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Research on the Evolution of the Spatial Structure of the Digital Economy and the Influencing Factors of the Guanzhong Plain Urban Agglomeration

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Abstract

Digital economy is a key force to promote the high-quality development of Guanzhong Plain Urban Agglomeration. Based on the digital economy development indexes of 11 cities in the Guanzhong Plain city cluster in 2012, 2016 and 2020, this study applies the modified gravity model to measure the degree of spatial connectivity within the city cluster and analyzes the network spatial structure of the digital economy in the Guanzhong Plain from the perspectives of centrality, linkage intensity and linkage density by combining the social network analysis method. Finally, this study conducts QAP empirical research on the impacts of the digital economy in 2020. The results found that: the digital economy network structure of Guanzhong Plain is stable, and the cities of Xi'an and Baoji have a stronger digital economy radiation effect; the cohesive subgroups have a poor clustering effect; the city GDP, scientific and technological innovation, and the strength of governmental support are the important factors influencing the spatial structure of the digital economy of the Guanzhong Plain Urban Agglomeration.

Keywords

Guanzhong Plain Urban Agglomeration, Digital Economy, Spatial Structure

1. Introduction

As special economic functional entities, urban agglomerations have become the main spatial form for carrying natural resources, labor, technology and other development factors. The report on the 20th National Congress of the Commun-

ist proposes to build a pattern of coordinated urban development and to promote urbanization using urban agglomerations and metropolitan areas as carriers. Located in western China, Guanzhong Plain Urban Agglomeration is an important bridge linking the southern and northern regions, and also an important hub extending the development of the western region to the east. As a key node of the New Eurasian Land Bridge, it is also a spatial carrier for the construction of the "Belt and Road". The Guanzhong Plain Urban Agglomeration Development Plan issued by the National Development and Reform Commission and the Ministry of Housing and Urban-Rural Development in 2018, includes the Guanzhong Plain Urban Agglomeration as a key development target of national-level urban agglomerations, clarifies the geographical boundaries of the urban agglomeration and its future development direction, sets a national-level urban agglomeration with a vibrant economy and international influence as a future development goal, and provides the overall planning guidance for the development of its economic spatial structure. While digitalization is a new feature of the development and progress of human society today, the digital economy has also become a key area of the new round of international competition. As the main economic form to promote China's economic development, the digital economy is transforming China's mode of production and life, advancing the profound change of national governance capacity, and becoming an important driving force for China to reshape its factor resources and promote the high-quality development of the economy.

The report clearly pointed out that it is necessary to accelerate the construction of digital China, accelerate the development of the digital economy, promote the deep integration of the digital economy and the real economy, and create internationally competitive digital industry clusters. Compared with the three major mature urban agglomerations in China, such as the Yangtze River Delta Urban Agglomeration and the Pearl River Delta Urban Agglomeration, the Guanzhong Plain Urban Agglomeration started late in its construction, and the overall development of the digital economy is relatively decentralized and slow, and there exists a certain digital divide with other urban agglomerations.

Based on this, this paper takes Guanzhong Plain Urban Agglomeration as the research object, uses modified gravity model and social network analysis to study the evolution characteristics of the network space structure of digital economy in Guanzhong Plain Urban Agglomeration, and analyzes the influencing factors affecting the development of digital economy in Guanzhong Plain with the aid of Quadratic Assignment Procedure (QAP) method, which can help to better understand the development of Guanzhong Plain Urban Agglomeration and provide scientific basis for the promotion of the deep development of the northwestern region as well as the construction of a new pattern for the development of digital economy. It will help to better understand the development situation of Guanzhong Plain Urban Agglomeration and provide scientific basis for promoting the deep development of Northwest China and building a new pattern of

digital economy.

2. Literature Review

As early as the 1990s, the concept of "digital economy" was formally put forward by the "father of the digital economy" Don Tapscott. In the digital economy: the prospects and risks of the era of network intelligence (1996), he detailed elaborated the connection between the Internet and the economy and society, so the digital economy was first understood as the information economy, and also laid the theoretical foundation for the subsequent development of the digital economy. The 11th G20 Summit provided a more comprehensive definition of the digital economy, identifying the digital economy as the effectiveness of the use of information and communication technology with digitized knowledge and information resources as the key elements, and with modern information networks as the important carrier as a series of economic activities that serve as an important driving force for efficiency and structural optimization. Digital economy is not just a single application of network technology and data and information resources, but a new economic form after the agricultural economy and industrial economy. Zhang Xueling and Wu Tiantian (2019) defined the digital economy on this basis as the realization of the digitalization of production and life consumption, organizational cooperation and communication and social governance.

In recent years, scholars have produced a wealth of research on the digital economy and the structure of cyberspace. First of all, at the regional level, Shen Yuliang et al. (2022) compared the trade rule claims of China, the United States and Europe from an international perspective, and found that China has stronger advantages in the field of data service trade, but lacks leading multinationals in high-end industries; and from the regional perspective in China, Yang Wenpu (2021) analyzed the role of the digital economy on the development of the regional economy through the panel threshold model, and found that the digital economy can promote the formation of economies of scale and economies of scope effects Wang Juanjuan (2023) analyzes the development of the "dualization" of China's regional digital economy, and finds that industrial digitization will further widen the regional development gap, and the western region lags behind in the development of dualization, and puts forward measures to enhance the digital economy of the western underdeveloped regions. Xu Hao (2021) analyzed the spatial network layout of China's digital economy from a macro perspective and found that a region's innovation, human capital level, Internet penetration, big data construction, digital industrialization, and industrial digitization factors all have a positive impact on the development of the local digital economy. It proposes measures to enhance the digital economy in the less developed regions in the west.

Secondly, in the provincial level research, Zhang Xueling and Wu Tiantian (2019) established a digital economy indicator system with three dimensions and

analyzed the pattern of digital economy differentiation from the provincial perspective, and put forward corresponding suggestions for regions with different levels of development. Liu Gang and Zhang Xinwei (2019) focus on less developed regions and analyze the value network of 45 data enterprises in Guizhou Province, and believe that the development of domestic data industry is still in the initial stage, and opening up application scenarios, building data platforms, and developing and applying data are the main conditions for the development of data industry. Li et al. (2022) used gray correlation, coupling coordination and spatial correlation network to explore the changing relationship between the digital economy and the real economy, and concluded that there is a high level of synergistic consistency between the two in most regions.

