Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 199 (2022) 946–953

Procedia Computer Science

www.elsevier.com/locate/procedia

The 8th International Conference on Information Technology and Quantitative Management (ITQM 2020 & 2021)

Evaluation of associated credit risk in supply chain based on trade credit risk contagion

Xiaofeng Xie[a], Xiuying Hu[a], Kai Xu[b], Junyao Wang[c], Xinyu Shi[c], Fengying Zhang[d],*

[a]West China Hospital/West China School of Nursing, Sichuan University, Chengdu, Sichuan, China
[b] Business School, Chengdu University, Chengdu, Sichuan, China
[c] School of Economics, Sichuan University, Chengdu, Sichuan, China
[d] West China School of Nursing/West China Hospital, Sichuan University, Chengdu, Sichuan, China

Abstract

The evaluation of associated credit risk in supply chain is a difficult problem in the current credit risk management practice. Based on graph theory and fuzzy preference theory, we put forward a new evaluation method of associated credit risk in the supply chain. First, the credit risk of enterprises in supply chain are divided into "self-own credit risk" and "credit risk contagion". Second, the indicator system of self-own credit risk evaluation of enterprises in the supply chain is designed, and the fuzzy comparative judgment matrix of self-own credit risk evaluation indicator is obtained by using fuzzy preference relation, and the evaluation basic model of "self-own credit risk" is established. On the basis, the evaluation derivative model of "credit risk contagion" is established. Furthermore, by integrating the two kinds of evaluation results, the credit risk of enterprises in supply chain is evaluated comprehensively, and the contagion effect of associated credit risk in supply chain based on trade credit risk contagion (TCRC) is revealed.

Keywords: Supply chain; Trade credit; Self-own credit risk; Credit risk contagion; Risk assessment

* * Corresponding author.
E-mail address: zhangfengying@scu.edu.cn.

1877-0509
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the The 8th International Conference on Information Technology and Quantitative Management (ITQM 2020 & 2021)
10.1016/j.procs.2022.01.119

1. Introduction

With the intensification of economic globalization, the supply chain gradually extends to the depth, showing the characteristics of cross-industry, cross-region, multi-member and multi-correlation. At present, the supply chain has evolved into a complex supply chain system composed of a number of interassociated enterprises[1]. The correlation relationship in the supply chain leads to the contagion effect among the credit risks of enterprises, and forms the contagion network of the associated credit risk in the supply chain[2]. The associated credit risk in the supply chain presents a strong contagion effect, which directly endangers the commercial banks that provide loans to the enterprises in the supply chain[3]. Therefore, when commercial banks evaluate the credit risk of enterprises in the supply chain, they must focus on the evaluation of the contagion effect of associated credit risk in the supply chain. Under the framework of traditional credit risk evaluation of commercial banks, it is generally believed that the credit status of enterprises changes independently. Therefore, when traditional credit risk assessment methods are used to evaluate enterprises in the supply chain, they are often isolated from the supply chain environment and only evaluate the credit status of a single enterprise without involving the interaction of credit risk among enterprises in the supply chain, resulting in inaccurate evaluation results. It is difficult to provide scientific theoretical basis for the credit decision and risk control of commercial banks.

As a short-term financing mode which widely adopted by enterprises in different regions such as China, the United States and British, trade credit has gradually become a common correlation in the supply chain [4]. About 70% of American and 80% of British businesses extend trade credit to customers. China’s financial system is not perfect, the impact of trade credit on the development of enterprises, even more than the bank credit [5-6]. However, with the widespread use of trade credit, the credit crisis caused by it has emerged in an endless stream [7]. In 2008, the bankruptcy and reorganization of General Motors led to its inability to pay off its trade credit, which caused a number of auto parts suppliers in China, Japan and South Korea and other countries to face huge financial difficulties and operational crises. In 2015, V&D, a well-known department store chain in the Netherlands, went bankrupt, putting hundreds of suppliers at risk and going bankrupt. The crisis involved a number of associated companies in the supply chain network, and affected several banks and financial institutions, which brought huge risks and hidden dangers to the stability of the financial system. Fewings believes that trade credit leads to the formation of a Markov payment chain among enterprises, and the credit crisis of any enterprise in the chain may lead to the breakage of the whole chain, which will bring negative effects on banks, and affect the volatility of the financial market [8].

