ISSN: 2688-8645

Study on Chains of Information Industry based on Average Propagation Lengths and Minimal Spanning Tree

Min Zhang, Anning Ye*, Yaqi Chen

School of Statistics and Applied Mathematics, Anhui University of Finance and Economics, Bengbu, Anhui, China

*yeanning@sohu.com

Abstract

Compared with the traditional methods of using industrial linkages to analyze the industrial chain, this paper introduces the theories of economic distance and graph theory to analyze the information industry chain. Industrial linkages reflects the size of economic and technological connection, and economic distance measures the distance between industries. The minimum spanning tree in graph theory measures the position of each industry in the information industry chain. There are complex indirect dependence and direct dependence in the industrial chain of electronic product manufacturing. The economic distance with most industries is 2 and 3, and most of the associated industries are manufacturing. The industrial chain of information service industry is relatively simple. Most related industries belong to the tertiary industry, and the economic distance is relatively close. The minimum spanning tree of information industry shows the central position of metal ore and metal smelting, and shows that the information industry chain still depends on metal ore resources. Using the time series input-output table, this paper analyzes the development and changes of the information industry chain, and finds that the information industry chain is relatively stable in this time span. Finally, it compares the difference between the competitive model and the non competitive model to measure the information industry chain. Using the non competitive model, it is found that the information industry chain becomes shorter and the economic distance between industries is closer.

Keywords

Information Industry; Industry Linkages; Industrial Chains; APL; Minimal Spanning Tree.

1. Introduction

The competitiveness of an industry is closely related to the vertical industry, and the vertical related industry constitutes the industrial chain. The efficiency and effect of information industry chain on economic activities have been verified in many information industry practices. Identifying the information industry chain is of great significance to optimize the structure of China's information industry chain, improve the overall competitiveness of China's information industry, shorten the gap with developed countries, and achieve the strategic goal of making China a powerful information country.

The research on the information industry chain in China started late, and rose after China's reform and opening up. Scholars summarized and analyzed the connotation, formation, optimization, integration and competitiveness of the information industry chain from different perspectives. Wang (2013) studied the information industry agglomeration mechanism and agglomeration power mechanism from the perspective of system dynamics theory and information industry agglomeration theory, and studied the reasons for the formation of the information industry chain and the formation mechanism of the information industry chain

ISSN: 2688-8645

using the industry chain theory [1]. Jiang (2008) proposed some ideas on the optimization path of China's information industry chain structure based on the internal structure of China's information industry chain and the development direction of the world's information industry [2]. Lu et al. (2004) believed that industrial chain analysis provides a new perspective for observing industrial development, is a powerful tool for understanding and judging the competitiveness of various sectors of the industry, and determines the industrial competitive advantage, and provides an effective way of thinking for the government and enterprises to make strategic decisions [3].

The quantitative analysis of the information industry chain mainly focuses on the industrial linkages. At the national level in China, as far as the research on the industrial linkages of the information industry is concerned, the main method is still the influence coefficient and the induction coefficient analysis. The two coefficients are used to measure the position of the information industry in the national economy. The general conclusion is that the industrial linkages of the electronic information production industry is strong, while the industrial linkages of the information service industry is weak (Wei, Dong, 2010) [4]. At the regional level in China, there is no significant difference between the conclusions obtained and the national level (Rong, Ouyang, Wei, 2013, Zhou, 2016) [5-6].

