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The Risk Analysis for Supply Chain Finance Based on Complex Network

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Abstract. The effective control and precaution of financial risks is becoming crucial for supply chain finance services. This paper establishes a supply chain finance system using complex network model approach, comprehensively analyze the network efficiency and network node and further evaluate their influences for supply chain finance risks with a case calculation. The assessment methodology and prevention mechanism for financial risk will provide consult and guidance for supply chain finance services.

Introduction

With economic globalization, supply chain finance is increasingly becoming one of the most important financing methods for banks and enterprises. In supply chain financial services, financial risks are still the crucial factor for supply chain participators. Supply chain finance integrates the business flow, capital flow, logistics and information flow in the supply chain and form a complex supply chain finance social network, namely a complex network.

The factors for Supply chain financial risks are various. On the one hand, in supply chain finance services, the relation between the bank and the loan enterprise is a typical principal-agent relationship. The asymmetric information between each other will greatly increase the probability of financial risk. On the other hand, there are many uncertain factors in the operation process of supply chain finance services including subjective and objective factors. These factors will lead to the deviation produced between the expected return and the actual gain for supply chain enterprise, and thus become other risks for supply chain finance services.

The nature of supply chain finance is a complex network, which will cause the risk diffusion between supply chain enterprises due to their network relations. In supply chain financial services, once a participator defaults that would cause to appear the financial risk for other related partners. In a supply chain finance network system, the relationship between enterprises is more complex and industry concentration is higher, thus the default infection often breaks out more intensively and more influentially. These risks are not only related to the characteristics of supply chain enterprises, but also to the structure of the complex network.

Construction of Supply Chain Financial Network System

In the supply chain finance network system, the core enterprise is crucial and has a central role. In the network system, nodes with high degree are in the minority which represents the core enterprises nodes, while most nodes with relatively low degree which represents the small and medium enterprise in the supply chain with intense financing demands. Shen (2013) and Zhon (2015) demonstrated that supply chain finance network is a scale-free network and the degree of node submits to the power-law distribution [1, 2]

Referring to relevant literature, we put forward a complex network system for supply chain finance using BA scale-free network model. BA network model has two characteristics, namely the growth and priority connection mechanism. For the growth, the network size is constantly increasing and so the number of network nodes is also constantly increasing. For the priority connection mechanism, the constantly emerging new nodes in the network system are more likely to connect to those nodes that have been more connected. The algorithm for the construction is as follows [3]:

(1) Growth: Starting from an initial network with m_0 nodes, each time a new node is introduced and connected to a node with m nodes already connected, where m<= m_0.

(2) Priority connection: The probability of a new node connected to an existed node i is p, and the degree of node i is k_i, which can be expressed as $p = k_i/(k_1 + k_2 + k_3 + \cdots + k_n)$, where n is the total number of nodes in the network.

(3) Weight assignment for the new edge.

Barrat et al. [4] for weighted network proposed that $\omega_{ij} \sim (k_i k_i)^{\theta}$, where θ is the control coefficient for the weight growth. If θ is zero, this represents a no-weight network. Referring to Xie [4], we can define the weight of network as follows:

$$w_{ij} = w_0 (k_i k_i)^{\theta}, w_0 = \frac{{k_0}^2}{(k_0)^{1+\theta^2}} \quad (1)$$

Following the algorithm proposed by Li et al. [5] and combined with the actual supply chain finance service in Industrial and Commercial Bank of China, a BA scale-free network was set up, where a scale-free network with 20 nodes was simulated.

Because the algorithm assumed each company in the network would connect with at least 3 companies, there are m=3 and $\theta = 2$. In the BA scale-free network, the degree of node for most of the enterprises is in the range from 3 to 5, while a few of them is over 8 that is the core enterprise in the complex network, as shown in figure2 by Ucinet application.

