Does the Degree of Digitalization Inhibit Credit Risk Contagion of New Economy Firms

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ABSTRACT

Based on 19 new economy firms in the Chengdu-Chongqing Economic Circle, this paper constructs a three-year new economy firms credit risk contagion network model from 2019 to 2021. On this basis, the topological properties of the network are measured from the full network structure and node attributes, and the contagion path of credit risk of new economic firms and the process of dynamic changes over time are analyzed. Further, the text analysis method is used to measure the degree of digitalization of new economy firms, combined with the credit risk contagion network, to study the effect of digitalization degree on the credit risk contagion of new economy firms. The final empirical results show that the degree of digitization has an inhibitory effect on the credit risk contagion of new economy firms, and the contagion inhibitory effect on the important "bridge" node firms in the contagion network are more significant.

Keywords: *Degree of digitalization, New economy, Credit risk contagion, Contagion network.*

数字化程度会抑制新经济企业信用风险传染吗

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摘要

文章以成渝双城经济圈的 19 家新经济企业为样本，构建 2019-2021 年三年期新经济企业信用风险传染网络模型。在此基础上从网络整体结构与节点属性方面测度网络的拓扑性质，并且分析新经济企业的信用风险传染路径和随时间动态变化的过程。进一步地，运用文本分析法对新经济企业数字化程度进行计量，结合信用风险传染网络，研究数字化程度对新经济企业信用风险传染的影响作用。最终实证研究表明，数字化程度对新经济企业信用风险传染具有抑制作用，并且对传染网络中重要“桥梁”节点企业的传染抑制作用更显著。

关键字：*数字化程度，新经济，信用风险传染，传染网络.*

1. INTRODUCTION

The number of Chinese new economy firms disclosed by State Administration of Market Regulation

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in 2021 increased by 15.8% year-on-year and 26.5% from 2019, which signifies an acceleration in the development of China's new economy. In the start-up and development stages of new economy firms, credit is the linking medium for external economic activities, providing support for firms to absorb investment, receive credit, and solidify supply chains, etc. However, credit risk arises from this default when there is a loss caused by the failure of the firms to perform. Moreover, credit risk has an associated contagion effect, which is manifested in lending, supply chain links or contagion among the same region and industry, forming a credit risk contagion network[1]. Previous studies on firms' digitalization and credit risk have mainly explored the impact of digitalization on individual credit risk, ignoring the fact that credit risk is not generated by individuals alone, but there are industry spillovers and contagion network. Therefore, this paper will analyze the credit risk contagion of new economy firms and further explore its role in influencing the credit risk contagion network in the context of the most obvious feature of the development of new economy firms, namely the degree of firm digitalization.

In the past three years, relying on national strategy of China to promote the construction of Chengdu-Chongqing Twin-city Economic Circle. Against this backdrop, Chengdu-Chongqing have the highest total new economy index in China, but the development of new economy firms is limited by the capital needs and the degree of technology. Moreover, new economy firms are in more obvious industry-related effects and are more likely to face intra-industry contagion of credit risk. The purpose of this paper is to investigate the role of digitalization of new economy firms on risk network. We take the new economy firms in Chengdu-Chongqing regions as samples to establish the credit risk contagion network of firms in the same region and industry, and further investigate the relationship between the both.

This paper is structured as follows. In Section 2 constructs the credit risk contagion network, detailing the establishment method and indicator measure. In section 3 presents the research hypotheses and research data. In Section 4 the empirical models are outlined. And Section 5 concludes.

2. CONSTRUCTION OF CREDIT RISK CONTAGION NETWORK

2.1. CREDIT RISK CONTAGION RELATIONSHIP

2.1.1. Relationship Determination

The relationship is a key factor in network analysis, and the modeling approaches used in the present research for the determination of credit risk contagion relationships have been abundant, mainly including the Pearson correlation coefficient method, Granger causality test, etc., which constructs the contagion relationships by risk indicators[2], as well as building complex network to portray the credit risk contagion mechanisms according to the association between organizations, such as credit-debt relationships, guarantee relationships, related party relationships, etc. [3,4]. Different analytical methods have different focuses when studying risk contagion. Pearson correlation coefficient method and Granger causality test are set on the basis of time statics, which to some extent show the direct risk contagion relationship between firms, but require higher requirements for the construction of risk indicators. While network connection based on inter-organizational operation and cooperation relationship focuses more on the risk contagion generated by mutual relationship. In contrast, network connections based on inter-organizational business and cooperative relationships focus more on the risk contagion generated by mutual relationships, and require certain business connections between organizations to build the network model.