The measurement of industrial linkages only measures the size and direction of Inter-industry purchase, but it cannot measure the distance between industries, nor can it show the relative position of each industry. Dietzenbacher et al. (2005) first proposed the method of measuring the average steps required for exogenous changes in one industry to affect the production value of another another industry by using the average propagation length (APL), and defined this distance as the economic distance between industries, and thus identified the industrial chain [7]. Dietzenbacher and Romero (2007) further expanded the form of industrial chain identification, and proposed three forms: drawing an industrial chain map, analyzing the links between industries among countries, and determining the role of each country in the system to visualize the production structure [8]. Romero, Dietzenbacher and Hewings (2009) believed that a low APL value represents the spatial fragmentation of the industrial chain, while a high value represents the complexity of the industrial chain [9]. Oosterhaven and Bouwmeester (2013) questioned this method and believed that in an economy with only one sector, the impact step between industries is strictly proportional to the impact between industries, and the complexity and fragmentation of industrial chains cannot be compared. In a multisectoral economy, there is a weak but significant negative correlation between the inter industry impact step size and the inter industry impact size [10]. Since then, some scholars have continued to apply and explore the practice based on the measurement method of economic distance between industries. Códigos et al. (2020) used the method of Dietzenbacher to estimate the production chain of the cultural sector in the Brazilian economy from 2011 to 2015, and studied the structural changes of the cultural industry [11]. Ye and Zhang (2019) introduced the minimum spanning tree method to identify the relative position of the agricultural industry chain [12].

The research on industrial linkages of information industry chain has the following shortcomings: previous research only involved the strength of industrial linkage, and did not involve the economic distance between information industry and other industries. Second, there is no accurate description of the relative position of other industries in the information industry chain. Third, the lack of time-series input-output table analysis can not grasp the dynamic situation of the development of the information industry chain. Fourth, the competitive input-output model is used, which exaggerates the relationship between industries and misleads the measurement of economic distance between industries.

The second part of this paper introduces the models and data sources we use. The third part uses the 2018 input-output table to identify the information industry chain with industrial

ISSN: 2688-8645

linkages, economic distance between industries, and complex network, which more clearly shows the status and role of the information industry in the national economy. The fourth part analyzes the development and changes of the information industry chain using the time series input-output table, and compares the measurement differences of the information industry chain under the competitive model and the non competitive model. The fifth part is the conclusion of this paper.

2. Models and Data

2.1. Economic Distance

The demand driven Leontief model:

$$X = (I - A)^{-1}Y \tag{1}$$

Where, X is the total output, Y is the final demand, and A is the input coefficient matrix. Leontief inverse matrix is $(I-A)^{-1}$, recorded as L, its element l_{ij} represents the output of industry i for each additional unit of final demand of industry j.

The Ghosh inverse matrix measures the relationship between the initial input and the total input. From the vertical balance of the input-output table, a supply driven Ghosh model is obtained:

$$X^T = V(I - B)^{-1} \tag{2}$$

Where, V is the initial input. The Ghosh inverse matrix is $(I - B)^{-1}$, Recorded as G ,Its element g_{ij} represents the supply of industry j with an initial input of industryi. And define the distance matrix S:

$$S = \frac{G(G - I)}{(G - I)} = \frac{L(L - I)}{(L - I)} \tag{3}$$

Where, s_{ij} shows the average step of industry j's demand pull on industry i's output, It is also the average step of the output driven by the supply of industry i to industry j.

If the industrial sector itself has a small degree of linkages, the economic distance is still considered, the industrial network will be very complex, and it will make the measurement of economic distance meaningless. Therefore, the industrial linkages matrix is introduced

$$F = \left[(G - I) + (L - I)\right] / 2 \tag{4}$$

Set the threshold value *a,* retain the economic distance value with large linkages, and round the distance.

$$S_{ij}^{*} = \begin{cases} \text{int}(s_{ij}) & f_{ij} \geq \alpha \\ 0 & f_{ij} < \alpha \end{cases} \tag{5}$$

2.2. Minimum Spanning Tree

The previous model cannot explain the relative position of each industry in the information industry chain. For this, we use the method of Ye and Zhang (2019) to further analyze the relative position of each industry in the industry chain using the minimum spanning tree model [12].The steps are as follows.

(1) Calculate the linkages matrix F.

(2) Obtain the industry serial number from the industry included in the production chain and extract the sub matrix of matrix F. If the set of industrial serial numbers included in the production chain is $k = \{1,5,8\cdots\}$, the sub matrix will be extracted. $F^* = F_{k,k}$.