Finally, at the municipal level, Deng Huihui et al. (2022) conducted a study on China's digital technology city network from the perspective of enterprises, and put forward targeted suggestions for the construction of networked urban agglomerations. Xu Weixiang et al. (2021) analyzed the comprehensive level of high-quality development of digital economy and urbanization in Chinese cities from multiple perspectives by using gravity model and modal analysis, and found that the spatial pattern of the digital economy is obviously characterized by spatial proximity, and has not yet formed a hierarchical community structure. Dai Ruochen et al. (2022) measured and compared the digital innovation capability of enterprises, and found that the synergistic development of neighboring cities is the main factor to shorten the difference between the digital industries in the north and south regions.

Regarding the research on the evolution of the spatial structure of digital economy in urban agglomerations, Zhong Yexi and Mao Weisheng et al. (2020) explored the differences and spatial distribution characteristics of the digital economy in the Yangtze River Economic Belt by using global spatial autocorrelation and geographically weighted regression at the city scale, and found that the level of informatization, city grade, and industrial structure significantly improved the level of digital economy development in the Yangtze River Economic Belt. Liu et al. (2020) compared the gap of digital economy development in five major city groups, and found that there is polarization in China's digital economy by using Kernel kernel density analysis and Markov chain analysis. Hu Yan et al. (2022) analyzed the digital economy network structure of Yangtze River Delta from the municipal level and found that the level of city economic development, the level of informatization, and the proximity of cities are important factors affecting the structure of their networks. Lian Ganghui et al. (2022) looked at 19 national-level urban agglomerations and found that the development trend of their digital economy ranges from weak to strong, with obvious regional heterogeneity and convergence within the urban agglomerations, and argued that synergistic development can be realized among urban agglomerations by breaking down internal barriers through the market-oriented application of modern information technology.

On the one hand, scholars at home and abroad have carried out a lot of research on the network structure of digital economy from a spatial perspective, but the starting point of the research mostly lies in the enterprises; on the other hand, with the implementation of the construction of the "One Belt, One Road" master plan, the development of digital economy in the central and western regions of China has gradually come into the focus of the vision, but the economic imbalance and slow pace of development of the region have highlighted the problem of regional heterogeneity. However, the economic imbalance in the region is obvious and the development growth rate is slow, digital elements need to circulate rapidly to promote the optimization of industrial structure, and there is an urgent need to accelerate the coordinated development of the regional economy by digital means, but there are few studies in the literature that take the Guanzhong Plain Urban Agglomeration as the object of research to explore the evolution of its spatial structure of the digital economy and its influencing factors. At present, the development status and future trend of digital economy have been emphasized, and the advantages of digital economy development with urban agglomeration as the carrier are more obvious, therefore, this study will focus on the contact network and spatial structure evolution of digital economy in Guanzhong Plain Urban Agglomeration, and on this basis, deeply explore the key elements affecting the development of digital economy in this urban agglomeration, so as to help understand the spatial effect of digital economy. At the same time, it will provide a theoretical basis and decision-making foundation for the Guanzhong Plain Urban Agglomeration to formulate and promote the coordinated development of the digital economy.

3. Research Design and Data Sources

3.1. Indicator Design

Referring to the design of digital economy indicators from related studies and combining with the Statistical Classification of the Digital Economy and its Core Industries issued by the National Bureau of Statistics of China in 2021, the digital economy indicator system of this study is established, and the indicators are measured in five dimensions, namely, digital product manufacturing, digital technology application, digital product service, digital factor driving and digital efficiency enhancement, and the entropy method is utilized and referred to the Wu Jingfei and Wang Xiaoyue (2022). The weight calculation method is used to measure the indicators, and the measurement results are shown in **Table 1**.

3.2. Research Methodology

3.2.1. Modified Gravity Model

Gravity model is widely used in the study of spatial role capacity, and this paper introduces the gravity model to study the degree of spatial connection of digital economy in cities within Guanzhong Plain Urban Agglomeration. Referring to the relevant studies of Hu Yan et al. (2022) and Yu Haihua (2021), the modified

Table 1. Measurement of digital economy in Guanzhong Plain Urban Agglomeration.

Goal	Tier 1 indicators	Tier 2 indicators	Tier 3 indicators	Weights (%)
Level of development of the digital economy	digital industrialization	Manufacturing of digital products	X1 Gross output value of electronic information industry (100 million yuan)	6.92
			X2 Main business income of electronic and communication equipment manufacturing industry (10,000 yuan)	7.76
		Application of digital technology	X3 Revenue from telecommunication services (10,000 yuan)	5.94
			X4 Number of cell phone subscribers at the end of the year (10,000 yuan)	2.69
			X5 Number of Internet broadband access subscribers (10,000 yuan)	2.85
		Digital Product Services	X6 Total sales of computer and communications equipment (10,000 yuan)	7.74
			X7 Total sales of electronic and digital publications (10,000 yuan)	8.33
		Driven by digital elements	X8 Computer, communication system employees (person)	8.35
			X9 Expenditures on internal funding for R&D (10,000 yuan)	8.42
			X10 Number of patents granted (pcs)	9.04
	Industrial digitization	Digital Efficiency Improvement	X11 Value added of agriculture, forestry, animal husbandry and fishery (10,000 yuan)	1.30
			X12 Volume of express delivery business (10,000 pcs)	8.23
			X13 Investment in fixed assets for digital economy infrastructure (10,000 yuan)	2.21
			X14 Expenditures on science and technology (10,000 yuan)	6.80
			X15 Number of higher education graduates (person)	9.39
			X16 Number of persons employed at the end of the period in urban units (person)	4.03

results of the gravity model are as follows:

$$\begin{cases} R_{m,n} = k_{m,n} \dfrac{\sqrt[3]{POP_m GDP_m DE_m}\sqrt[3]{POP_n GDP_n DE_n}}{D_{m,n}^2} \\ k_{m,n} = \dfrac{DE_m}{DE_m + DE_n} \\ D_{m,n} = \dfrac{d_{m,n}}{g_m - g_n} \end{cases} \quad (1)$$

In Equation (1), $R_{m,n}$ denotes the strength of the linkage between the digital economy of city m and city n, POP_m and POP_n are the urban resident population of city m and city n; GDP_m and GDP_n denote the total amount of economic development of city m and city n, and DE_m and DE_n represent the level of the digital economic development of city m and city n; $k_{m,n}$ denotes the digital economic development role coefficient, $d_{m,n}$ denotes the geographical distance between city

m and city n; g_m, g_n denote the per capita GDP of city m and city n respectively; $D_{m,n}$ denotes the economic distance between city m and city n.