Based on this, this paper puts forward an new evaluation method of the associated credit risk in the supply chain in view of the common contagion effect exists widely among enterprises’ credit risks in the supply chain. Since trade credit is the most widely used financing mode between upstream and downstream enterprises in the supply chain, for many enterprises in the supply chain, the contagion of credit risk mainly comes from the trade credit among enterprises in the supply chain. In other words, the trade credit between enterprises in the supply chain makes the associated credit risk in the supply chain have the contagion effect. In this study, based on graph theory and fuzzy preference theory, we construct a credit risk assessment model based on Trade Credit Risk Contagion (TCRC), and evaluate the credit risk of enterprises in the supply chain. It reveals the contagion effect of associated credit risk in supply chain.

2. Evaluation model setup of associated credit risk based on TCRC

Considering a complex supply chain system composed of *n* enterprises S_1, S_2, $\cdots$, S_n in the supply chain, node *I* represents enterprises in the supply chain, and the direction of edge (i, j) is $i \rightarrow j$ indicating that trade credit flows from S_j to S_i. If the enterprise on the chain S_j provides trade credit to S_i, once S_i falls into financial crisis, its credit risk will be transmitted to S_j along the contagion chain formed by trade credit. Therefore, (*I*, *j*) represents the direction of credit risk contagion between S_i and S_j of enterprises on the chain. The weight of (I, t) is the trade credit contract, *I* is the trade credit limit provided by S_j to S_i, and *t* is the corresponding trade credit period.

In the credit risk contagion network, the credit risk of the enterprise is expressed as $TR = (R_1, R_2, \cdots, R_n) = R_s + R_c$, $R_s = (R_{s1}, R_{s2}, \cdots, R_{sn})$ is the enterprise's self-own credit risk, and $R_c = (R_{c1}, R_{c2}, \cdots, R_{cn})$ is the enterprise's credit risk contagion. R_i $(i = 1, 2, \cdots, n)$ represents the credit risk of the enterprise S_i, R_{si} represents the self-own credit risk of the enterprise S_i, and R_{ci} represents the credit risk contagion of the enterprise S_i. In order to evaluate the enterprise's credit risk *TR*, a basic model to measure the enterprise "self-own credit risk" R_s is constructed firstly. Then, based on the credit risk contagion network formed by trade credit, a derivative model is established to measure the "credit risk contagion" of enterprises in the supply chain. Finally, by integrating R_s and R_c, the credit risk of enterprises in the supply chain based on TCRC is evaluated, and the contagion effect of associated credit risk in the supply chain based on TCRC is revealed.

In order to measure the "self-own credit risk" R_s, we draw on the basic framework of traditional enterprise credit risk evaluation of commercial banks and designs the self-own credit risk evaluation indicator system of the enterprises under the supply chain situation according to the characteristics of supply chain. In particular, it focuses on the historical credit record of the enterprise in the supply chain, the relationship with the core enterprises in the supply chain, and the operation of the whole supply chain. The "credit risk contagion" R_c of the enterprise is closely associated to the risk contagion network structure of the trade credit, the source of infection and the size of the infected enterprise's self-own credit risk. Different trade credit to the same infectious object, or the same trade credit to different infectious objects, the intensity of the contagion effect may be different. We use trade credit limit and period to measure the degree of enterprise interaction in the supply chain.