(3) Obtained by symmetrical processing . $\overline{F^*} = F^* + \left(F^*\right)^T$

ISSN: 2688-8645

(4) Find the reciprocal of the element of $\overline{F^*}$.

$$\tilde{F^*} = \begin{cases} \frac{1}{\bar{F^*}_{ij}} \bar{F^*}_{ij} \neq 0 \\ \infty \bar{F^*}_{ij} = 0 \ or \ i = j \end{cases} \tag{6}$$

(5) Drawing undirected graph based on $\tilde{F^*}$, the classical Prim algorithm is used to solve the minimum spanning tree.

2.3. Data Source

This data set is the input-output table of 8 years in 2002, 2005, 2007, 2010, 2012, 2015, 2017 and 2018. There are 42 sectors and 41 sectors in these input-output tables. Except for individul sector that are inconsistent, the information product manufacturing industry and the information service industry are listed as two separate industries. See Ye (2021) for the classification and interpretation of this data set[13].

3. Result Analysis

3.1. Electronic Product Manufacturing Industry Chain in 2018

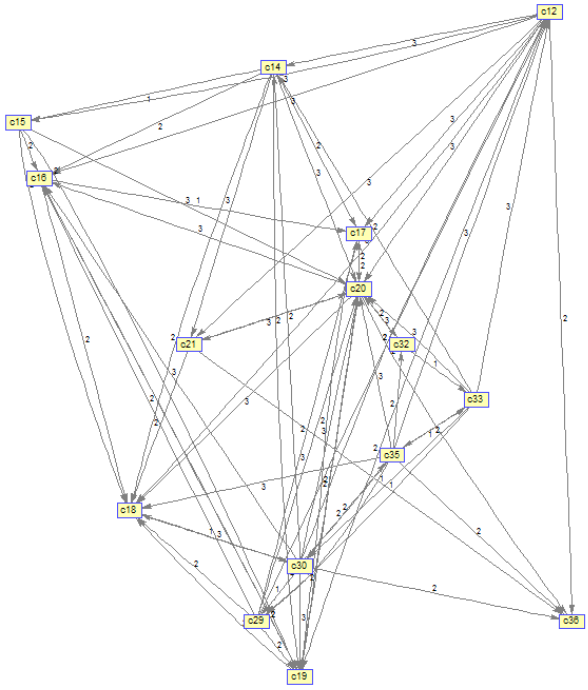

Figure 1. Production Network of Electronic Product in 2018

After setting the threshold value to 0.08 and the economic distance is no more than 3 (rounded), there are still 15 industries left, Chemical products (c12), Metal smelting products (c14), Metalwar (c15),General equipment (c16), Special equipment (c17), Transportation equipment (c18), Electrical machinery (c19), Electronic product (c20), Instruments and Apparatuses (c21), Wholesale and retail (c29), Transportation and post (c30), Information service (c32), Finance (c33), Leasing and business (c35), Scientific research (c36)Respectively.The production network is shown in Figure 1.Electronic products (c20) are located in the center of the electronic product production network, and most of them are indirectly dependent on other industries. The economic distance is basically 2 and 3. The indirect impact of the industry is greater than the direct impact.

ISSN: 2688-8645

Table 1. Industrial chain of electronic products with threshold changes in 2018

Threshold	Distance		
	2	3	4
0.08	Special equipment,Electrical machinery, Electronic product, Instruments and Apparatuses, Information service, Scientific research	Chemical products, Metal smelting products, Metalware, General equipment, Transportation equipment, Wholesale and retail, Transportation and post, Finance, Leasing and business	Metal ore, Waste products, Construction
0.12	Special equipment,Electrical machinery, Electronic product, Instruments and apparatuses, Information service, Scientific research	Chemical products, Metal smelting products, General equipment, Wholesale and retail	Metal ore
0.16	Electrical machinery, Electronic product, Instruments and apparatuses	Metal smelting products	Metal ore
0.20	Electronic product, Instruments and apparatuses	/	/
0.24	Electronic product, Instruments and apparatuses	/	/

