Analysis of Spatial Structure of Digital Information Service Industry - Based on Social Network Model and Modified Gravity Model

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Abstract. Digital economy, as a more advanced and sustainable new economic form after the agricultural economy and industrial economy, is not only an important factor affecting China's and even the global economic development in the present and the future, but also a key weight in constructing a new pattern of China's regional economic development. The digital information service industry is the fundamental driving force for the development of the digital economy, while the development of communication is the basic power of digital information service industry, and the Internet is the combined power of the digital information service industry. Based on this background, this paper investigates the spatial structure and effects of the digital information service industry as well as the communication and Internet industries through the social network model and the modified gravity model. The study shows that in 2020-2022, the strength of spatial links of digital information services, telecommunications, and Internet industries are to be strengthened, and the problem of unbalanced development of the East and West is still significant, in which the Internet has the smallest spatial density and the strongest imbalance, and the spatial distribution of telecommunications industry is relatively balanced.

Keywords: Digital information services, Spatial structure, Modified gravity matrix, Social network relationship model, Ucinet, GIS

1 INTRODUCTION

With the accelerated evolution of the new round of scientific and technological revolution and industrial change, the kinetic role of digital information service industry in the growth of digital economy is more and more significant. Digital information service as a new type of information service generated under the environment of digitalization and networking [1], its development is closely related to the level of information technology [2], with the characteristics of high-tech services [3], by virtue of the high degree of industrial relevance, value-added benefits and other characteristics, widely used

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in thousands of industries [4], is the key base for the depth of the integration of digital technology and the real economy. In the development of digital information services, communication network is the root, for digital information services to provide digital capacity; the Internet is the basis, for digital information services to provide digital synergy; software is the soul, for digital information services to provide digital capacity.

Regional space has the characteristics of openness and complexity, which has gradually become the basic territorial unit for countries to participate in international competition as well as the main form of spatial organization for the development of regional economic integration [5], and is also the endogenous social structure closely related to the practical activities of the subjects of the digital economy, exerting a complex influence on the development of regional digital information services through the networked territorial proximity and beyond the market of the institutional factors. This study adopts a social network analysis approach based on the social science research paradigm of contact, liaison, and relationship, abstracting social actors and their interactions with each other as network nodes and edges, and seeks to investigate the structure of network relationships and the role of networks using graph theory, multidimensional scales, statistical science, and other technical methods [6]. Taking into account the deterministic nature of network boundaries and the selective constraints of relational data, social network analysis has better applicability to the study of relationships at the meso level, and provides a new research methodology for the study of spatial connections [7]. The current application of social network analysis mainly focuses on the fields of environment [8-9], engineering [10-11], aviation [12], education [13-14], etc., and there is no analysis of the spatial relationship between information service industries. This paper calculates the linkage intensity value of provincial spatial digital information service based on the modified gravity model, constructs the provincial linkage network of digital information service by using social network analysis, and explores the linkage situation of the development of provincial spatial digital information service and the characteristics of the network structure through the empirical analysis to provide references and policy recommendations for the enhancement of the spatial function of the digital information service, the optimization of the regional economy, and the integrated development.

2 RESEARCH METHODOLOGY AND DATA

2.1 Gravity model

Gravity model is often used as a research method to study the strength of economic ties between two provinces and cities, which has the following basic assumptions: assuming that the economic activities of provinces and cities are similar; assuming that the economic activities within the jurisdiction of a province and city are concentrated in the point representing the province and city; assuming that the economic contacts between provinces and cities are similar; assuming that there are no huge institutional or geographic barriers between provinces and cities, and so on. The formula for the classical gravity model is:

$$R_{ij} = K\frac{M_i M_j}{{D_{ij}}^2} = K\frac{\sqrt{P_i V_i}\sqrt{P_j V_j}}{{D_{ij}}^2} \quad (1)$$

Rij is the intensity of economic ties between the two cities and provinces; Mi and Mj are the quality indicators of cities i and j, respectively, and the quality indicators are often replaced by population size and GDP; in practice, the quality of provinces and cities is usually replaced by the square of the product of population size and GDP; Pi and Pj are the number of non-agricultural population of the two cities; Vi and Vj are the GDPs of the two cities; and Dij is the shortest distance between the two cities, and K is a constant. K is a constant.

