo	106.85	106.87	107.15	107.87	108.62	109.21	110.06	111.03	111.55	112.15	111.66
Qingdao	105.01	105.42	105.79	106.99	110.05	109.00	109.02	109.45	109.97	111.01	111.29
Jinan	105.08	105.38	105.66	106.55	107.43	108.25	108.69	109.44	110.41	110.27	111.05
Fuzhou	106.00	105.40	105.59	106.07	107.02	107.27	107.86	108.86	110.36	109.97	110.06
Shijiazhuang	104.31	104.58	104.86	105.28	106.14	106.55	106.73	107.40	108.08	108.20	108.99
Shenyang	105.16	105.48	105.84	106.19	106.81	107.74	108.33	108.09	108.46	109.18	108.73
Changchun	104.17	104.35	104.72	105.09	105.59	106.08	107.00	107.27	106.96	108.07	108.51
Nanning	103.79	104.56	104.81	104.70	105.27	105.76	106.27	106.82	106.88	107.19	108.50
Guiyang	103.94	104.08	104.54	105.23	106.87	114.59	115.33	108.77	110.73	108.30	108.29
Harbin	105.00	105.72	105.29	106.34	106.76	106.95	107.01	107.53	107.08	107.91	108.13
Nanchang	103.94	104.04	104.09	104.61	105.07	105.38	105.85	106.96	106.96	107.47	108.10
Kunming	104.65	104.54	104.81	105.27	105.85	106.22	106.57	107.04	107.36	107.93	107.67
Dalian	105.00	105.59	105.85	106.33	106.40	106.50	106.92	107.26	107.84	107.84	107.66
Taiyuan	104.05	104.41	104.53	105.05	105.55	105.56	105.73	106.40	106.87	107.45	107.33
Hohhot	103.45	103.34	104.07	104.17	104.20	104.58	105.08	104.73	105.26	105.92	105.88
Urumqi	103.83	104.34	104.23	104.52	105.00	105.18	105.34	105.52	105.89	107.50	105.81
Xining	103.33	103.19	103.30	103.44	103.66	103.92	104.07	104.27	104.95	105.31	105.74
Haikou	103.88	103.62	103.66	103.84	104.35	104.64	104.80	105.26	105.16	105.14	105.69
Lanzhou	103.39	103.51	103.48	103.97	104.51	104.37	104.83	104.89	105.19	105.25	105.68
Yinchuan	103.26	103.40	103.56	104.01	104.77	104.68	104.78	104.96	104.94	105.13	104.42

3.2. The development trend of urban digital finance sub-index

In order to further illustrate the source of changes in urban digital finance, this part analyzes the development trend of urban digital finance sub-index. The overall results of China’s urban digital financial services index are shown in Figure 2. The mean of the urban digital financial services index has risen from 104.06 in 2010 to 106.23 in 2020, with an average annual growth rate of 0.21%. The

median of urban digital financial services index has risen from 103.42 in 2010 to 104.13 in 2020, with an average annual growth rate of 0.07%. The mean value of urban digital finance services is significantly larger than the median, and the gap is gradually widening. From 2011 to 2017, the urban digital financial services index achieved steady growth, and the growth rate continued to increase. Growth rate in urban digital financial services saw a sharp drop due to frequent occurrence of net loan platform in China Peer to-Peer risks in 2018.

In 2020, China is facing the severe impact of the sudden COVID-19, and the service industry has been hit hard. The average growth rate of the urban digital financial service index has dropped from 0.54% in 2019 to 0.49% in 2020, showing a small decline in growth rate. The median growth rate of the financial services index increased from 0.09% in 2019 to 0.19% in 2020, and the median urban digital financial index still maintained a positive growth, showing the unique advantages and strong resilience of digital financial service.