Note: ① The row title is the threshold, and the column title is the distance
② If it is a two-way distance, take the minimum distance

Table 1 lists the industrial chain of electronic products when the threshold changes. At the same threshold, from left to right, the economic distance is getting farther and farther. Taking the threshold value of 0.12 as an example, industries with an economic distance of 2 include Special equipment, Electrical machinery, Electronic product, Instruments and apparatuses, Information service, Scientific research. The economic distance of 3 includes Chemical products, Metal smelting products, General equipment, Wholesale and retail. The economic distance of 4 includes Metal ore only.

In the case of the same economic distance, from top to bottom, the greater the threshold, the industrial set at the same distance includes less industries. Taking the case of economic distance 3 as an example, industries with a threshold value of 0.08 include Chemical products, Metal smelting products, Metalware, General equipment, Transportation equipment, Wholesale and retail, Transportation and post, Finance, Leasing and business. Industries with a threshold of 0.12 include Chemical products, Metal smelting products, General equipment, Wholesale and retail. Industries with a threshold of 0.16 include Metal smelting products. Obviously, under the same column, the number of industries included in the industrial set is less and less, and the industrial set at the same distance has the following relationship: the above industrial set includes the following industrial set

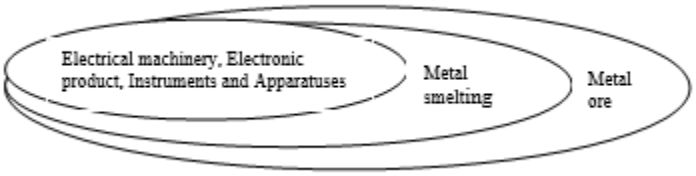

Figure 2. Economic distance of electronic product industry chain under the threshold value of 0.16

When the threshold value is certain, the economic distance can also be represented intuitively in Figure 2. In the above figure, each elliptical layer reflects the distance between each industry in the electronic product chain and electronic products. The closer to the inner layer, the closer

ISSN: 2688-8645

the economic distance is. The inner economic distance is 2, the middle layer is 3, and the outer layer is 4.

3.2. Identification of Production Chain in Information Service Industry

Similarly, this part identifies the industrial chain of the information service industry. Because the information service industry is relatively simple, the industries with an economic distance of 4 are included here, and the information service industry network diagram is drawn, as shown in Figure 3.

It can be seen from Figure 3 that there are both direct and indirect dependencies on the production chain of the Information service industry (IS). Specifically, the economic distance between Information service industry and Financial industry (FIN) and Public management organization (PM) is 1; Its distance from Paper and printing industry (PP), Electronic product (EP), Construction industry (CON) and Leasing business (LB) is 2. The economic distance of the Information service industry itself is 1, which is mainly based on direct dependence. Secondly, the Information service industry is closely related to the Construction, Finance and Public management industries in the forward direction, the Paper printing industry and the Leasing and business industry in the backward direction, and the Information service industry and Electronic product (EP) in the two-way relationship.

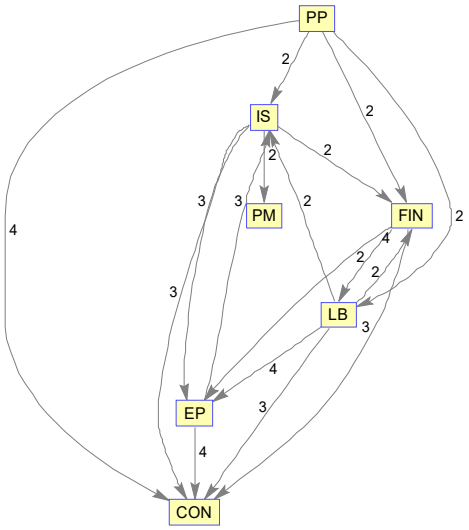

Figure 3. Network Diagram of Information Service Industry in 2018

Table 2. Industrial chain of Information service industry when threshold changes in 2018