2.2 Model Revision

In this paper, respectively, the income and employment-population multiplier of digital information services represent the size of the quality of digital information services in each provincial and municipal jurisdiction； the communication income and its employment-population multiplier represent the size of the quality of communication in each provincial and municipal jurisdiction； the Internet income and employment-population multiplier represent the size of the quality of the Internet in each provincial and municipal jurisdiction, and the actual geographic distance between the province/city represents the shortest distance, considering that the Internet broadband export traffic better reflects the value of Internet broadband export traffic between provinces/municipalities is used as a moderating coefficient variable, considering that the development level of digital information service capacity is better reflected. The modified gravity model expressions for digital information services, communication and the Internet are as follows:

$$RD_{ij} = K_{ij}\frac{MD_i MD_j}{{D_{ij}}^2} = K_{ij}\frac{\sqrt{PD_i VD_i}\sqrt{PD_j VD_j}}{{D_{ij}}^2} \quad (2)$$

$$RT_{ij} = K_{ij}\frac{MT_i MT_j}{{D_{ij}}^2} = K_{ij}\frac{\sqrt{PT_i VT_i}\sqrt{PT_j VT_j}}{{D_{ij}}^2} \quad (3)$$

$$RI_{ij} = K_{ij}\frac{MI_i MI_j}{{D_{ij}}^2} = K_{ij}\frac{\sqrt{PI_i VI_i}\sqrt{PI_j VI_j}}{{D_{ij}}^2} \quad (4)$$

$$K_{ij} = \frac{BP_i}{BP_i + BP_j} \quad (5)$$

Among them, RD_{ij} is the linkage intensity of digital information services; MD_i and MD_j are the quality indicators of digital information services in provinces i and j, respectively; PD_i and PD_j are the employed population of digital information services; and VD_i and VD_j are the income of digital information services.

RT_{ij} is the linkage intensity of the communication industry; MT_i and MT_j are the quality indicators of the communication industry in provinces i and j respectively, PT_i and PT_j are the employed population of the communication industry, and VT_i and VT_j are the income of communication industry.

RI_{ij} is the intensity of Internet connection between two provinces and cities; MI_i and MI_j are the Internet quality indicators of provinces i and j respectively, PI_i and PI_j are the employed population in the Internet, and VI_i and VI_j are the revenues from digital information services.

K_{ij} is the adjustment coefficient, BP_i, BP_j are the Internet inter-provincial export broadband traffic of province I and j respectively, and D_{ij} is the shortest distance between provinces/municipalities.

2.3 Social network modeling

A social network is a collection of social actors and their relationships, and social network analysis is to study the structure and properties of such social relationships, which can reveal the overall characteristics, individual characteristics and spatial structure of social networks. In this paper, based on the values of inter-provincial digital information service, communication and Internet calculated by the modified gravity model, the association strength matrix is obtained, and the data are binarized. The mean value of the reference data in this paper is the critical value M, i.e., it takes the value of 1 when the contact volume is larger than M value, and takes the value of 0 when it is smaller than M value, so as to convert the association strength matrix into the relationship matrix X. The expression of the relationship matrix X is as follows:

$$X = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \vdots & \vdots \\ X_{n1} & \ldots & X_{nn} \end{bmatrix}, x_{ij} = \begin{cases} 0 & R_{ij} > M \\ 1 & R_{ij} > M \end{cases} \tag{6}$$

In this paper, each province in China is regarded as a network node, and the digital information service/communication industry/Internet industry between provinces is regarded as an edge. Considering the flow direction of digital information service, we construct the spatial relationship network of digital information service/communication industry/Internet industry without right and direction, and analyze the characteristics and evolution law of the spatial structure of digital information service/communication industry/Internet industry by calculating the indexes of the relationship network with the method of social network analysis. By calculating the indicators of the relationship network, we analyze the characteristics and evolution law of the spatial structure of the digital information service/communication industry/Internet industry.

2.4 Network Density

Network density is used to reflect the closeness of the spatial network of China's digital economy, and is an important indicator of the robustness of the spatial network. The

larger the value of network density is, the closer the relationship between members of the network is, and the more robust the network is. The formula of network density is as follows:

$$D = \sum_{i=1}^{k} \sum_{j=1}^{k} d(n_{i,} n_j) \Big/ k(k-1) \tag{7}$$

Where D is the network density, $d(n_i,n_j)$ is the amount of relationship between network members n_i,n_j, and k is the number of members in that network.