3.2.2. Social Network Analysis

The social network analysis method is to quantitatively analyze the node relationship data in the social network system from the network perspective, focusing on the importance of the nodes themselves and the node associations, and mining the essential features contained therein according to the formed network relationship patterns and data results. In this paper, we use Ucinet and other software to study the possible network relationships of digital economic development in Guanzhong Plain, and analyze the digital economic connections and network structure evolution of the urban agglomeration as a whole and the cities within it from multiple perspectives in terms of individual centrality, network connectedness, network strength and cohesive subgroups.

Individual centrality analysis. Individual centrality is used to measure the importance of the digital economy development of a city node in the urban agglomeration, which is an indicator of the centrality of a node in the overall network. The analysis of individual centrality includes measures such as point degree centrality, between centrality, and closeness centrality. Among them, point degree centrality represents the number of connections between a city's digital economy and other city nodes in the city network, including two directional indicators, point in-degree and point out-degree. Between centrality is used to describe the extent to which a node city in the city network is located in the shortest connection path of the other two node cities. The higher the value of intermediary centrality is, the stronger the control ability of the city node is. Closeness centrality is used to measure the shortest path distance between a city node and the digital economy connections generated by other cities in the city network. The shorter the distance is, the stronger the digital economy connectivity of the city node is proved to be.

Network connectedness analysis. It systematically measures the closeness of urban digital economy network's connection, affiliation, structural grade, node influence, network stability, etc. through the indicators of network's density, connectedness, hierarchy, and network efficiency, reflecting the indicators of sparseness of urban connection in the network structure system.

Network strength analysis. Network strength refers to the size of the amount of digital economic connections between cities in the city network, the greater the network connection strength, proving that the greater the frequency of connections between city nodes, the higher the quality of connections.

Cohesive subgroup analysis. Cohesive subgroup is a sub-set formed by clustering the node cities with relatively strong connections and closer relationships in the city network, which is to analyze the characteristics of subgroups within the network through different layering methods, and to conduct in-depth investigation of the characteristics of subgroups and the evolution of the relationships

between subgroups within the digital economy of urban agglomerations.

3.2.3. QAP Analysis

Quadratic Assignment Procedure (QAP) analysis an analytical method of randomization test based on resampling and non-parametric test of coefficients based on matrix data replacement (Liu et al., 2019). QAP analysis includes correlation test and QAP regression analysis, which examines the correlation between the matrices and the regression relationship between the dependent variable matrix and the independent variable matrix, respectively. Compared with the traditional Ordinary Least Square method, QAP analysis is able to perform parameter estimation and statistical tests on matrices that are not independent of each other, and can avoid the bias of regression results due to multicollinearity or autocorrelation of independent variables. This paper adopts the QAP method to study the influencing factors of digital economy in Guanzhong Plain Urban Agglomeration.

3.3. Data Sources

In this study, the three nodes of 2012, 2016 and 2020 are selected as representative years, and data are obtained from 11 cities involved in Shaanxi, Shanxi and Gansu provinces based on the delineated area of the Guanzhong Plain City Cluster Development Plan. The data for the digital economy development indicators are mainly obtained from the China Statistical Yearbook, China Urban Statistical Yearbook, China Science and Technology Statistical Yearbook, and the economic and social statistical bulletins of each city for the years 2013, 2017 and 2021. The data required for the gravity model were obtained from the China Urban Statistical Yearbook. The coordinates of city nodes were obtained using the geographic coordinate system GCS_WGS_1984 and the projected coordinate system WGS_1984_World_Mercator in ArcGIS, and the geographic distances of the cities were obtained from Amap measurements.The results of the model measurements are shown in Table 2 below.

4. Spatial Structural Characteristics of the Digital Economy

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4.1. Analysis of Individual Centrality Degree

The results of digital economy point degree centrality of Guanzhong Plain Urban Agglomeration in 2012, 2016 and 2020 are shown in Table 3, which shows that Xi'an city's digital economy point out degree is high and always keeps the first place in Guanzhong Plain Urban Agglomeration, and as the core city of the

Table 2. Modified gravitational modeling results.

City(i)	City(j)	2012	2016	2020
Baoji	Shangluo	0.62	1.10	3.84
Baoji	Xi'an	1.82	2.62	2.15
Baoji	Tianshui	4.10	10.43	30.10
Baoji	Xianyang	0.35	0.50	4.80
Baoji	Weinan	0.65	2.10	5.71
Baoji	Pingliang	5.34	17.66	43.54
Baoji	Tongchuan	0.05	0.43	0.80
Baoji	Yuncheng	0.33	1.40	3.50
Baoji	Qingyang	0.36	2.03	6.79
Baoji	Linfen	0.04	0.65	1.87
Linfen	Shangluo	0.15	0.00	0.01
Linfen	Xi'an	0.38	1.35	1.70
Linfen	Baoji	0.03	0.42	0.79
Linfen	Tianshui	0.11	0.04	0.11
Linfen	Xianyang	0.00	0.57	0.54
Linfen	Weinan	0.24	0.00	0.01
Linfen	Pingliang	0.11	0.07	0.10
Linfen	Tongchuan	0.00	0.08	0.29
Linfen	Yuncheng	0.79	0.23	0.15
Linfen	Qingyang	0.02	0.00	0.01
Pingliang	Shangluo	0.00	0.06	0.05
Pingliang	Xi'an	0.72	1.83	2.93
Pingliang	Baoji	1.88	6.59	12.73
Pingliang	Tianshui	0.02	0.00	0.03
Pingliang	Xianyang	0.71	3.54	4.13
Pingliang	Weinan	0.03	0.11	0.23
Pingliang	Tongchuan	0.15	0.30	0.81
Pingliang	Yuncheng	0.01	0.02	0.04
Pingliang	Qingyang	0.23	0.33	0.32
Pingliang	Linfen	0.06	0.04	0.07
Qingyang	Shangluo	0.02	0.00	0.00
Qingyang	Xi'an	0.33	0.86	1.70
Qingyang	Baoji	0.15	0.83	2.36
Qingyang	Tianshui	0.13	0.09	0.19