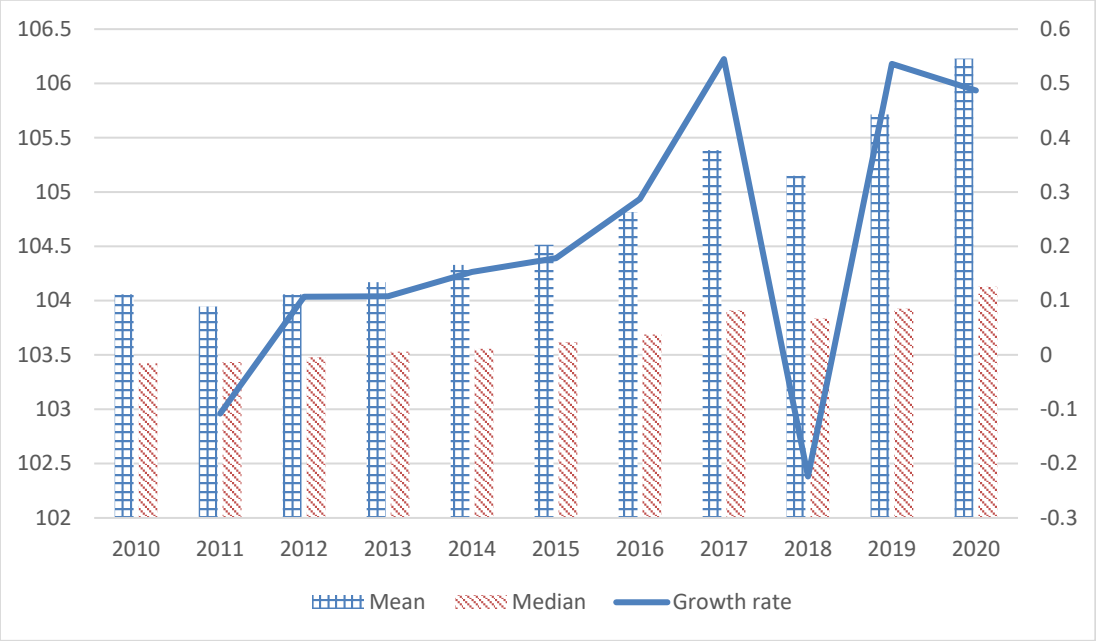

Figure 2. China's urban digital financial services index.

The overall results of China's urban digital financial technology index are shown in Figure 3. The mean of the urban digital financial technology index has risen from 103.92 in 2010 to 105.49 in 2020, with an average annual growth rate of 0.15%. The median of urban digital financial technology index has risen from 103.48 in 2010 to 103.72 in 2020, with an average annual growth rate of 0.03%. The urban digital financial technology index maintained a steady growth trend, although the growth rate was small. From the perspective of growth rate changes, the growth rate of the urban digital financial technology index fluctuated greatly, showing an inverted "U" shape distribution, which decreased to −0.09% in 2020. This is mainly due to the synergistic effect of the reduction of R&D expenditure and the reduction of the number of invention patents. The median of urban digital financial technology index barely changed, indicating to a certain extent that digital financial technology in most cities has not received much attention.