2.5 Centrality

Centrality is used to reflect the degree of centrality of each province in the spatial network of China's digital economy, and the measurement methods are mainly divided into three types: centrality, proximity centrality and intermediary centrality. Among them, centrality is the most direct and intuitive indicator to portray centrality, which is the number of nodes in the digital information service/communication/Internet industry spatial relationship network of the province that have digital economic ties with other provinces; the greater the centrality, the more digital economic ties the province has with other provinces, i.e., the higher the status of the province in the digital information service/communication/Internet industry spatial relationship network. In addition, since this paper is a directed network, the point-in degree is used to express the agglomeration capacity of the province's digital information service/communication/Internet industry economy, and the point-out degree is used to express the radiation capacity of the province's digital information service/communication/Internet industry economy. The formula is as follows:

$$C_{D(in)}(n_i) = \sum_{j=1}^{n} X_{ij(in)} \tag{8}$$

$$C_{D(out)}(n_i) = \sum_{j=1}^{n} X_{ij(out)} \tag{9}$$

where $CD_{(in)}(n_i)$ is the point in degree, $CD_{(out)}(n_i)$ is the point out degree, $X_{ij(in)}$ is the in edge between province i and province j, and $X_{ij(out)}$ is the out edge between province i and province j.

2.6 Core-Edge Structure

According to the degree of connection between the nodes in the network, the nodes in the network can be divided into core and edge regions. Nodes in the core region occupy an important position in the network; core nodes represent the main forces in the network, and they play a key role in disseminating information, maintaining network coherence and facilitating group activities. Edge nodes represent members that are new to the network, members that interact less, or those that are relatively independent from the core of the network. In this paper, the community detection algorithm is chosen for the calculation.

2.7 Data Source

The data in this paper comes from the Annual Statistics of the Communication Industry, the Statistics of the Internet and Related Services Industry, and the Annual Statistics of the Software and Information Technology Services Industry for the years 2020-2022 published by the Ministry of Industry and Information Technology (MIIT), and the sum of revenues and the sum of the employed population of communication, software, and the Internet are used to represent the input of digitized information services and the employed population.

3 ANALYSIS

3.1 Analysis of overall spatial layout

According to equations (1)-(7), using Ucinet and Arcgis to make graphical analysis, it can be seen (Figure 1−3) that the network formed by the telecommunications industry is the densest, and although the linkage relationship among provinces has a tendency to diminish from east to west, it basically forms a broader regional connectivity. The Internet industry has the weakest network density and is only concentrated in Beijing and the southern coastal area, with relatively serious development imbalance. The network density of the digital information service industry is moderate, and regional linkages inland could be further strengthened.