Assuming risk numerical matrix $A=(a_{ij})_{nxn}$, which represents the contagion path and contagion degree among enterprise credit risks in the risk contagion network of supply chain. a_{ij} reflects the degree to which S_j is affected by S_i. For example, if a_{ij}=0.4, it means that the self-own credit risk of the enterprise S_i may be transmitted to the enterprise S_j and the probability of infection is 0.4. Since the associated credit risk in the supply chain can be transmitted directly or indirectly, referring to the references [9] and [10], we uses the reachable matrix $\sum_{i=1}^{m} A^i$ to measure the contagion degree of the associated credit risk. *i* is the length of the channel, represents the contagion distance between credit risks of enterprises on the chain, reflects the direct and indirect contagion of credit risks in the supply chain risk contagion network, and *m* represents the maximum contagion distance in the supply chain risk contagion network. Therefore, in the supply chain risk contagion network, "credit risk contagion" $R_c = \sum_{i=1}^{m} A^i R_s$. Combining R_s and R_c, the enterprise credit risk TR in the supply chain risk contagion network is :

$$TR = R_s + R_c = \left(E + \sum_{i=1}^{m} A^i\right)R_s = \begin{cases} \left(E + \sum_{i=1}^{m} A^i\right)R_s, & \text{if } m \text{ is a finite positive integer} \\ (E-A)^{-1}R_s, & \text{if } m \to +\infty \end{cases} \quad (1)$$

3. The basic model of self-own credit risk evaluation

3.1 Self-own credit risk evaluation indicator system

Drawing on the research work of scholars Xiong et al. [11], Hu et al. [12] and Dai [13], this paper selects and constructs the self-own credit risk evaluation indicator system under the supply chain scenario from three aspects: the external environment of the supply chain, the enterprise's own factors in the supply chain and the factors of the associated enterprises in the supply chain.

(1) External environment of supply chain. The fluctuation of the external environment of the supply chain leads to the default of enterprises in the supply chain, which is called the systemic risk of enterprises. External environment of supply chain includes macroeconomic environment, political environment, industry growth and industry competition.

(2) Enterprise's own factors in the supply chain. In the supply chain, as the financing subject, the enterprise's own operation and management status, debt paying ability and so on are the key objects of commercial banks. The enterprise's own factors in the supply chain mainly include the quality of enterprise, profitability, operating capacity, solvency, and credit history.

(3) Factors of associated enterprises in the supply chain. This indicator mainly includes credit rating, industry characteristics, operating capacity and solvency of associated enterprises in the supply chain. The qualification inspection of the core enterprises in the supply chain mainly reflects the debt repayment willingness of the core enterprises in the supply chain. In the supply chain finance business, the core enterprises in the supply chain play the role of counter-guarantee for small and medium-sized enterprises (SMEs), and the credit status of the core enterprises directly affects the quality of transactions between

SMEs and them. If the credit quality of core enterprises is good, the credit risk faced by commercial banks can be reduced to a large extent. Our evaluation indicator system for the supply chain enterprise self-own credit risk is described in Appendeix A.

3.2. Construction of fuzzy comparison judgment matrix

Suppose that enterprises S_1, S_2, $\cdots$, S_n in the supply chain risk contagion network have *m* self-own credit risk evaluation indicatores, X_1, X_2, $\cdots$, X_m. In order to obtain the comparative judgment matrix of enterprises under a given quantitative indicator, we construct the utility function $\mu_i^{(l)} = \mu_R\left(X_i^{(l)}\right)$ of the evaluation object, and $X_i^{(l)}$ is the value of the quantitative indicator X_l of the enterprise S_i. $\mu_i^{(l)}$ is the utility value corresponding to the quantitative indicator X_l of the enterprise S_i, i =1,2,...,n. By comparing the utility value $\mu_i^{(l)}$ and $\mu_j^{(l)}$ of enterprises in different supply chains under the same quantitative indicator, the preference degree of decision-makers for evaluation object S_i and S_j is judged.

Based on the setting of utility function in Tversky and Kahneman (1979)'s prospect theory [14], it is assumed that the utility function of the evaluation object is $\mu_i^{(l)} = \left(X_i^{(l)}\right)^\alpha$, 0<α<1. Where, α is the concave and convex degree of the utility function based on the prospect theory, reflecting the different degrees of risk avoidance of decision makers. Let $X_{Max}^{(l)} = Max\{X_1^{(l)}, X_2^{(l)}, \cdots, X_n^{(l)}\}$, $X_{Min}^{(l)} = Min\{X_1^{(l)}, X_2^{(l)}, \cdots, X_n^{(l)}\}$, $i = 1,2,\cdots,n$. Therefore, $\mu_{ij}^{(l)}$ can be used to measure the degree of decision-makers' preference for enterprises S_i and S_j under the quantitative indicator X_l:

$$\mu_{ij}^{(l)} = 1 - \frac{\mu_i^{(l)}}{\mu_i^{(l)}+\mu_j^{(l)}} = \frac{\mu_j^{(l)}}{\mu_i^{(l)}+\mu_j^{(l)}}, i, j = 1,2,\cdots,n \quad (2)$$