Continued

Qingyang	Xianyang	0.07	0.86	1.37
Qingyang	Weinan	0.01	0.00	0.04
Qingyang	Pingliang	0.27	0.36	0.38
Qingyang	Tongchuan	0.02	0.08	0.48
Qingyang	Yuncheng	0.01	0.01	0.00
Qingyang	Linfen	0.01	0.00	0.01
Shangluo	Xi'an	2.49	5.27	9.26
Shangluo	Baoji	0.26	0.55	1.48
Shangluo	Tianshui	0.01	0.05	0.09
Shangluo	Xianyang	0.30	0.76	1.15
Shangluo	Weinan	0.06	0.00	0.08
Shangluo	Pingliang	0.00	0.08	0.07
Shangluo	Tongchuan	0.12	0.06	0.38
Shangluo	Yuncheng	0.03	0.06	0.00
Shangluo	Qingyang	0.02	0.00	0.00
Shangluo	Linfen	0.10	0.00	0.01
Tianshui	Shangluo	0.01	0.06	0.10
Tianshui	Xi'an	0.91	1.75	3.38
Tianshui	Baoji	2.43	5.74	13.87
Tianshui	Xianyang	0.53	1.57	2.46
Tianshui	Weinan	0.06	0.09	0.30
Tianshui	Pingliang	0.03	0.00	0.04
Tianshui	Tongchuan	0.12	0.15	0.54
Tianshui	Yuncheng	0.03	0.02	0.08
Tianshui	Qingyang	0.18	0.13	0.26
Tianshui	Linfen	0.10	0.04	0.12
Tongchuan	Shangluo	0.11	0.04	0.26
Tongchuan	Xi'an	0.48	0.91	0.95
Tongchuan	Baoji	0.02	0.14	0.21
Tongchuan	Tianshui	0.08	0.09	0.31
Tongchuan	Xianyang	0.00	0.47	0.03
Tongchuan	Weinan	0.37	0.35	1.29
Tongchuan	Pingliang	0.17	0.27	0.72
Tongchuan	Yuncheng	0.08	0.15	0.39
Tongchuan	Qingyang	0.02	0.06	0.36

Continued

Tongchuan	Linfen	0.00	0.04	0.18
Weinan	Shangluo	0.15	0.00	0.15
Weinan	Xi'an	7.36	14.55	21.71
Weinan	Baoji	0.63	1.90	4.09
Weinan	Tianshui	0.10	0.15	0.46
Weinan	Xianyang	1.03	4.71	4.71
Weinan	Pingliang	0.08	0.28	0.55
Weinan	Tongchuan	0.91	0.95	3.53
Weinan	Yuncheng	0.01	0.44	0.60
Weinan	Qingyang	0.02	0.00	0.08
Weinan	Linfen	0.36	0.00	0.02
Xi'an	Shangluo	86.30	157.46	300.14
Xi'an	Baoji	26.35	38.92	26.92
Xi'an	Tianshui	22.29	47.34	91.85
Xi'an	Xianyang	162.56	224.54	385.74
Xi'an	Weinan	109.50	238.18	380.42
Xi'an	Pingliang	29.58	72.90	125.79
Xi'an	Tongchuan	17.29	40.87	45.73
Xi'an	Yuncheng	32.55	84.51	150.88
Xi'an	Qingyang	11.36	31.17	61.37
Xi'an	Linfen	8.53	31.27	50.01
Xianyang	Shangluo	0.87	1.42	2.88
Xianyang	Xi'an	13.83	14.07	29.70
Xianyang	Baoji	0.43	0.46	4.63
Xianyang	Tianshui	1.10	2.66	5.16
Xianyang	Weinan	1.31	4.83	6.35
Xianyang	Pingliang	2.48	8.83	13.65
Xianyang	Tongchuan	0.00	1.32	0.12
Xianyang	Yuncheng	0.43	2.22	3.00
Xianyang	Qingyang	0.20	1.96	3.79
Xianyang	Linfen	0.00	0.83	1.22
Yuncheng	Shangluo	0.05	0.10	0.01
Yuncheng	Xi'an	1.70	4.47	9.95
Yuncheng	Baoji	0.25	1.10	2.90
Yuncheng	Tianshui	0.04	0.02	0.15

Continued

Yuncheng	Xianyang	0.27	1.88	2.57
Yuncheng	Weinan	0.00	0.39	0.69
Yuncheng	Pingliang	0.03	0.04	0.12
Yuncheng	Tongchuan	0.16	0.37	1.24
Yuncheng	Qingyang	0.01	0.02	0.00
Yuncheng	Linfen	0.93	0.28	0.28

Table 3. Guanzhong plain urban agglomeration digital economy degree centrality.

City	2012		2016		2020	
	Out-degree	In-degree	Out-degree	In-degree	Out-degree	In-degree
Xi'an	5	10	8	10	9	10
Baoji	3	3	5	7	8	9
Xi'anyang	2	4	5	8	8	9
Weinan	2	2	3	3	4	4
Shangluo	1	1	3	1	3	3
Tongchuan	1	0	2	0	3	1
Yuncheng	1	1	3	3	3	4
Linfen	1	0	1	1	3	1
Tianshui	3	1	3	3	3	3
Pingliang	3	1	3	3	3	3
Qingyang	1	0	3	0	3	3

cluster, it has a very strong digital economy radiation effect. Baoji and Xi'anyang also ranked in the top three in terms of point out degree, and the radiation-driven effect of the digital economy is gradually increasing. Weinan, Shangluo, Tongchuan, Yuncheng and other cities have a relatively small digital economy point out degree and insufficient radiation capacity.

From the point of view of the degree of entry, Xi'an, Baoji and Xi'anyang are still higher, and the concentration level is stronger; among them, the concentration capacity of Baoji and Xi'anyang was still at the lower middle level in 2012, and the rate of increase was obvious in 2016, which indicates that the concentration capacity of the digital elements of the city has been improving during this period, and it is affected by the influence of the "Twelfth Five-Year Plan" to gradually absorb digital resources from the outside, and accelerate the development of digital economy. The influence of the "12th Five-Year Plan" is gradually absorbing digital resources from the outside and accelerating the development of the digital economy. Weinan, Shangluo, Yuncheng, Tianshui and other cities of the digital economy point of entry continues to grow, but the speed is slower and

the level is lower, unable to form a stable digital resource agglomeration. Looking at the digital economy centrality of the 11 cities, Xi'an, Baoji and Xi'anyang are stable at a high position and the point in-degree is greater than the point out-degree, and the point out-degree is growing steadily over time, with a good foundation for development, abundant human resources and digital infrastructure, and the new pillar industries are supported by policies to form enough digital agglomeration results to be gradually exported. Weinan, Shangluo, Tianshui, Pingliang, Qingyang and other cities have a low degree of centrality and flat point in-degree and out-degree, with low digital innovation capacity and infrastructure construction that needs to be further strengthened; Tongchuan and Linfen's out-degree is greater than the in-degree, which indicates that the city's digital elements are flowing outward more, while its own digital development capacity is poor, and it is unable to sustainably improve digital agglomeration capacity. In the Guanzhong Plain Urban Agglomeration, cities with higher centrality levels absorb those with lower levels, and there is serious polarization and certain regional imbalance.