Threshold	Distance	
	1	2
0.08	Information service,Finance, Public management organization	Paper and printing,Electronicproduct,Construction, Leasing business
0.12	Information service	Electronic product
0.16	Information service	/
0.20	Information service	/
0.24	Information service	/

Note: If it is a two-way distance, take the minimum distance

Table 2 lists the industrial chain of Information service industry under different thresholds. Taking the threshold value of 0.08 as an example, industries with an economic distance of 1 include Information services, Finance and Public management. The economic distance of 2 is

ISSN: 2688-8645

Paper and printing, Electronic products, Construction and Leasing and business. When the threshold is greater than or equal to 0.16, the Information service industry chain shrinks to a node, the information service industry itself.

Comparing the Electronic product industry chain with the Information service industry chain, we can see that, first, under the same threshold, the Electronic product industry chain is longer than the Information service industry chain, which indicates that the Electronic products and other industries should have close and extensive economic and technological links. Second, the economic distance between the Information service industry and other industries is close, which means that the linkages effect between the Information service industry and other industries are simple and direct.

3.3. Spanning Tree of Information industry

The minimum spanning tree method is used to further identify the relative position of each industry in the information industry chain. This relative position includes whether an industry is located at the center or the edge of the industrial chain. Being located at the center means that the industry is important in terms of both demand and supply on average, while being located at the edge only means that the industry's demand or supply is not important. As we discussed the manufacturing industry and service industry separately in the information industry, we found that there is a strong linkage between them. Here, the Information manufacturing industry and the Information service industry are put on the same chart again to analyze the minimum support tree, as shown in the figure 4.

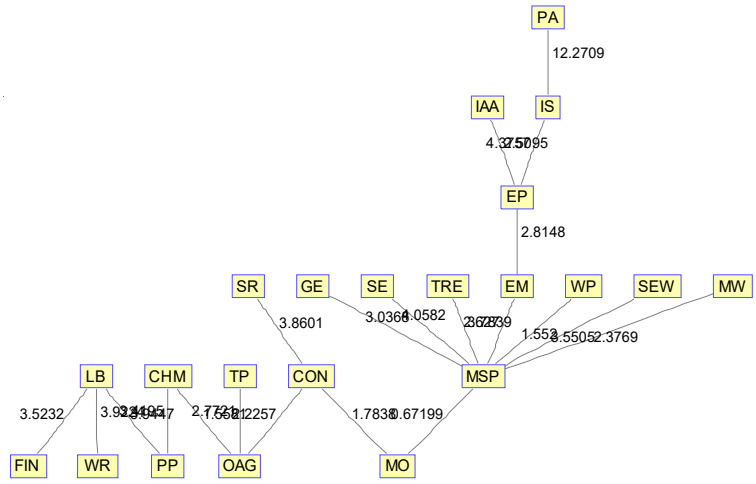

Figure 4. Minimum Spanning Tree of Information industry

It can be seen from the figure 4 that Construction(CON), Metal ore(MO) and Metal smelting products(MSP) are the central industries throughout all industries. Electronic products(EP) have a direct linkage with Instruments and apparatuses(IAA), Electrical machinery(EM) and Information service industry(IS), which further validates the conclusion that drawn from figure 2 and figure 3. Information service industry andElectronic products are combined to extend the industrial chain to the Public management industry(PM).

4. Further Analysis

4.1. Evolution of Information Industry Chain Over the Years

The threshold value is 0.12, and the industries of the 8-year electronic product industry chain are listed in the table. The industry chain shows stability, which is reflected in two aspects. First,

ISSN: 2688-8645

the length of the industry chain does not change much, and the length over the years is 7, 15, 11, 9, 10, 12, 11 and 11 respectively. Secondly, the stability is also reflected in the fact that the relevant industries in the industrial chain and their economic distance change less. For example, in most years, the industries with closer economic distance include Electronic products, Electrical machinery, Instruments and apparatuses, while the economic distances of Metal ores and Metal smelting productsare far.