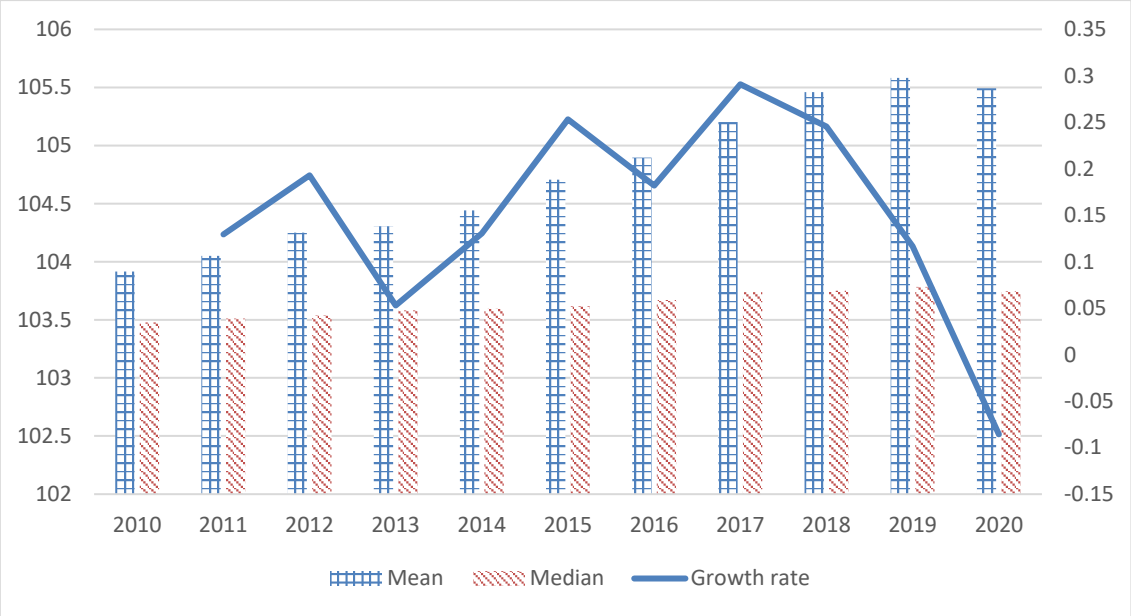

Figure 3. China's urban digital financial technology index.

The overall results of China's urban digital financial environment index are shown in Figure 4. The mean of the urban digital financial environment index has risen from 102.52 in 2010 to 107.26 in 2020, with an average annual growth rate of 0.45%. The median of urban digital financial environment index has risen from 101.45 in 2010 to 104.70 in 2020, with an average annual growth rate of 0.32%. The urban digital financial environment index maintained a steady growth trend, and the increase was obvious. In 2019, the urban digital financial environment index showed the only negative growth, which was mainly due to the decline in the attention of digital finance.

In terms of sub-indices, the urban digital financial environment index grew the fastest, followed by urban digital financial services, and urban digital financial technology grew the slowest. In the 11 years from 2010 to 2020, the growth rate of the environment index exceeded that of the service and technology indexes for 8 years. The digital financial operating environment has become an important driving force for the growth of the urban digital financial index. As the environment of digital finance reach a certain level, there is limited room for further expansion, the digital finance services and technology is an important driving force for the growth of the urban digital finance index.

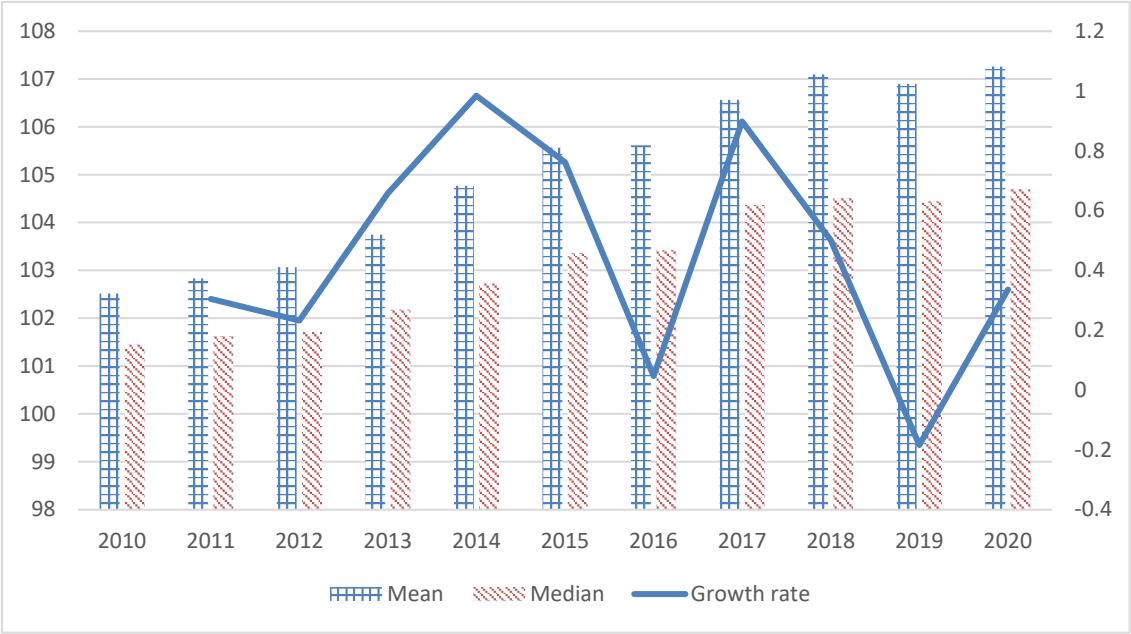

Figure 4. China's urban digital financial environment index.