The comparative analysis of the degree of intermediary center of digital economy in Guanzhong Plain city cluster is shown in Table 4. The intermediary center degree of Xi'an always ranks first, and its deployment and control over other cities in the Guanzhong Plain is extremely strong. Baoji, Xi'anyang, Weinan, Yuncheng, and Tongchuan are in a low-quality zone at the beginning of the intermediary centrality, but gradually grow over time, and their control of the digital economy over other cities increases slowly. Tianshui, Pingliang, Linfen, Qingyang and Shangluo have low intermediary centrality degrees, with the existence of and their weak control over other cities, among which the intermediary centrality degrees of Tianshui and Pingliang have changed their upward trend to 0, suggesting that the deployment capacity of the two cities has shifted to other cities. In terms of the proximity centrality degree, Xi'an has been maintained at the level of 100, and is the central actor of the Guanzhong Plain Urban Agglomeration, generating an extremely strong correlation between the digital economy of other cities. The proximity centrality of Baoji and Xi'anyang has increased significantly, the influence of the digital economy is expanding rapidly and both are at a high level, and the degree of digital economy connection has become even stronger. The proximity centrality of the remaining cities in the Guanzhong Plain Urban Agglomeration is also above 50, indicating that the digital economy exchanges between the cities in the Guanzhong Plain are relatively smooth and the gap between them is very small.

4.2. Analysis of Network Density

The digital economy network structure of Guanzhong Plain is measured, and the results are shown in Table 5. The spatial association network density is 0.2091 in 2012, rises to 0.3545 in 2016, and has increased to 0.4545 in 2020, which can

Table 4. Between centrality and closeness centrality of digital economy in Guanzhong plain urban agglomeration.

City	2012		2016		2020	
	Between Centrality	Closeness Centrality	Between Centrality	Closeness Centrality	Between Centrality	Closeness Centrality
Xi'an	51.333	100.000	34.067	100.000	27.583	100.000
Baoji	18.000	58.824	6.667	76.923	13.917	90.909
Xi'anyang	1.000	62.500	8.667	83.333	13.917	90.909
Weinan	0.000	55.556	0.400	58.824	9.667	62.500
Shangluo	0.333	58.824	0.400	58.824	0.000	58.824
Tongchuan	0.333	58.824	0.400	58.824	0.000	58.824
Yuncheng	0.000	52.632	0.400	58.824	0.667	62.500
Linfen	0.000	52.632	0.000	55.556	0.250	58.824
Tianshui	0.000	52.632	0.000	52.632	0.000	58.824
Pingliang	0.000	52.632	0.000	58.824	0.000	58.824
Qingyang	0.000	52.632	0.000	58.824	0.000	58.824

Table 5. Network structure characteristics of digital economy in Guanzhong plain urban agglomeration.

Year	2012	2016	2020
Density	0.2091	0.3545	0.4545
Connectedess	1.0000	1.0000	1.0000
Hierarchy	0.0000	0.3333	0.0000
Efficiency	0.8889	0.7111	0.6222
LUB	1.0000	0.9778	1.0000

show that the digital economy of Guanzhong Plain Urban Agglomeration is accelerating, and the frequency of the digital connection between the cities has been increased, but the overall network density is still low. At the same time, the digital economy network correlation degree of all three stages is 1, which proves that there is an obvious correlation between the digital economy of the cities within the Guanzhong Plain, and the network structure is more stable. The network hierarchy degree rises from 0 in 2012 to 0.33 in 2016, and then drops to 0 in 2020, which shows that there are sufficient channels of direct digital economy connections within the urban agglomeration, and the hierarchical distinction is not obvious. The network efficiency drops from 0.89 in 2012 to 0.62, which shows that the connection between cities within the Guanzhong Plain Urban Agglomeration is getting stronger and the digital economy network tends to be stabilized.

4.3. Network Strength Analysis

The strength of digital economic ties in Guanzhong Plain is measured according to the modified gravity model, with each city represented by a network node, and the value of digital economic ties between cities within the urban agglomeration is represented by the connecting lines between the nodes. With the help of ArcGIS software, the digital economic linkage network between cities within the Guanzhong Plain Urban Agglomeration is drawn in each year, and the natural breakpoint method is used to separate the effective connections to analyze the digital economic linkage strength for better visualization. As can be seen from Figure 1, the digital economic connection strength of Guanzhong Plain shows the following characteristics:

The radiation structure of the node city center with Xi'an as the core is characterized significantly. Xi'an's digital economic ties with other cities have always been strong, of which, in 2012, Xi'an-Xianyang unidirectional link strength is 162, and the strength of the link between the rest of the cities is generally low. 2016, the strength of digital economic ties between cities in the Guanzhong Plain increased, Xi'an and Xianyang and Weinan digital economic ties are getting closer and closer, the strength of the link with Weinan has increased to 238, and the strength of the link with Shangluo increased to 157. The digital economic network structure of Xi'an as the core is characterized by the following features. The digital economy network structure centered on Xi'an gradually tends to be multi-directional from unidirectional development. 2020, the number of city groups with a digital economy network strength of more than 100 reaches 5 groups, namely Xi'an - Xi'anyang (386), Xi'an - Weinan (380), Xi'an - Shangluo (300), Xi'an - Yuncheng (151), and Xi'an - Pingliang (126), and the digital economy network structure of Guanzhong Plain centered on Xi'an gradually stabilizes. economy network structure is gradually solidifying, meanwhile, the digital economy network structure centered on Baoji is initially formed, and the connection with Tianshui, Pingliang and other cities is enhanced, starting to break through the provincial boundary. Overall, the digital economy linkages within the Guanzhong Plain Urban Agglomeration are relatively homogeneous, with Xi'an having the strongest unidirectional linkages with other cities in the early stage, while other cities have little linkages with each other, resulting in a thin network structure. 2020 will see Baoji develop into a sub-core city, and the strength of linkages between other cities will gradually increase, but the digital economy linkage network will still be at the early stage, with plenty of room for subsequent development.