Based on the advantages of previous methods, this paper mainly calculates the quarterly default distance as a one-year risk indicator based on the KMV model, followed by the Pearson correlation coefficient method to establish the relationship matrix, and finally analyzes the multi-subject credit risk contagion by social analysis network to realize the risk contagion from "point" to "surface", which overcomes the static and single nature of the correlation coefficient method to a certain extent.

2.1.2. KMV Model

Credit risk usually measured using the KMV model. Based on Merton's idea of constructing a model in which the face value of debt is subtracted from the market value of the firm and divided by the estimated volatility of the firm's value[5], the KMV model treats the firm's debt as a European call option with the firm's assets as the underlying assets. As well as the market value of the firm's equity is calculated through the Black-Scholes option pricing model. Finally, based on KMV's definition of default distance, which is a multiple of the standard deviation of the value of the firm's assets from the default point, the quarterly default distance *DD* formula is obtained.

$$DD = \frac{V - D}{V\sigma_V} \tag{1}$$

Where V is the firm's asset value, σ_V is the firm value volatility. D is the default threshold, which is the book value of debt. The smaller the *DD*, the higher the credit default risk.

2.1.3. Pearson correlation method

To establish the credit risk contagion network of firms, first need to determine the credit risk connection relationship between firms, and this paper uses the

Pearson correlation coefficient method to determine. In the credit risk contagion network of firms, each firm is taken as a network node, and the contagion network is established by the quarterly default distance *DD* within a year period for that year, and the connected edge weights of nodes indicate the risk correlation between nodes. The Pearson correlation coefficient is measured by dividing the covariance of two continuous variables by the product of their respective standard deviations with coefficients in the [-1,1] interval, with coefficients tending to 0 indicating weaker correlations between the variables, with the formula.

$$\rho_{ij} = \frac{E(DD_i DD_j) - E(DD_i)E(DD_j)}{\sqrt{[E(DD_i^2) - (E(DD_i))^2] \cdot [E(DD_j^2) - (E(DD_j))^2]}} \quad (2)$$

Where the DD_i and DD_j are the default distance between firm *i* and firm *j*, respectively. Considering that this paper intends to build a valued undirected network, an absolute value measure is used for ρ_{ij}. Then, an adjacency matrix containing all pairs of firms (i, j) in accordance with ρ_{ij} is created and the diagonal value is defined as 0.

2.2. NETWORK STRUCTURE METRICS

2.2.1. Full Network Density

Network density is the most basic measure at the network level, which reflects the closeness of firm risk connections in the credit risk network. The higher the network density, the closer the contagion relationships and the greater the impact of the network structure of risk contagion on the credit risk generated by each firm. Density is calculated by dividing the total number of dyadic ties in the risk network by the maximum number of possible dyadic ties in the network, with the formula.

$$D_{FN} = \frac{\sum\sum k_{ij}}{N(N-1)} (i \neq j) \quad (3)$$

Where the k_{ij} is the two-party relationship between firm *i* and firm *j*, and *N* is the total number of nodes in the network.

2.2.2. Degree Centrality

Centrality is a measure of the node hierarchy, and degree centrality is the simplest and most important way to characterize centrality. The degree centrality is obtained by measuring the sum of the number of nodes of other firms connected to the target firm and the number of relationships of the target firm. If the degree centrality of an firm in the network is larger, it indicates that the firm is at the center of the credit risk contagion network. The formula follows.

$$C_D(i) = \sum_{j=1}^{N} a_{i,j} (i \neq j) \quad (4)$$

Where the $a_{i,j}$ is the number of edges from firm *i* to firm *j*. In a network consisting of *N* nodes, the degree centrality of firm *i* is the number of edges of other firms directly connected to it.