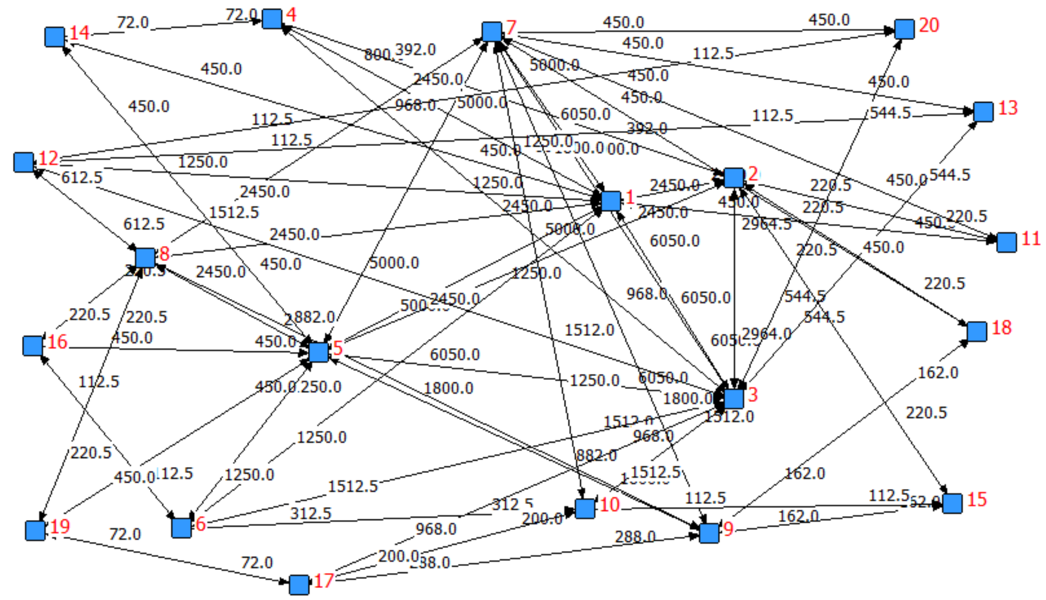

Figure 2. Supply chain finance complex network.

Network Analysis of Supply Chain Finance

Influence Analysis of Network Node

Because supply chain finance services involve many small and medium-sized enterprises, the risk communication will also involve every node in the complex network, and nodes with different influence have different promotion effects for risk communication. In a relational network, each node's choice of connection is different. Some nodes are selected by more actors. Although some nodes are selected by a few actors which are the most influential points, the feature cannot just be measured by degree. This paper analyzes influences of nodes by influence index.

In the supply chain finance network, the influence index reflects the mutual influence of two enterprises in the network, and is only related with the network structure but irrelevant with the amount of debt. The network structure represents whether there is a supply relationship between enterprises (direct or indirect upstream or downstream, competition, etc.) or whether the affiliated enterprises have sufficient influence (namely the core enterprise).

The influence index is usually more suitable for a directed network, and thus we assume that the relationship between supply chain enterprises would be bi-directional, and a transaction between two enterprises would cause same impact for them.

Referring to Huber influence index, the matrix of influence index can be expressed by the function as follows:

$$T = (aC)^0 + (aC)^1 + a^2C^2 + \cdots + a^kC^k + \cdots = I + \sum_{k=1}^{\infty}(aC)^k = (I - aC)^{-1} \quad (2)$$

where C_{ij} of the matrix C represents one-step reachable from node i to node j, and ${C_{ij}}^2$ represents two-step reachable and so on, a is the attenuation factor, and its impact obviously will become weakened for multi-step reachable. If a =0 that indicates complete decay, while if a =1 that indicates no decay. During calculating Huber influence index, a unit matrix I is brought in for the matrix sequence to represent the external influencing factors. In the extreme case, the impact matrix is defined as $(I - aC)^{-1}$.

By summing up the rows and the columns of influence index matrices respectively, the influence index of the every node in the whole network can be obtained.