4.4. Analysis of Cohesive Subgroups

Changes in city cohesion subclusters of the Guanzhong Plain Urban Agglomeration for the digital economy from 2012 to 2020 are shown in Table 6.

In 2012, there were three secondary subclusters and four tertiary subclusters in the Guanzhong Plain Urban Agglomeration, which increased to four secondary

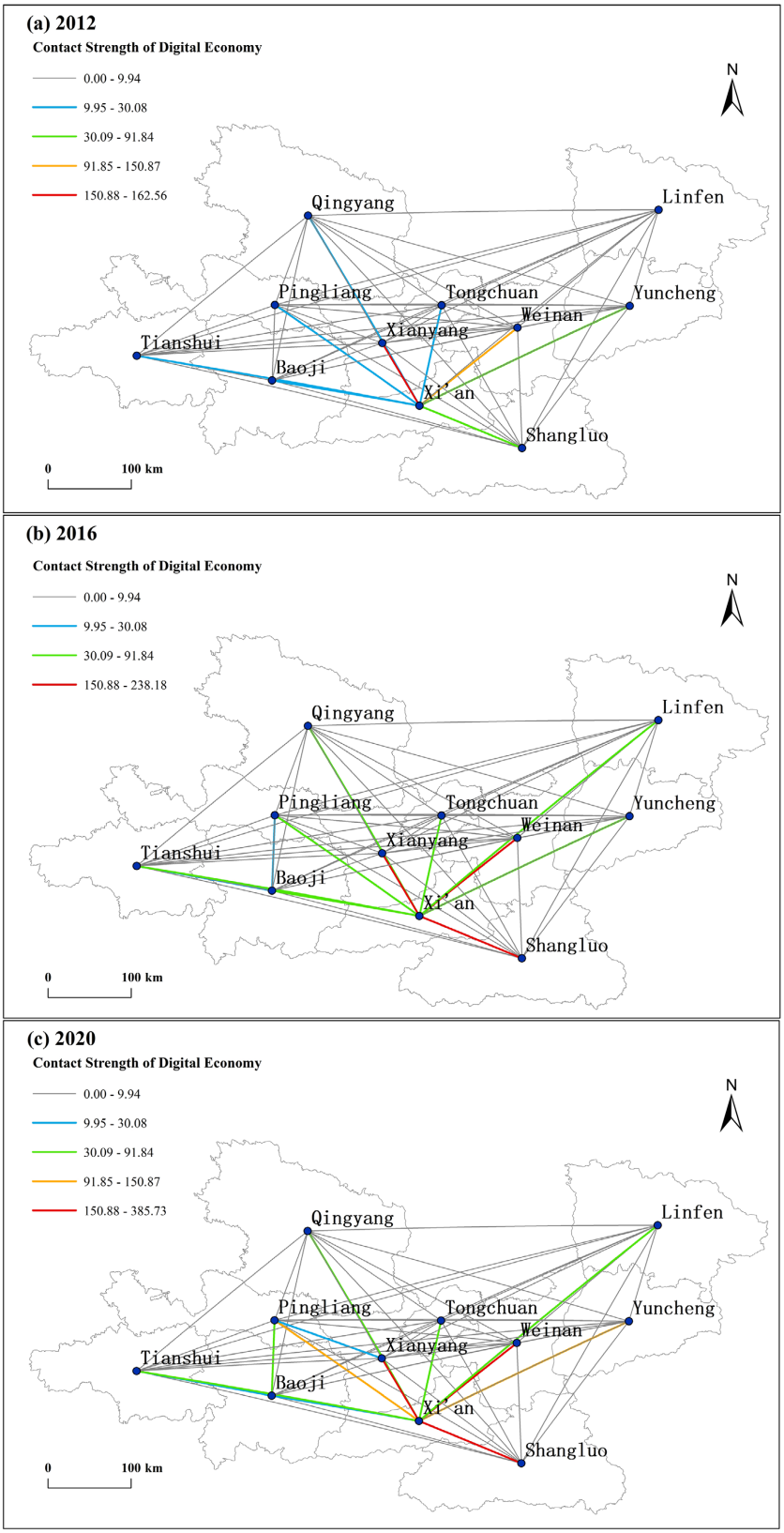

Figure 1. Intensity of digital economy network in Guanzhong Plain city cluster in 2012, 2016 and 2020.

Table 6. Results of cohesive subgroup division of Guanzhong plain urban agglomeration.

Year	2-level network	3-level network	City
2012	One	1	Baoji, Xianyang
	Two	2	Tianshui, Pingliang
		3	Weinan
	Three	4	Linfen, Tongchuan, Qingyang, Xi'an, Shangluo, Yuncheng
2016	One	1	Baoji, Xianyang
	Two	2	Xi'an
	Three	3	Linfen
		4	Pingliang, Tianshui, Yuncheng, Weinan
	Four	5	Qingyang, Shangluo
		6	Tongchuan
2020	One	1	Baoji, Xianyang
		2	Xi'an
	Two	3	Tongchuan
	Three	4	Linfen
	Four	5	Tianshui, Pingliang, Shangluo, Qingyang
		6	Yuncheng, Weinan

subclusters and six tertiary subclusters from 2016 to 2020, while the number of cities within the subclusters and their structure changed. In 2012, there were Baoji - Xianyang sub-cluster, Tianshui - Pingliang sub-cluster, and three tertiary city sub-clusters centered on Yuncheng and Xi'an, while Weinan was unable to form a tertiary sub-cluster with other cities, and in general the overall tier of the Guanzhong Plain's digital economy was not high, and the clustering capacity was weak. The number of cohesive sub-clusters and the structure of the Guanzhong Plain's urban agglomerations changed significantly in 2016, with the number of tier-two sub-clusters growing from three to four, and tertiary sub-clusters also in 2016, the number and structure of cohesive sub-clusters in the Guanzhong Plain Urban Agglomeration changed significantly, with the number of secondary sub-clusters increasing from three to four, and the number of tertiary sub-clusters also increasing from four to six, with Xi'an separating from the Yuncheng-Xi'an-dominated sub-cluster to form the independent Xi'an sub-cluster and rising to the first level, while at the same time separating from it to form new sub-clusters, such as the Shangluo-Qingyang sub-cluster and Tongchuan sub-cluster, and Weinan merging with the Tianshui-Pingliang sub-cluster to form the tertiary sub-cluster dominated by Weinan and Tianshui. Xianyang subgroup and Xi'an subgroup merge into the same secondary subgroup, which is more closely connected, while Linfen subgroup and Tongchuan subgroup sepa-