2.2.3. Betweenness Centrality

Betweenness centrality is a measure of the target firm's "middle" position in the risk contagion network among other firms, reflecting the extent to which the firm controls the risk contagion relationship among other firms. The greater the betweenness centrality, the greater the influence of the firm on the credit risk of other firms, as the firm is in the key connection of the risk transmission network. According to the measure proposed by Freeman[6], with the following formula.

$$C_B(i) = \sum_{j<k}^{N} \frac{a_{j,k}(i)}{a_{j,k}} (i \neq j \neq k) \quad (5)$$

Where the $a_{i,j}$ is the number of edges between firm *j* and firm *k*, $a_{i,j}(i)$ is the number of edges between firm *j* and firm *k* that pass through firm *i*. The sum of the risk transmission paths between all other firms in the network that pass through firm *i* is the betweenness centrality of firm *i*.

2.2.4. Closeness Centrality

The closeness centrality portrays how quickly the risk of the target firm in the credit risk network can be transmitted to other firms, and the larger the closeness centrality, the stronger the firm's ability to transmit credit risk to other firms in the network and belongs to the central actor in the credit risk network. It is mainly obtained by calculating the reciprocal of the sum of the shortest path lengths of the target firm and other firms, with the formula.

$$C_c(i) = \frac{1}{\sum_{j=1}^{N} d(i,j)} (i \neq j) \quad (6)$$

Where the $d(i, j)$ is the number of shortest distance edges from firm *i* to firm *j*. In addition, the closeness centrality does not include isolated nodes in the network because the denominator measures the sum of the shortest distance of node connections.

3. RESEARCH HYPOTHESIS AND DATA

3.1. RESEARCH HYPOTHESIS

3.1.1. Degree of Digitalization and Credit Risk Contagion

In the digital economy, digital technologies have a multidimensional impact on the way organizations do business and create value. Specifically, the impact of

digitization on credit risk is divided into two dimensions. Firstly, individual firms generate heterogeneity. In the digital context, firms change their original business models through digital use, especially new economy firms mainly rely on digital technology to carry out a series of innovations, and they need a high degree of digitization more to enable themselves to gain competitive advantages in the industry, thus reducing the possibility of their own risk contagion. Second, firms' Reputation improvement, the increased digitalization of new economy firms not only facilitates the dissemination of information[7], but also improves the convenience of supervision by creditors and regulators, and saves the cost of information acquisition. Thus enhancing the reputation of firms and indirectly weakening the degree of contagion of firms in the credit risk network. Accordingly, this paper proposes the following hypotheses.

H1: The degree of digitization among new economy firms inhibits the intensity of credit risk contagion.

3.1.2. Degree of Digitization and Credit Risk Network Characteristics

The degree of digitization represents the importance and investment of firms in new technologies. Especially for new economy firms whose core competencies are new technologies, new models and other innovative approaches, the adoption of digital technologies helps new economy firms optimize factor resources and improve resource allocation efficiency[8]. The degree of digitization of new economy firms affects the risk contagion of firms, but individual firms are in different positions in the credit risk contagion network and the degree of importance is not consistent. Nodes with significant influence on credit risk contagion have the characteristics of having more contagion chains, being in the intermediary position of network propagation, and having short contagion paths. But the nodes of firms corresponding to the three characteristics are often not the same, and the three types of firms are different in nature. The degree of digitization also has different inhibiting effects on the risk contagion of firms in different positions. For firms that are not the main source of risk but are in a "bridge" position in the contagion chain, the degree of digitization has a stronger inhibiting effect on the credit risk contagion of such firms. Because of their relatively good business conditions and digital technology. Accordingly, this paper proposes the following hypotheses.

H2: The degree of digitalization among new economy firms inhibits credit risk contagion at "bridge" nodes.

3.2. MATERIALS

This paper takes the new economy listed companies in Shanghai and Shenzhen A-shares of Chengdu-Chongqing Economic Circle in 2019-2021 as the research object and eliminates the missing samples of key variables, and finally obtains the data of 19 firms. The data are obtained from the CSMAR database, and the types of industries belonging to the new economy are screened according to the Industry Classification Guidelines for Listed Companies revised by CSRC in 2012, which are divided into three industries[9].