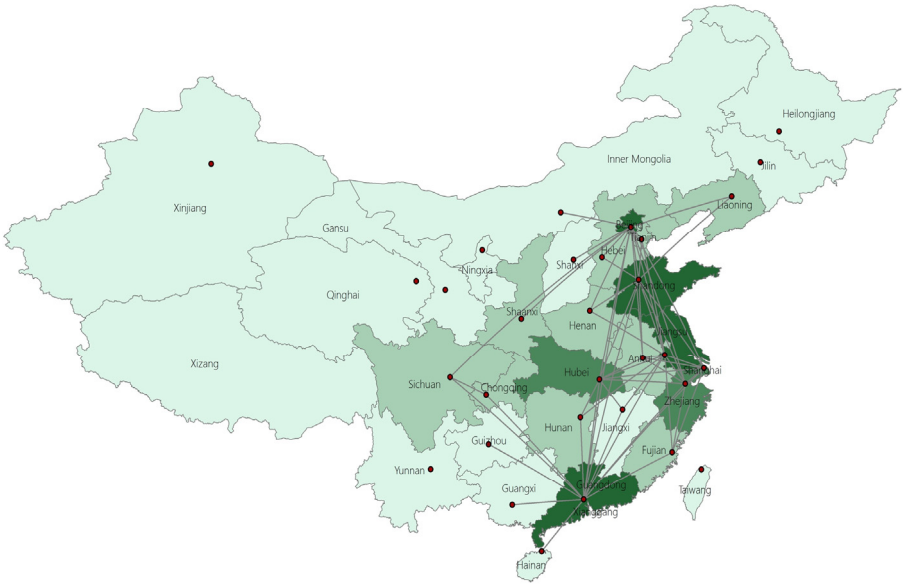

Fig. 1. Spatial linkage of digital information services

Fig. 2. Spatial linkage of telecommunications

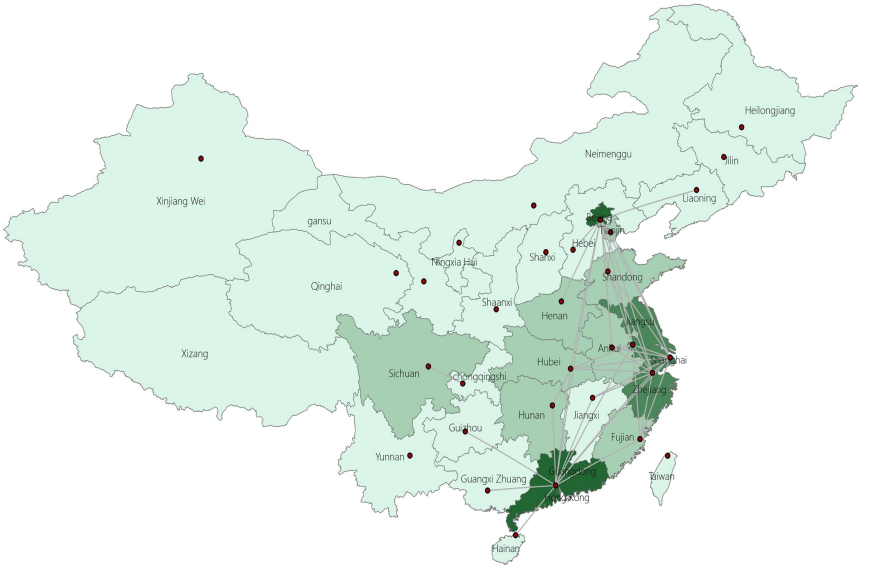

Fig. 3. Spatial linkage of Internet networks

3.2 Network density analysis

As shown in Table 1, a horizontal comparison of digital information services, telecommunications and the Internet shows that telecommunications has the highest network density, indicating that the telecommunications industry has the closest mutual influence and association among provinces, while the Internet economy network has the lowest density, indicating that the Internet economy has low interactive influence among provinces and has not yet formed the desired network effect.

From the time dimension, digital information services, telecommunications and the Internet have not changed much in general, and their development is all relatively stable. Among them, the density of communication and Internet industries has slightly increased, and the density of information services has slightly decreased.

Table 1. Results of the density analysis of digital information services, telecommunications and Internet networks from 2020-2022

	2022	2021	2020
Digital information services	0.1065	0.1065	0.1129
Telecommunications	0.1989	0.1935	0.1957
Internet networks	0.0753	0.072	0.072

3.3 Degree of centrality: uneven development trend is still obvious

As shown in Table 2, the digital information service industry from 2020 to 2022, the center degree out of each province is basically stable, of which Beijing, Guangdong, Jiangsu and Shandong out of the degree is greater than 10, stronger influence. Compared with Beijing and Guangzhou, the employment-population and Internet inter-provincial export bandwidth growth rate of 22% and 138%, 8% and 174%, Jiangsu is only 1% and 55%, and its out-degree declined continuously.

Table 2. Digital information service out of the degree center degree from 2020-2022

Serial number	province	2022	2021	2020
1	Beijing	14	14	13
2	Guangdong	14	12	14
3	Jiangsu	12	13	16
4	Shandong	11	11	12

As shown in Table 3, Beijing, Guangdong, Jiangsu and Shandong are still the four provinces with the highest incidence centrality, but only Beijing's incidence centrality is greater than 10, indicating that Beijing's ability to be influenced by the surrounding provinces and to influence the other provinces is more balanced, while Guangdong, Jiangsu and Shandong are more capable of influencing the other provinces.

Table 3. Digital Information Service Entry Degree Center Degree from 2020-2022

Serial number	province	2022	2021	2020
1	Beijing	12	13	14
2	Guangdong	9	9	9
3	Jiangsu	9	9	8
4	Shandong	9	9	8

As for the communication industry, the centrality of the out-degree of Guangdong, Henan, Jiangsu, Shandong, Zhejiang, Hebei and Hunan is greater than 10, indicating that there are more provinces with strong radiating ability in the communication industry, while there are 19 cities with a centrality of out-degree of between 10 and 1 (including 10 and 1), and there are only 13 cities with digitalized information service industry. Among them, Hunan has the fastest increase in influence due to the significant increase in Internet inter-provincial export bandwidth by province (as shown in Table 4).