Network Efficiency Analysis

In the complex network, there are many ways to measure the communication efficiency between nodes. The traditional methodology includes average distance and aggregation coefficient which are based on the no weight network and sparse network.

In supply chain finance, we mainly study the communication and dissemination between network nodes. Network efficiency index can reflect the effective level of information communication between nodes, and apply to weighted network. Therefore, this paper chooses the network efficiency index to study the closeness of communication between the nodes.

In supply chain financial networks, network efficiency is related to the amount of debt and the proximity of relation. The greater amount of debt is, the greater volume of transactions between enterprises is, the more frequent transactions are, and the higher network efficiency is. Likewise, the closer enterprises in the supply chain are, the higher network efficiency index is.

Referring to the definition of network efficiency for the no-weight network and the dissimilarity-weight network by Latora, the efficiency of node i, j can be expressed by the function as follows:

$e_{ij} = \frac{1}{d_{ij}^*}$, where d_{ij}^* is the shortest path. Thus the global efficiency can be expressed as

$$E(G) = \frac{1}{N(N-1)}\sum_{i \neq j}\frac{1}{d_{ij}}, \quad (3)$$

For similarity network, the weight is inversely proportional to the distance; that is, the greater the weight is, the closer the connection between the nodes is. The supply chain financial network belongs to the similarity network. In supply chain finance, the weight represents the amount of transactions between enterprises. Referring to the similarity network by Tian etc. [6], we define $e_{ij} = d_{ij}^*$, namely the efficiency is equal to the shortest path.

For the node with multi-step path, this paper further defines the efficiency factor γ. If γ is 1, that represents the normal operation for enterprises in the system. If there is a mutation in the enterprise, γ is adjusted appropriately. Since $d_{ij} = 1/w_{ij}$, the shortest path $d_{ij}^* = min(d_{ik} + \cdots + d_{kj}, i, j, k \in N)$, so for the similarity network, the network efficiency is defined as follows:

Efficiency between nodes i, j is

$$e_{ij} = \gamma_{ij} \cdot d_{ij}^* = \gamma_{ij} \cdot (\min({w_{ik}}^{-1} + \cdots + {w_{kj}}^{-1}, i, j, k \in N))^{-1} \quad (4)$$

Global efficiency is

$$E(G) = \frac{1}{N(N-1)} \sum_{i \neq j} \left(\gamma_{ij} \cdot \min\left(w_{ik}^{-1} + \cdots + w_{kj}^{-1}, i, j, k \in N \right) \right)^{-1} \quad (5)$$

To calculate the network efficiency between any two nodes and traverse the network adjacency matrix, this paper uses the Floyd algorithm to find the shortest path. Specific steps are as follows:

①Establishing the network adjacency matrix A. The weight between i and j is equal to *0* means no connection.

②A can be converted to a distance matrix D, according to $d_{ij} = 1/w_{ij}$. Infinity between two points means no link.

③Finding the shortest path between two nodes, $min(w_{ik}^{-1} + \cdots + w_{kj}^{-1}, i, j, k \in N)$ using Floyd algorithm, and setting up a distance matrix I.

④To solve the network efficiency according to the shortest path matrix and network efficiency formula (3) (4).

Calculation Analysis of Sample

Through the overall network analysis of supply chain financial network, we can calculate its node influence index and node network efficiency to analyze the overall network risk of different nodes. Using Ucinet platform to solve the Huber influence index in the above simulation network, the calculation results are shown in Table 1.

Table 1. The influence index of all enterprise.

Enterprise ID	Degree	influence index	Enterprise ID	Degree	Influence index
1	10	33.42578	11	3	1
2	7	17.05469	12	5	2
3	11	16.39063	13	3	1
4	4	1.5	14	3	1
5	10	11.21875	15	3	1
6	5	2.625	16	3	1.5
7	10	7.6875	17	4	1
8	7	4.375	18	3	1
9	6	2.75	19	3	1
10	5	2.25	20	3	1

(1) The node with high degree has relatively high influence, but not absolutely. In other words, the degree does not have an absolute correlation with the index of influence. For the enterprise 3, its influence is only half of node 1, and the risk impact is also less than enterprise 1, but its degree is highest.