3.3. VARIABLE DEFINITION

3.3.1. Independent Variable

To test the hypothesis, the degree of digitization is used as the independent variable in this paper. From the existing literature for digitization degree, it is known that the measurement of digitization degree is divided into qualitative description and quantitative analysis. The quantitative analysis mainly identifies the frequency of key words with digitization characteristics through text analysis, and the frequency of words appearing in the current annual reports of firms is used as the basis for measuring the degree of digitization. The digitalization discussed in this paper is to make the technology applied at the practical level through the development of digital technology, so the measurement of the degree of digitalization is based on four typical digital technologies "ABCD" (A for Artificial Intelligence, B for Blockchain, C for Cloud Computing, and D for Big Data) according to the method of Wu et al.[10]. Finally a feature lexicon is obtained by applying them at the technical practical level to build an index to measure the degree of digitalization of firms (*Digital*). The digitization word frequency of Chengdu-Chongqing new economy firms shown in Figure 1 for the three-year period is increasing year by year, indicating that the digitization of new economy firms is gradually increasing.

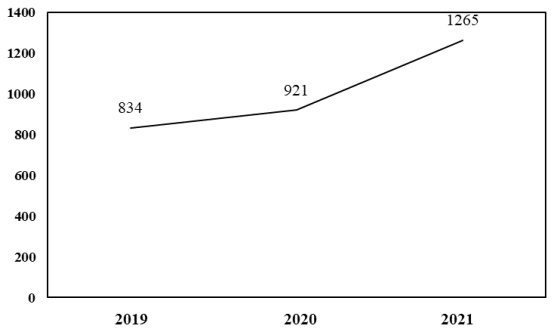

Figure 1. Digitization Words

3.3.2. Dependent Variable

The node centrality property of each firm in the network is an important indicator in network analysis, reflecting the intensity and location of credit risk contagion among firms. As such, this paper measures the contagion intensity of the credit risk network of the new economy firms in Chengdu and Chongqing by three indicators: degree centrality, betweenness centrality, closeness centrality.

4. EMPIRICAL RESULTS

4.1. NETWORK STRUCTURE CHARACTERISTICS

4.1.1. Full Network Characteristics

By measuring the full characteristics of the credit risk contagion network of the new economy firms in Chengdu-Chongqing, the data of risk contagion network nodes, connected edges and network density characteristics for the three-year period of 2019-2021 were obtained. As shown in Table 1, the risk contagion network nodes are 19 for all three years, indicating that individual credit risk has a spillover effect on other firms in similar industries in the same geographic area, which corroborates with Leary's study[11]. Secondly, the number of connected edges and network density of risk contagion are increasing by years, indicating that the credit risk contagion chain among the new economy firms in Chengdu-Chongqing is increasing and the overall risk contagion is closer. The development of new economy industry is continuously promoted, so that the business connection among new economy firms in Chengdu-Chongqing is more frequent. At the same time, the degree of individual credit risk contagion increases step by step with business cooperation.

Table 1. Full Network Characteristics

Year	Nodes	Edges	Density
2019	19	161	0.471
2020	19	162	0.474
2021	19	165	0.482

The topology of the credit risk contagion network of the new economy firms in Chengdu-Chongqing is further drawn, and limited to space, only for 2021, as shown in Figure 2. The area of firm nodes is measured by betweenness centrality, which represents the high and low status in the network, and it can be seen that there are 14 firms occupying the core position in the credit risk contagion network, and these nodes are connected to many surrounding nodes. The thickness of the connected edges represents the degree of risk contagion between nodes, and the thicker the connected edges, the higher the degree of contagion of the node by the corresponding node.