4. Spatial characteristics of urban digital finance

4.1. Convergence of urban digital finance

Table 3 reports descriptive statistics for urban digital finance. In 2010, the minimum value of urban digital finance is 102.42, the maximum value is 132.75 and the average value is 103.66. In 2020, the minimum value of urban digital finance is 102.73, the maximum value is 214.94 and the average value is 106.24. The standard deviation of urban digital finance continued to rise from 2.97 to 9.58, and the range of urban digital finance continued to expand from 30.33 to 112.24. This shows that the differences in urban digital finance are expanding.

The mean value of urban digital finance is closer to the minimum value. This is mainly due to the fact that the development of digital finance in some cities is much higher than that in other cities. The urban digital finance index of Beijing, Shanghai, Shenzhen and Guangzhou is much higher than other cities, and the growth is obvious. Especially in Beijing, the digital finance index rose from 132.75 to 214.97, making it the only city with more than 200. The digital finance level of eastern coastal cities is significantly higher than other cities.

Table 3. Descriptive statistics for urban digital finance.

Year	Mean	Median	Std. Dev.	Max	Min
2010	103.66	102.99	2.97	132.75	102.42
2011	103.72	103.05	2.58	128.88	102.46
2012	103.89	103.09	3.09	134.54	102.47
2013	104.11	103.24	3.60	139.77	102.53
2014	104.46	103.38	4.56	156.10	102.55
2015	104.82	103.60	5.35	169.71	102.60
2016	105.02	103.66	6.10	179.92	102.55
2017	105.39	103.91	6.33	176.47	102.65
2018	105.69	103.99	7.39	184.69	102.74
2019	105.95	104.01	8.61	201.06	102.72
2020	106.24	104.16	9.58	214.97	102.73

We use the convergence analysis method of regional economics to analyze the differences in the development of urban digital finance (Barro and Sala-i-Martin, 1992; Sala-i-Martin, 1996). σ convergence can reflect the deviation of urban digital finance from the overall average level and the dynamic process of this difference. If this difference becomes smaller and smaller, it can be considered that urban digital finance has convergence. Specifically, the σ convergence model can be defined as Equation (1).

$$\sigma_t = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\ln index_{it} - \frac{1}{n}\sum_{i=1}^{n}\ln index_{it}\right)^2} \tag{1}$$

where i is the city, n is the number of cities, t is the year, lnindex is the logarithm value of the urban digital financial index in the i city in year t, and the σ_t is the convergence coefficient of the urban digital financial index in year t. If $\sigma_t < \sigma_{t-1}$, it can be considered that the urban digital finance in year t is more convergent than in year t.

Figure 5 presents the σ convergence coefficient of the urban digital financial. The urban digital finance index and its sub-indices have maintained a continuous upward trend, which shows that the differences in the development of urban digital finance are gradually expanding.