(2) The calculation of influence index is not about the weight. By observing the supply chain network diagram, it can be found that the direct coverage of the supply chain of enterprise 1 is relatively broader than other enterprises. Therefore, the influence index can be distinguished from the network efficiency and degree, measuring the enterprise's influence in the supply chain network is persuasive, and it can be considered that the overall network risk is closely related to the network structure.

(3) The enterprises with low influence index have little influence on the entire network. Therefore, for small and medium-sized suppliers and terminal dealers, if they encounter a crisis, they will have less impact on the entire supply chain network.

The global network efficiency *E(G)*=0.124. By further analyzing 20 enterprise nodes, we can calculate the average network efficiency of all the nodes and the overall network efficiency after removing a node, as shown in Table 2.

(1) For the core enterprise with high degree, both the average network efficiency and the difference of overall network efficiency after node removal are greater. The communication between the core enterprises and each node enterprise is tight, which plays an important role on the connection of entire supply chain network and is in line with the actual situation.

(2) Enterprises that have high communication efficiency may not increase the communication efficiency of the entire network. Taking core enterprise 3 and 5 as an example, enterprise 5 is lower than enterprise 3 both in terms of degrees and their respective average network efficiencies, but its influence on the overall network efficiency is much higher than that of Enterprise 3, which indicating that an enterprise connected with a stronger core enterprises may not have a higher efficiency of communication, but has higher influence on the entire network communication efficiency.

Table 2. The global network efficiency of nodes.

Enterprise Id	Degree	Average network efficiency	Overall network efficiency after node removal	The difference of overall network efficiency after node removal
1	10	0.256136	0.097044	0.026956
2	7	0.162057	0.10636	0.01764
3	11	0.281881	0.102632	0.021368
4	4	0.082451	0.115371	0.008629
5	10	0.26005	0.092354	0.031646
6	5	0.108392	0.11264	0.01136
7	10	0.255906	0.095009	0.028991
8	7	0.148778	0.108389	0.015611
9	6	0.119746	0.111445	0.012555
10	5	0.108014	0.11268	0.01132
11	3	0.048951	0.118897	0.005103
12	5	0.107897	0.112692	0.011308
13	3	0.056299	0.118123	0.005877
14	3	0.049007	0.118891	0.005109
15	3	0.027045	0.121203	0.002797
16	3	0.048596	0.118934	0.005066
17	4	0.082451	0.115371	0.008629
18	3	0.048392	0.118956	0.005044
19	3	0.048596	0.118934	0.005066
20	3	0.056299	0.118123	0.005877

Moreover, network efficiency can indicate the information exchange efficiency among enterprises such as the communication of risk knowledge, as thus the risk tolerance of network nodes is related to the risk knowledge, and the risk spreads quickly to other enterprises because of high network efficiency. Therefore, network efficiency has a more complicated relationship with the financial risks in the network.

Conclusion

Following merchandise flows through upstream and downstream of the supply chain, there are various capital flows generated among the supply chain enterprises, such as short-term loans, as well as accounts receivable and prepayments, and they eventually form a typical complex network.

In the supply chain finance network system, the transaction information and roles for each enterprise in the system can be represented by the influence of nodes and the efficiency of network. Moreover, the impact of the social network further highlights and the default risks are discussed and measured, including either the external interference effected by the default risk of the social network and the influence to the whole network caused by the default of a enterprise in the system.

The study indicates that for enterprises in the social network, the higher influence of the network node for the default enterprise is, the higher probability of default is. Meanwhile, the greater influence of the default enterprise is, the stronger infection of the risk is.

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