rate into the first level subgroup, which has a reduced clustering ability with other city subgroups; Yuncheng and Weinan separate from the Weinan and Yuncheng-based subgroups to form the Yuncheng-Weinan subgroup, and at the same time, the Shangluo-Qingyang subgroup is merged into it to form the tertiary subgroup mainly dominated by Tianshui and Pingliang. The changes in the three time nodes can be seen in the Guanzhong Plain Urban Agglomeration's digital economy network structure continues to change and reorganize, but the digital economy development is little affected by the administrative division, and geographically neighboring cities are more likely to form a solid cohesive subcluster. At the same time, the cohesive subclusters centered on Xi'an subcluster and Baoji Xianyang subcluster have gradually stabilized the digital economy network to be more closely linked to the digital economy clustering effect is constantly increasing. The digital economy network structure of cities in the Guanzhong Plain is constantly differentiating and reintegrating, with subgroups gradually becoming more and more distinct and closely connected, but the overall clustering effect is still poor and in the early stage.

5. Analysis of Digital Economy Influencing Factors

5.1. Selection of Variables

The change and development of digital economy in Guanzhong Plain Urban Agglomeration is the result of a variety of influencing factors. The digital economy realizes its own development in the integration with the real economy, and its trend is inevitably affected by the regional economy. At the same time, the close degree of digital economy connection between different cities is more likely to be affected by the spatial proximity, and it is easier to produce digital factor agglomeration in the closer cities. The degree of openness of the city region is related to the level of international trade and technological interconnection, which is an important factor to promote the coordination and innovative development of the regional digital economy. In recent years, the development of 5G network technology, big data technology, AI and other cutting-edge science and technology innovations have created favorable conditions for the sustainable development of the digital economy. The government's policy guidance and financial support can also point out the direction of the development of the digital economy, and the differentiation of governmental support can provide the development focus for the regional digital economy, and focus resources to play a regional advantage. The digital economy is highly related to the regional information industry and informatization, and the development and construction of informatization resources reflect the development level of the digital economy of the city to a certain extent.

Based on the analysis of the evolution of the digital economy network structure of the urban agglomeration, this paper analyzes the influencing factors of the digital economy development of Guanzhong Plain Urban Agglomeration in 2020 from six aspects: economic development level, geographic distance, region-

al openness, scientific and technological innovation, governmental support, and informatization level. Among them, the GDP of a city represents the economic development level of the city; the distance between city nodes represents the geographical distance; the ratio of total imports and exports to GDP of each place represents the regional openness ability; the number of patents granted represents the scientific and technological innovation ability; the ratio of scientific expenditure to local financial expenditure represents the strength of governmental support; and the number of Internet broadband access represents the level of informatization. Each indicator calculates the difference between city nodes to form the difference matrix and takes it as an independent variable, the Guanzhong Plain digital economic development difference matrix as a dependent variable, and each variable is constructed to form an 11 × 11 dimensional matrix, and the final QAP regression model is as follows:

$$DE = f\left(GD, UD, RO, RN, GS, IL\right) \tag{2}$$

The data required in this section are mainly from the 2021 China Urban Statistical Yearbook and the statistical yearbooks of Shaanxi, Shanxi and Gansu provinces. Among them, the explanatory variable DE is the digital economy development difference matrix among cities in Guanzhong Plain; the GDP difference network of cities in Guanzhong Plain is denoted by GD; the geographic relationship matrix of cities is denoted by UD; the openness difference matrix of city regions is denoted by RO; the science and technology innovation difference network matrix of cities is denoted by RN; the difference matrix of governmental support of cities is denoted by GS; and the informatization level of cities is denoted by IL. The difference matrix is denoted by IL. In this paper, the differences in digital economy development are taken as the explanatory variables, and the GDP difference network, geographical distance matrix, regional open network, science and technology innovation network, government support network, and informatization network are taken as the explanatory variables, and the mean value of each row of the network matrix where each variable is located is determined as the threshold, and each row that is higher than the threshold is marked as 1, and the one that is less than or equal to the threshold is marked as 0, so as to form the 0 - 1 matrix for QAP correlation analysis and regression analysis. analysis and regression analysis.

5.2. Empirical Tests and Analysis

The results of the correlation test and regression using QAP are shown in **Table 7**, where the probability A and probability B are the probabilities that the absolute values of the evaluation coefficients derived from the random transposition of the matrix are not less than and not greater than the observed coefficients. The results of the correlation test show that the correlation between the difference in digital economic development in Guanzhong Plain and the difference matrix of the six influencing factors is significant at least at the 10% level, and all

Table 7. QAP correlation test and regression results.

Variable	Correlation Test		Regression Analysis			
	Correlation	Significance Level	Coefficient of Regression	Probability value	P-A	P-B
GD	0.610	0.003	0.131103	0.006	0.006	0.994
UD	0.287	0.047	0.024370	0.225	0.225	0.776
RO	0.431	0.090	−0.062390	0.931	0.931	0.069
RN	0.959	0.003	0.897757	0.000	0.000	1.000
GS	0.536	0.007	0.061885	0.079	0.079	0.922
IL	0.495	0.002	0.025474	0.260	0.260	0.740

of them show positive correlation, which indicates that the spatial network of the city's digital economic development is positively affected by the level of the city's economic development, the spatial distance, the openness of the region, the technological innovation, the governmental support and the level of informatization to varying degrees. Among them, the level of economic development, scientific and technological innovation, government support and informatization level all play a significant role at least at the level of 1%, indicating that the digital economy development network of Guanzhong Plain Urban Agglomeration tends to expand in the cities with developed economy, strong scientific and technological innovation capacity, strong scientific and technological financial support, and complete informatization infrastructure, and that the digital economy is more likely to develop in the cities with frequent connections with the outside world and strong regional openness, and to break down the digital economy development in cities with strong spatial distance and regional openness. At the same time, the digital economy is more likely to develop in cities with frequent contact with the outside world and strong regional openness, and breaks the limitations of geographic location, so that the digital elements can flow and expand across the region.