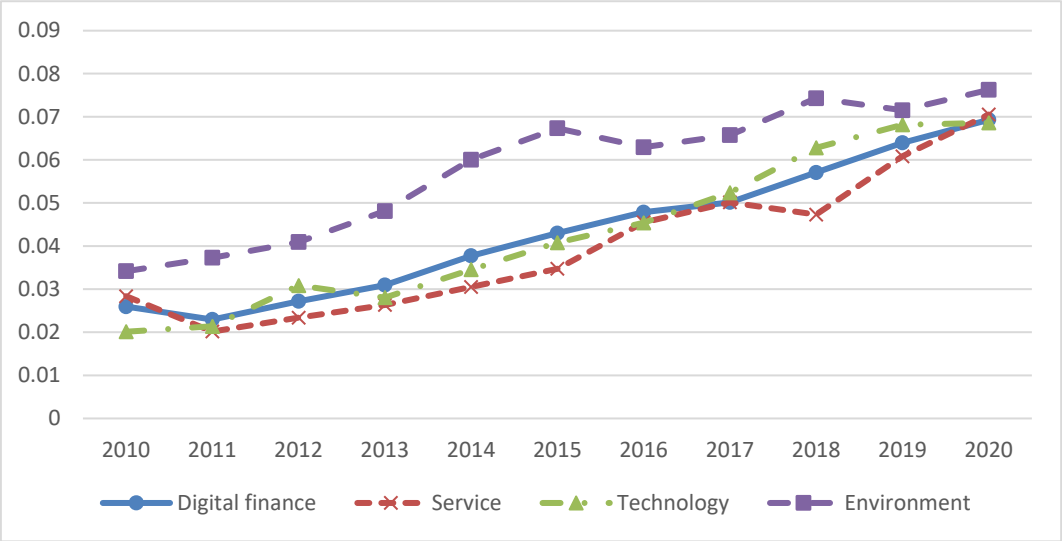

Figure 5. Convergence coefficient of urban digital finance.

4.2. The spatial agglomeration of urban digital finance

The Moran index can effectively test the spatial agglomeration of urban digital finance. Generally speaking, the normalized value range of Moran index is between −1 and 1. When the index is greater than 0, it means that there is a positive spatial correlation in urban digital finance, and the development of urban digital finance between adjacent regions tends to be homogeneity. Cities with a high level of digital finance development are clustered together, and cities with a low level of development are clustered together. The larger the Moran index, the stronger the positive correlation of the spatial distribution and the stronger the intensity of the agglomeration. When the Moran index is less than 0, it means that there is a negative spatial correlation in the regional digital finance; when the Moran index is equal to 0, it means that the regional digital finance presents spatial randomness. The use of the local Moran index can further examine the spatial dependence of digital finance in specific regions, and the spatial relationship pattern between regions is depicted through the local Moran index scatter plot, including the cluster pattern of four quadrants. The first quadrant is High-High agglomeration, which means that the digital finance level of the city and neighboring cities is relatively high; the second quadrant is Low-High agglomeration, which means that the digital finance level of the city is low and the level of neighboring cities is high; the third quadrant It is a low-low agglomeration, indicating that the digital finance level of the city and neighboring cities is relatively low; the fourth quadrant is a high-low agglomeration, which means that the digital finance level of the city is high and the level of neighboring cities is low.

Table 4. Moran index of urban digital finance.

Year	Index	Service	Environment	Technology
2010	0.049***	0.023***	0.018***	0.074***
2011	0.048***	0.029***	0.010***	0.068***
2012	0.038***	0.030***	0.005***	0.068***
2013	0.045***	0.032***	0.036***	0.060***
2014	0.050***	0.031***	0.050***	0.061***
2015	0.036***	0.022***	0.042***	0.041***
2016	0.033***	0.026***	0.052***	0.026***
2017	0.040***	0.026***	0.054***	0.042***
2018	0.037***	0.026***	0.053***	0.037***
2019	0.031***	0.027***	0.037***	0.028***
2020	0.037***	0.028***	0.037***	0.039***

Table 4 shows the global Moran index of China's urban digital finance index from 2010 to 2020. In terms of significance, the Moran index of China's urban digital finance is positive and significant at the 1% level, which means that China's urban digital finance development There is a positive spatial correlation, indicating that China's urban digital finance has agglomeration in the global space. From the overall trend, the Moran index of China's urban digital finance fluctuates to a certain extent, showing a downward trend, while the technology's Moran index shows an upward trend. This shows that the spatial correlation of China's urban digital finance is a complex and constantly changing process.