By the Equation (2), $0 < \mu_{ij}^{(l)} < 1$, $\mu_{ij}^{(l)} + \mu_{ji}^{(l)} = 1$, $\mu_{ii}^{(l)} = 0.5$, $\forall\, i, j = 1,2,\cdots,n$. Thus, $\mu_{ij}^{(l)}$ can be understood as the fuzzy evaluation of decision-makers on the degree of self-own credit risk preference of enterprises S_i and S_j under the quantitative indicator X_l. The larger the $\mu_{ij}^{(l)}$ is, the more the decision maker thinks the self-own credit risk of S_i is greater than that of S_j. To sum up, based on the quantitative indicator X_l, the fuzzy comparative judgment matrix FCJM of enterprises can be expressed as

$$U^{(l)} = \left(\mu_{ij}^{(l)}\right)_{n\times n} \quad (3)$$

The higher $\mu_{ij}^{(l)}$ is, it indicates that under the quantitative indicator X_l, decision makers believe that the self-own credit risk of enterprises S_i is higher than that of enterprises S_j.

When the decision maker evaluates the qualitative indicators of the self-own credit risk evaluation of the enterprise in the supply chain, the decision maker mainly makes the judgment based on the subjective judgment and the objective information of the indicators, and the judgment results are often difficult to be measured by precise numerical values. According to the above analysis, this section defines the fuzzy comparative judgment matrix FCJM on the enterprises in the risk contagion network of supply chain based on a certain qualitative indicator X_l by using the 0.1-0.9 scale method

$$R^{(l)} = \left(r_{ij}^{(l)}\right)_{n\times n} \quad (4)$$

where, $r_{ij}^{(l)}$ is a random variable, and its probability density function is $f(r_{ij}^{(l)})$, and the cumulative probability distribution function is $F(r_{ij}^{(l)})$.

3.3 Weight calculation based on eigenvector method

For the self-own credit risk evaluation indicator X_l, its fuzzy comparison judgment matrix of $R^{(l)}, l = 1,2,\cdots,m$. If the probability distribution function of $r_{ij}^{(l)}$ is known, then the set of all possible matrices of fuzzy comparison judgment matrix $\mathcal{H}(R^{(l)})$ is obtained. $\forall R^{(l)} \in \mathcal{H}(R^{(l)})$, according to the feature vector method and matrix set $\mathcal{H}(R^{(l)})$ in all $R^{(l)}$, as well as the eigenvectors corresponding to eigenvalue $\omega_{R^{(l)}} = (\omega_{1,R^{(l)}}, \omega_{2,R^{(l)}}, \cdots, \omega_{n,R^{(l)}})$. Then, the maximum eigenvalue $\lambda_{Max}^{(l)}$ of $\mathcal{H}(R^{(l)})$ can be obtained. The eigenvector $\omega_{R^{(l)}}$ measures the weight coefficients of enterprises in the supply chain risk contagion network under the self-own credit risk evaluation indicator X_l. Therefore, under the self-own credit risk evaluation indicator X_l, n enterprises can be ranked according to the weight vector $\omega_{R^{(l)}}$.