Further QAP regression analysis of the difference matrix of digital economy development level and the difference matrix of six influencing factors shows that spatial distance, regional openness and informatization level do not show significance at least at the 10% level, which proves that the differences in spatial distance, regional openness and informatization level among cities in the Guanzhong Plain Urban Agglomeration do not have a significant driving effect on the differences in digital economy development. This may be due to the fact that the digital economy relies mainly on Internet platforms, digital information transfer is less dependent on spatial proximity, and cities with a faster rate of development of the digital economy may also be found in areas that are farther away from cities with a developed digital economy. Compared with the developed regions, the Guanzhong Plain urban agglomeration is located in Northwest China,

and the market and scale effects of the import and export trade and regional openness under the driving force of the Belt and Road policy are insufficient, which is the reason for the differences in the development of digital factors and data resources. and the dissemination and influence of digital elements and data resources are small, so that the difference in regional openness has weakly promoted the development of the digital economy interconnection in Guanzhong Plain. The construction of informatization is still in the stage of sharing and integrating the basic information resources and reinforcing the information infrastructure, which fails to form a major condition for the development of the regional interconnection of digital economy.

In addition, the results of the indicators of city GDP, science and technology innovation and government support pass the significance test at the 10% level, and the regression coefficients are all positive, indicating that the differences in economic development, science and technology innovation capacity and government support in the Guanzhong Plain city cluster will promote the effective cross-regional flow of digital resources and the development of the digital economy network. The reason may be that the cities are affected by the differentiation of economic development level and scientific and technological innovation ability, and the basic conditions for the development of digital economy are different, which in turn promote the rapid flow of digital factor resources at the spatial level. Through mutual reference, guidance, demonstration and learning of good communication methods, the "siphon effect" between cities is formed, which enhances the strength of the association and network density of the digital economy among city nodes, and promotes the linked development of the digital economy among cities and the rapid formation of the digital economy network of the Guanzhong Plain Urban Agglomeration as a whole. At the same time, the scientific financial expenditure given by the government indicates the development focus of digital economy for each region, and the policy support promotes the reasonable flow of digital elements within the region and accelerates the development of digital economy on a large scale.

6. Conclusions and Recommendations

Based on the digital economy development levels of 11 cities in the Guanzhong Plain Urban Agglomeration in 2012, 2016 and 2020, this paper uses the modified gravity model to establish the spatial correlation matrix of the digital economy development in the Guanzhong Plain, adopts the method of social network analysis to explore the spatial structural evolution characteristics of its digital economy, and carries out empirical research on the factors influencing the digital economy in 2020, and draws the following conclusions:

1) The overall network structure of the digital economy of the Guanzhong Plain Urban Agglomeration is stable, and the degree of network connection becomes more and more intense over time, but the density of the network is still low; at the same time, the network as a whole is gradually expanding from a sin-

gle network structure with Xi'an at its core, and Baoji rises to be a sub-central city by 2020, and the strength of the connection between other cities further increases, so there is still enough room for subsequent development.

2) With regard to the centrality of cities, the individual centrality and intermediary centrality of Xi'an, Baoji, and Xi'anyang are all at a high level in the entire Guanzhong Plain Urban Agglomeration, and the radiation-driven effect of the digital economy, agglomeration capacity, and the ability to regulate the other cities are relatively strong. However, there is an imbalance in the development of digital economy in Guanzhong Plain Urban Agglomeration, and the polarization phenomenon is serious.

3) In terms of cohesive subgroups, the digital economy network structure of Guanzhong Plain Urban Agglomeration is constantly changing and reorganizing, and it is easier for neighboring cities to form solid subgroups; at the same time, the subgroups are gradually obvious in terms of hierarchical level and close internal connection, but the clustering effect is not good, and the whole is in the primary stage.

4) In terms of influencing factors, GDP, geographic distance, regional openness, technological innovation, government support and informatization level are all significantly correlated with the development of digital economy in the Guanzhong Plain, while the level of economic development, technological innovation and government support of the cities in the Guanzhong Plain have a significant positive impact on the overall development of digital economy in the urban agglomeration.

Based on the above findings, this paper puts forward the following suggestions:

1) Continuously coordinate and optimize the digital economy layout, enhance the connectivity of the spatial network of the Guanzhong Plain Urban Agglomeration, continuously promote the coordinated development of the digital economy in the Guanzhong Plain, and implement differentiated strategies according to local conditions. Xi'an, Baoji, Xi'anyang and other cities have stronger digital economy regulation capabilities and more concentrated digital resources, and should continue to play a radiation-driven ability to further promote digital industrialization and industrial digitization, promote the output of data element resources to neighboring cities, and drive the efficient development of the regional digital economy with digital sharing. Qingyang, Linfen, Tongchuan and other cities at the edge of the network have a lower level of digital economic development, and should enhance their spatial correlation ability with the core cities, clarify their development conditions and play to the advantages of their location, accelerate the digital transformation of industries, and alleviate the status quo of uneven development of the digital economy.

2) Build a digital economy circle, enhance urban cohesion, and promote the overall digital economy development of the Guanzhong Plain Urban Agglomeration with a small band. Relying on the existing subgroup structure, break the

provincial boundaries, link up across provinces to create a scientific digital economy circle, strengthen digital exchanges and cooperation within the same subgroup, provide policy, financial and other support for the digital economy cooperation of subgroups such as Baoji-Xianyang, Tianshui-Pingliang-Qingyang, etc., and realize the exchanges and sharing of data resources, digital talents and other multi-disciplinary fields within the circle.

3) Efficiently utilize policy dividends to strengthen the scientific and technological innovation capacity of urban agglomerations. Under the guidance of the Belt and Road Initiative, the Guanzhong Plain Urban Agglomeration has already achieved initial results in digital infrastructure and digital industry transformation. In the future, Tongchuan, Linfen and other cities with relatively slow development of digital economy can continue to optimize the Internet infrastructure in terms of the construction of 5G base stations and smart cities. For cities such as Xi'an, Baoji, Xi'anyang and other cities with faster economic development, they can further optimize the industrial structure, promote the development of digital economy in artificial intelligence, cloud computing and other cutting-edge areas of cooperation, and at the same time vigorously promote the digital transformation of enterprises through the strengthening of the introduction of digital talents, the creation of digital innovation platforms, etc., so as to continue to improve the competitiveness of the core city's digital economy.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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