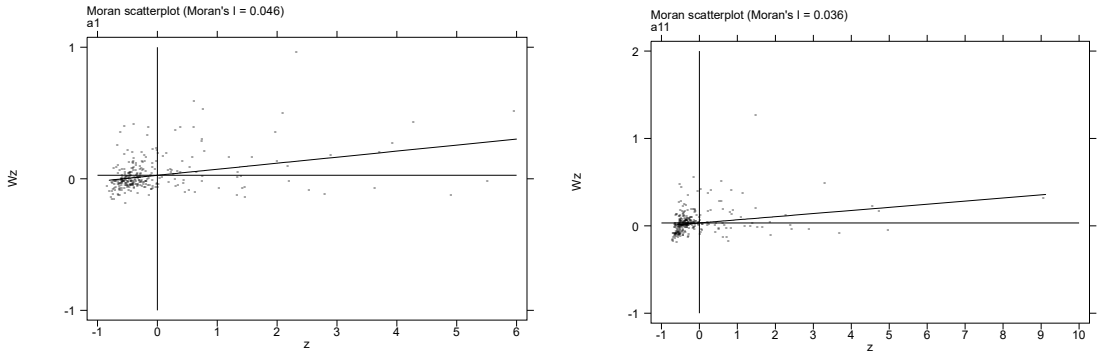

Figure 6. Local Moran index scatter plot of the city digital finance in 2010 and 2020.

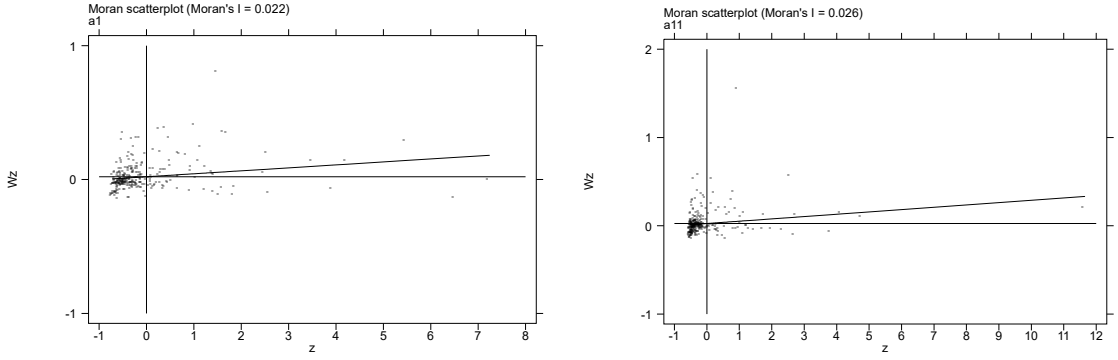

Figure 7. The scatter plot of the local Moran index of the urban digital service in 2010 and 2020.

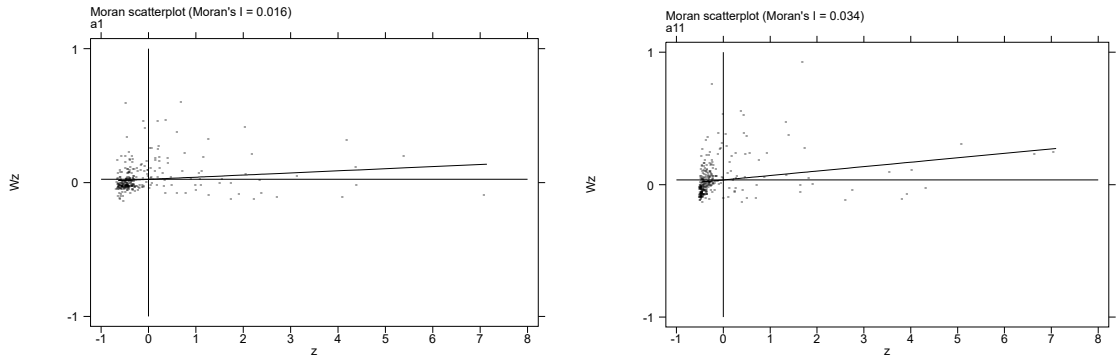

Figure 8. Scatter plot of local Moran index of urban digital technology in 2010 and 2020.