For the self-own credit risk evaluation indicator X_l, the ranking function $Rank_i(\omega_{R^{(l)}}) = 1 + \sum_{k=1}^{n} \theta(\omega_{k,R^{(l)}} > \omega_{i,R^{(l)}}) = r$, $\theta(\omega_{k,R^{(l)}} > \omega_{i,R^{(l)}}) = 1$, $\theta(\omega_{k,R^{(l)}} \le \omega_{i,R^{(l)}}) = 0$. The set of comparison judgment matrix of all ordering r of enterprise S_i is $Z_i^r(R^{(l)}) = \{R^{(l)}: Rank_i(\omega_{R^{(l)}}) = 1 + \sum_{k=1}^{n} \theta(\omega_{k,R^{(l)}} > \omega_{i,R^{(l)}}) = r\}$. Therefore, under the self-own credit risk evaluation indicator X_l, for the fuzzy comparative judgment matrix set $\mathcal{H}(R^{(l)})$, the probability that the overall ranking r of S_i is

$$p_{i,(l)}^{r} = \sum_{Z_i^r(R^{(l)})} p(R^{(l)}) = \sum_{Z_i^r(R^{(l)})} \left[\prod_{r_{ij}^{(l)} \in R^{(l)}} p\left(r_{ij}^{(l)}\right)\right] \quad (5)$$

In order to obtain the overall probability of all possible ratings for enterprise S_i, we need to integrate the probabilities of each possible ranking of S_i. Drawing on scholars Lahdelma and Salminen [15], we used the weight coefficient to carry out the weighted sum of each sorting probability. Thus, The probability of all possible ratings of the enterprise S_i is $\mu_i^{(l)} = \sum_{r=1}^{n} b^r p_{i,(l)}^{r}$). Let $p_i^{(l)} = \mu_i^{(l)} / \left(\sum_{i=1}^{n} \mu_i^{(l)}\right)$, $p^{(l)} = (p_i^{(l)})_{n\times 1} = \left(p_1^{(l)}, p_2^{(l)}, \cdots, p_n^{(l)}\right)^T$, $i = 1,2,\cdots,n$, $p^{(l)}$ measures the weight of each enterprise in the supply chain risk contagion network for its self-own credit risk evaluation indicator X_l.

In the same way, the weight vectors $\omega = (\omega_1, \omega_2, \cdots, \omega_m)$ of the evaluation indicator system X_1, X_2, $\cdots$, X_m can be obtained by using the method of eigenvector. Thus, the measurement model of the enterprise's self-own credit risk in the supply chain risk contagion network can be obtained:

$$R_s = (\omega_1, \omega_2, \cdots, \omega_m)\left(p^{(1)}, p^{(2)}, \cdots, p^{(m)}\right)^T = \left(R_{s1}, R_{s2}, \cdots, R_{sn}\right) \quad (6)$$

4. Derivative model of credit risk contagion evaluation

According to the foregoing analysis, in order to obtain the "credit risk contagion" R_c, the core work is to construct the risk numerical matrix A=$(aij)_{nxn}$ in the risk contagion network of the supply chain.

Let

$$A = \left(a_{ij}\right)_{N\times N}, \quad a_{ij} = \begin{cases} 0 < I^t \leq 1, \text{If there is an edge that goes from } i \text{ to } j \\ 0, \text{ Otherwise,} \end{cases} \qquad (7)$$

I is the trade credit limit provided by enterprise S_j to S_i, and t is the corresponding trade credit period. The risk numerical matrix A reveals the contagion intensity of credit risks among enterprises with trade credit correlation.

In order to analyze the impact of trade credit on the contagion effect from the perspective of supply chain as a whole, a standardized treatment was carried out on the trade credit limit I:

$$\overline{I_{ij}} = \frac{I_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} B_{ij}} \qquad (8)$$

If the maximum contagion distance m in the supply chain risk contagion network is a finite positive integer, credit risk contagion $R_c = \sum_{i=1}^{m} A^i R_s$. If the maximum contagion distance m in the supply chain risk contagion network approaches infinity, credit risk contagion $R_c = \lim_{m\to+\infty} \sum_{i=1}^{m} A^i R_s$.

In particular, "credit risk contagion" R_c measures the contagion effect of associated credit risk on the supply chain. Since enterprise credit risk is composed of "self-own credit risk" R_s and "credit risk contagion" R_c, the credit risk of enterprises in the supply chain risk contagion network can be evaluated as a whole according to Equation (1).