Table 3. Evolution of electronic productsIndustry chain with a threshold of 0.12

year	distance		
	2	3	4
2002	Electrical machinery,Electronic product, Instruments and apparatuses, Wholesale and retail, Leasing and business	Chemical products, Metal smelting products	/
2005	Non metallic mineral products,Electricalmachinery,Electronic product, Instruments and apparatuses, Information service, Leasing and business, Scientific research	Chemical products, Metalware, Transportation equipment, Wholesale and retail	Metal ore,Oil and gas,Metal smelting products,Supply of electricity and heat
2007	Electronic product, Instruments and Apparatuses, Other manufactured products, Leasing and business	Chemical products, Metalware, Electrical machinery,Finance, Scientific research	Metal smelting products, Waste products
2010	Electrical machinery,Electronic product, Instruments and apparatuses, Scientific research	Chemical products, Metalware, Finance	Metal smelting products,Supply of electricity and heat
2012	Electrical machinery,Electronic product, Instruments and apparatuses, Information service, Scientific research	Chemical products, General equipment, Wholesale and retail, Finance	Metal smelting products
2015	Electrical machinery,Electronic product, Instruments and apparatuses, Information service, Scientific research	General equipment, Transportation equipment, Wholesale and retail, Leasing business	Chemical products, Metal smelting products, Finance
2017	Electrical machinery,Electronic product, Instruments and apparatuses, Information service, Scientific research	Chemical products, Metal smelting products, General equipment, Special equipment, Wholesale and retail	Metal ore
2018	Special equipment ,Electrical machinery,Electronic product, Instruments and Apparatuses, Information service, Scientific research	Chemical products, Metal smelting products, General equipment, Wholesale and retail	Metal ore

Table 4. Evolution of information services Industry chain with a threshold of 0.12

year	distance			
	1	2	3	4
2002	Finance, Construction	/	/	/
2005	Electrical machinery	Electronic product, Construction	/	/
2007	Electrical machinery, Electronic product	/	/	/
2010	/	/	/	/
2012	Information service	Electronic product	/	/
2015	Information service	Electronic product	/	/
2017	Information service	Electronic product	/	/
2018	Information service	Electronic product	/	/

ISSN: 2688-8645

The industries of the information service industry chain for 8 years are listed in the table 4. The industry chain also shows stability. Compared with the industry chain of electronic products, the information service industry chain is shorter, and the economic and technological links are more direct.

The reasons for this stability include the following, the economic and technological links between industries have changed less, the forward and backward linkages of industries remain at the historical level, and the industrial input structure and output structure have not changed fundamentally.

4.2. Impact of Non Competitive Models

Table 5. Evolution of electronic products Industry chain in non competitive model

year	distance			
	1	2	3	4
2002	Electrical machinery,Electronic product	Chemical products	/	/
2005	Electrical machinery,Electronic product, Leasing and business	Chemical products	Metal smelting products	/
2007	Electronic product, Instruments and apparatuses	Chemical products	Metal smelting products	/
2010	Electronic product, Instruments and apparatuses	Chemical products	Metal smelting products	/
2012	Electronic product, Instruments and apparatuses	Chemical products	/	/
2015	Electronic product, Instruments and apparatuses	/	Chemical products	/
2017	Electronic product, Instruments and apparatuses	Electrical machinery	/	/
2018	Electronic product, Instruments and apparatuses	Electrical machinery	/	/

Take the threshold value as 0.12, and use the non competitivemodel, we list the industries in the electronic product industry chain for 8 years. The information service industry chain has the following two characteristics, the industrial chain is shorter and the distance is closer.

The length of the industrial chain in 8 years is 3, 5, 4, 4, 3, 3, 3, respectively. The reason for the shortening is that the import commodity is removed from the industrial chain. At this time, the linkage effect of domestic production is weakened, so the chain of industry is shorter.