Table 4. Communication out degree center degree from 2020-2022

serial number	province	2022	2021	2020
1	Guangdong	17	17	17
2	Henan	16	14	15
3	Jiangsu	15	15	16
4	Shandong	13	14	16
5	Zhejiang	11	11	10
6	Hebei	11	9	11
7	Hunan	10	8	4

While Hunan is affected by a significant decline, from 14 in 2020 to 9 in 2022 (e.g., Table 5).

Table 5. Communication Entry Degree Center Degree from 2020-2022

serial number	province	2022	2021	2020
1	Hubei	13	11	11
2	Henan	12	13	12
3	Jiangsu	12	11	9
4	Shandong	12	11	11
5	Anhui	11	11	10
6	Zhejiang	10	9	11
7	Hunan	9	10	14

In terms of the Internet, Beijing and Guangdong are relatively stable provinces with strong radiation, Shanghai's influence has gradually increased for three consecutive years, while Jiangsu's influence has declined year by year. In addition, the spatial distribution of Internet radiation has a more obvious difference between the north and the south, with cities in the south being significantly stronger than those in the north (as shown in Table 6).

Table 6. Internet out of the center degree from 2020-2022

serial number	province	2022	2021	2020
1	Beijing	11	12	9
2	Guangdong	11	9	13
3	Shanghai	10	9	8
4	Zhejiang	9	9	6
5	Jiangsu	8	9	10
6	Hubei	4	4	3
7	Shandong	4	3	5
8	Fujian	3	3	3
9	Anhui	3	4	4
10	Hunan	2	1	0
11	Tianjin	2	1	1
12	Henan	1	1	1
13	Sichuan	1	1	1
14	Hebei	1	1	1

3.4 Core edge structure analysis

As shown in Table 7, the number of edge nodes in the telecommunications industry is more compared to digital information services and the Internet, but the density between the edge and the center nodes is not zero, indicating that the degree of imbalance in the telecommunications industry is smaller than that in digital information services and the Internet industry. At the same time, there is a contact density between edge nodes in the communication industry, indicating that the edge nodes are not completely independent from each other. As for the digital information industry and the Internet, the center and edge provinces basically remain stable, but the contact density of the digital information industry decreases year by year. among the 31 provinces/municipalities, six provinces, namely, Yunnan, Tibet, Gansu, Qinghai, Ningxia, and Xinjiang, are in the edge position for all three industries.

Table 7. Core edge structure analysis

	center	verge
Digital Information services	Beijing, Tianjin,Hebei,Shanxi,Inner,Mongolia,Liaoning,Jilin,Heilongjiang,Shanghai,Jiangsu,Zhejiang,Anhui,Fujian,Jiangxi,Shandong,Henan,Hubei,Hunan,Guangdong,Hainan,Guangxi,Chongqing,Sichuan,Shaanxi and Guizhou	Yunnan, Tibet, Gansu, Qinghai, Ningxia and Xinjiang.
telecommunicate	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Shanhai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Chongqing and Shaanxi	Jilin, Heilongjiang, Guangxi, Hainan, Hainan, Guizhou, Yunnan, Tibet, Gansu, Qinghai, Ningxia and Xinjiang

Internet	Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang,Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Hainan, Guangxi, Chongqing, Sichuan, Guizhou	Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

4 CONCLUSIONS

This paper has argued that the spatial density of the digital information service industry as a whole is still low, and the spatial balance needs to be strengthened. Among them, the Internet industry has the lowest density and the most significant imbalance, while the density of the telecommunication industry is relatively high, and a relatively close connection has been formed among the provinces. Guangdong Province in the digital information services, telecommunications industry and Internet industry are core provinces, playing a key node, playing a strong radiation role. The six provinces of Yunnan, Tibet, Gansu, Qinghai, Ningxia and Xinjiang are all marginalized in the spatial network formed by the three industries, i.e., they do not have a radiating effect on other provinces, and it is also difficult to receive the radiating effect of other identities. Subsequently, the spatial distribution of digital information services can be further optimized on the basis of the findings of the study to provide references and policy recommendations for the optimization and integrated development of the regional economy.

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