5. Conclusions

Traditional credit risk evaluation methods of commercial banks fail to consider the contagion of credit risks among associated enterprises, leading to unscientific credit risk evaluation results of loan applying enterprises, unreasonable credit decision-making and risk control measures, and thus the credit risks faced by commercial banks themselves are increased accordingly. This paper divides the credit risks of enterprises in the supply chain into "self-own credit risk" and "credit risk contagion". Based on the risk contagion network formed by trade credit, this paper constructs the evaluation basic model of "self-own credit risk" and the evaluation derivative model of "credit risk contagion" in the supply chain, and combines the two evaluation models to comprehensively evaluate the credit risk of enterprises in the risk contagion network of the supply chain. The evaluation method proposed in this paper not only effectively evaluates the credit risk of the enterprises in the supply chain risk contagion network, reveals the contagion effect of the associated credit risk in the supply chain, but also helps the commercial banks reduce or even eliminate the negative impact of the associated credit risk in the supply chain, and reduces the potential loss of the commercial banks.

Acknowledgements

The authors acknowledge the National Natural Science Foundation of China (Grant: 71871147), the National Natural Science Foundation of China (Grant: 71701166), the National Natural Science Foundation of China (Grant: 71671144), the National Natural Science Foundation of China (Grant: 71271043), the Science and Technology Department of Sichuan Province Project (Grant: 2018ZR0201 & 21YYJC2873), Chengdu Philosophy and Social Science Project (Grant: YY0920200643), and West China Nursing Discipline Development Special Fund Project, SichuanUniversity(Grant: HXHL20013).

References

[1] Qian, Q, Yang, Y, Zhou, ZF. Research on trade credit spreading and credit risk within the supply chain. Int. J. Inf. Technol. Decis. Making; 2019;18 (1), 389~411.

[2] Martin, Judith. Suppliers participation in supply chain finance practices: predictors and outcomes. Int. J. Integrated Supply Manag; 2017; 11 (23), 193.

[3] Jiang, SS, Fan, H. Credit risk contagion coupling with sentiment contagion. Phys. Stat. Mech. Appl; 2018; 512 (12), 186–202.

[4] Alavi, SH, Jabbarzadeh, A. Supply chain network design using trade credit and bank credit: A robust optimization model with real world application. Computers & Industrial Engineering; 2018; 125, 69-86.

[5] Devalkar, SK, Krishnan, H. The impact of working capital financing costs on the efficiency of trade credit. Production and Operations Management; 2019; 28(4), 878-889.

[6] Peura, H, Yang, SA, Lai, G. Trade credit in competition: a horizontal benefit. Manufacturing & Service Operations Management; 2017; 19(2), 263-289.

[7] Zhong, YG, Zhou, YW. Improving the supply chain's performance through trade credit under inventory-dependent demand and limited storage capacity. International Journal of Production Economics; 2013; 143(2), 364-370.

[8] Fewings, DR. Trade Credit as a Markovian Decision Process With an Infinite Planning HorizonQuarterly Journal of Business and Economics; 1992; 31(4):51-79.

[9] Gu, J, Xia, X, He Y. An approach to evaluating the spontaneous and contagious credit risk for supply chain enterprises based on fuzzy preference relations. Computers & Industrial Engineering; 2017; 106: 361-372.

[10] Fang C, Marle, F. Dealing with project complexity by matrix-based propagation modelling for project risk analysis Journal of Engineering Design; 2013; 24(4): 239-256.

[11] Xiong, X, Ma, J, Zhao, WJ. Credit risk evaluation under supply chain finance model. Nankai Management Review,; 2009; 12(4): 92-9.

[12] Hu, HQ, Zhang, L, Zhang, DH. Research on credit risk assessment of small and medium-sized enterprises from the perspective of supply chain finance: A comparative study based on SVM and BP neural network. Management Review; 2012; 22(11): 70-80.

[13] Dai, XQ. Research on credit risk assessment model of commercial banks: An empirical study based on online supply chain finance. Soft Science; 2018; 221(5): 143-148.

[14] Tversky, D, Kahneman, A. Prospect theory: An analysis of decision under risk. Econometrica; 1979; 47(2): 263-292.

[15] Lahdelma, R, Salminen, P. SMAA-2: Stochastic multicriteria acceptability analysis for groupdecision making. Operations Research; 2011; 49(3): 444–454.