The closer economic distance can be explained from two aspects. Firstly, the industrial linkage effect is weakened, and all sectors present "fragmented" production. The complexity of production is reduced, and the degree of circuitousness of production is weakened, which is reflected in the closer economic distance between industries. Secondly, the linkages effect of each industry are relatively balanced. Since imports are excluded, the coefficient with large industrial linkages will decrease by a larger margin. Therefore, the input coefficient of the non competitive model tends to be more evenly distributed, and the connection channels between industries increase, which also shows that the distance between industries is closer.

5. Conclusion

This paper analyzes the information industry chain by using the theory of industry linkages, economic distance and minimum spanning tree. Industrial linkage determines the length of the industrial chain. Economic distance can be used to judge the cumulative speed of influence

between industries. The minimum spanning tree theory is used to judge the relative position of related industries in the information industry chain.

The development and changes of electronic product industry chain and information service industry chain are analyzed by time series input-output table. Under a certain threshold, the industrial chain maintains a considerable degree of stability, which is reflected in the consistency of the length of the industrial chain, the related industries included in the industrial chain, and the economic distance between the industries.

Our calculation results show that using the non competitive model, the linkages effect between industries on the information industry chain is weakened, the industry chain is shorter, and the economic distance between industries is closer. The weakening of the linkages effect and the shortening of the industrial chain can be explained by removing the import coefficient. The closer economic distance can be explained from two aspects: the fragmentation of industrial production leads to the weakening of indirect linkages, the equalization of linkages effect also weakens the indirect linkages of information industry.

Acknowledgments

This work is supported by scientific research project of Anhui university humanities and social sciences (Grant No: SK2021A0228).

References

[1] Wang, X., Wu, Y., Zhang, Y. Research on modeling and simulation of systematic dynamics modle of development of information industry chain[J].Information science, 2013(12): 27-32.

[2] Jiang, X. An analysis to the logical structure of our country’s information industry chain [J].Journal of Zhoukou normal university, 2005, 25(04):153-156.

[3] Lu, M., Li, G., Y ang, X. On the development of China's electronic information industry from the perspective of industrial chain[J]. China Science and Technology Forum, 2004(04): 18-22.

[4] Wei,Y., Dong, Y. An empirical study on the linkages effect of China's information industry [J].Statistics and decision-making,2010(16):123-124.

[5] Rong, L., Ouyang, H., Wei, K. Analysis on the linkages effect of Guangxi information industry [J]. Journal of Guangxi university of science and technology,2013(04):91-97.

[6] Zhou, M. Research on the correlation effect of information industry in Zhejiang province [J]. Research on financial issues, 2016(06):18-22.

[7] Dietzenbacher E, Luna I R, Bosma N S. Using Average Propagation Lengths to Identify Production Chains in the Andalusian Economy [J]. Estudios de Economía Aplicada, 2005, 23(2): 405-442.

[8] Dietzenbacher, E., Romero I. Production chains in an interregional framework: Identification by means of average propagation lengths[J]. International Regional Science Review, 2007, 30(4):362-383.

[9] Romero, I., Dietzenbacher, E., & Hewings, G.J.D. Fragmentation and complexy: analyzing structural change in the Chicago regional economy[J]. Revista de Economia Mundial, 2009, 23:263-282.

[10] Oosterhaven,J.,Bouwmeester,M.C.The average propagation length conflcting macro, intra-industry and interindustry conclusions[J].International Regional Science Review.2013,36(4):481-491

[11] Códigos J, O R, Morrone H, et al. The cultural sector's productive chain in Brazil: estimation and structural change from 2011 to 2015 [J]. Nova Economia, 2020, 29(Especial): 1171-1194.

[12] Ye, A., Zhang, M. Study on the identification of agricultural industry chain in Liaoning province [J]. Journal of Shenyang agricultural university (Social science edition), 2019(03):269-275.

[13] Ye, A., Chen, Y., Zhang, M. Industrial linkages analysis of China's information industry [J]. International core journal of engineering, 2021, 7(11):70-82.