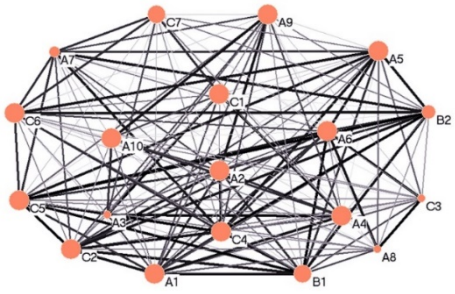

Figure 2. 2021 Credit Risk Contagion Network of New Economy Firms

4.1.2. Node Network Characteristics

The centrality of each node is calculated according to formulas (4), (5) and (6), and the results in Table 2 show that the degree centrality of the credit risk network of individual firms in the Chengdu-Chongqing New Economy indicates that the risk contagion chain varies greatly among firms. The betweenness centrality indicates that the number of firms playing the role of "bridge" in the risk contagion network is high. Closeness centrality indicates that as long as a few firms are quickly connected to other firms in the risk contagion network, they belong to the actors of credit risk contagion. Figure 3 depicts the centrality of firm nodes in 2021, where the horizontal axis represents betweenness centrality, the vertical axis is degree centrality, and the circle area represents closeness to centrality, from which it can be judged that in 2021, there are four firms with mediated bridge role in the risk contagion network of new economy firms in Chengdu-Chongqing, and there is a correlation between the degree centrality, betweenness centrality and closeness centrality of firm nodes.

Table 2. Node Network Characteristics

	Degree Centrality	Betweenness Centrality	Closeness Centrality
Mean	9.944	18.877	0.439
Median	10.200	19.000	0.443
Std.Dev	1.717	0.927	0.156
Max	12.700	22.000	0.674
Min	6.600	18.000	0.059

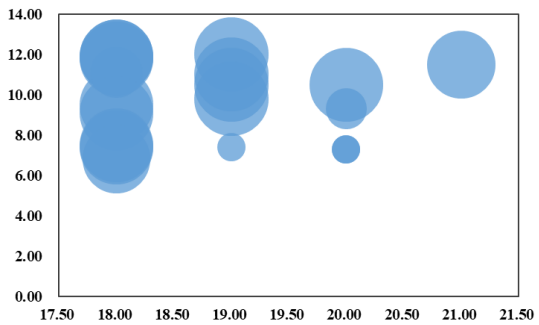

Figure 3. 2021 Node Network Characteristics

4.2. HYPOTHESIS TEST

The regression results presented in Table 3 show that the degree of digitization of new economy firms weakens the centrality of individuals in the credit risk contagion network and inhibits the risk contagion of nodal firms, and we hypothesis H1 is verified. Among them, the degree of digitization has the most significant

inhibitory effect on the betweenness centrality of nodes in the risk contagion network ($p < 0.01$), indicating that the contagion intermediary paths are decreasing, which in turn inhibits the credit risk contagion of the whole network. So that hypothesis H2 is verified. Meanwhile, both degree centrality and closeness centrality are significantly weakened by the degree of digitization.

Table 3. Results of Multidimensional Fixed Effects Regression

	Degree Centrality	Betweenness Centrality	Closeness Centrality
Digtal	-0.005**	-0.001***	-0.004*
	(-2.175)	(-2.840)	(-1.804)
Constant	7.231***	0.410***	16.642***
	(21.915)	(17.602)	(106.319)
Controls	Yes	Yes	Yes
Year Controls	Yes	Yes	Yes
Observations	57	57	57
Adj R^2	0.102	0.488	0.040

Note: *, **, *** respectively indicate statistically significant at 10%, 5%, 1% level with t-values in parentheses.

5. CONCLUSION

In this study, we establish a valued undirected network for credit risk contagion of new economy firms in the Chengdu-Chongqing region to mine the contagion network characteristics of credit risk of new economy firms. And this paper finds that the full network edge counts and density of risk contagion of new economy firms in Chengdu-Chongqing rises during 2019 to 2021, while the firm nodes differ significantly in degree centrality and betweenness centrality performance. The effect of digitization is further investigated and it is found that digitization weakens the credit risk contagion of new economy firms and has the most significant effect on reducing the betweenness centrality of the node firms.

This paper systematically composes and establishes a network for credit risk contagion among new economy firms, especially in the context of the rapid development of new economy and digital technology. It also examines three paths by which the degree of digitization affects credit risk contagion, providing a reference for developing a new economy, accelerating digitization, resolving credit risks and crises. In addition, credit risk contagion will show differences according to inter-firm relationships, and the effect of digitalization degree on risk contagion varies by industry, which will be a direction for future research.

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