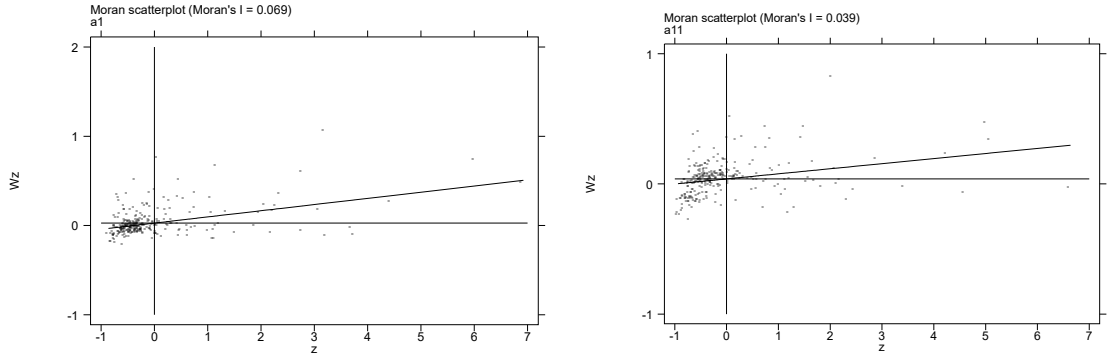

Figure 9. Scatter plot of local Moran index of urban digital environment in 2010 and 2020.

This paper uses the local Moran index to examine the differences between sample cities and neighboring cities, and further analyze the spatial agglomeration pattern of digital finance. Figures 6 to 9 show that the scatter plot of local Moran index of urban digital finance. Whether it is digital finance, digital finance service, digital finance environment or digital finance technology, most cities are distributed in the first and third quadrants, some cities are in the second quadrant, and a few are in the fourth quadrant. The first and third quadrants mean that the development of urban digital finance is homogeneous. The economic development foundation and technical level of the eastern coastal cities are relatively high, so the digital finance development of the city itself and surrounding cities is in a stage of rapid development. Due to the lack of economic strength and other factors in the region, the digital financial development of the city itself and surrounding cities is struggling to catch up. The third and fourth quadrants indicate that there are differences in the development of urban digital finance, so the development of urban digital finance extremely prone to spillover effects. The positive spillover effect is conducive to the improvement of the level of digital finance development in surrounding cities.

5. Conclusions

The objective of this paper is to measure urban digital finance for 278 cities in mainland China, over the period 2010 to 2020.First, we compiled the digital financial index from the three dimensions of digital financial services, digital financial technology, and digital financial operating environment. Then, we use the dynamic evaluation method based on grey target to evaluate the level of each indicator,

and use the analytic hierarchy process to measure the weight of each dimension. Finally, we analyze the overall and spatial characteristics of urban digital finance. The main conclusions drawn from this analysis are as follows.

First, China's urban digital finance has been on an upward trend from 2010 to 2020. The mean of the urban digital finance index has risen from 103.65 in 2010 to 106.24 in 2020, with an average annual growth rate of 0.25%. Among them, the urban digital finance indices of Beijing, Shanghai, Shenzhen and Guangzhou have been much higher than other cities, and have grown significantly.

Second, the digital finance operating environment is an important driving force for the growth of the urban digital finance index. The mean of the digital finance operating environment index has risen from 102.52 in 2010 to 107.26 in 2020, and the growth rate is significantly greater than other dimensions of digital finance. The digital finance services and technology is an important driving force for the growth of the urban digital finance index.

Third, the convergence of China's urban digital finance is decreasing, indicating that the gap in digital financial development between cities is increasing. The convergence coefficient of urban digital finance has risen from 0.026 in 2010 to 0.069 in 2020. This is mainly due to the fact that the development of digital finance in developed cities is significantly better than that of other cities, expanding the differences between cities.

Fourth, urban digital finance has positive spatial agglomeration, but this spatial agglomeration is decreasing. From the scatter plot of the local Moran index, most cities are distributed in the first and third quadrants, indicating that the development of urban digital finance is homogeneous.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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