Dean&Francis
ISSN 2959-6130

Supply Chain Networks, Firm Heterogeneity, and Credit Risk Contagion: Insights from Business Linkages in the Automotive Industry

Yuezhe Cao

Abstract:

Using the Chinese automotive industry as the research subject, this study constructs a supply chain network based on real transaction data of business interactions between upstream and downstream enterprises in the automotive sector from 2011 to 2020. It analyzes the topological properties and structure of the supply chain network, simulates the risk-bearing capacity of supply chain enterprises under risk shocks, and focuses on exploring the impact of firm heterogeneity within the supply chain network on credit risk contagion. The findings reveal that there are differences in the complexity of supply chain networks between the procurement and sales ends, with the procurement network being more complex. Additionally, different supply chain network structures exhibit varying levels of risk perception and damage; the longer the supply chain structure, the more complex and concealed the risk propagation.

Keywords: Supply Chain Networks; Firm Heterogeneity; Credit Risk Contagion

1. Introduction

With the development of the information technology revolution and economic globalization, the supply chain model has become one of the effective ways for enterprises to cope with intense market competition. Enterprises within the supply chain form intricate interconnected networks and interdependent credit chains through various means such as business transactions, debt guarantees, cross-shareholding, and financial intermediation. However, these close connections and dependencies also lead to potential supply chain credit risks. This refers to the risk of economic loss or termination of supply chain relationships caused by customers or suppliers failing to fulfill transactions or defaulting. The supply chain tightly links core enterprises with upstream suppliers, downstream distributors, and customers, forming an integrated functional network structure. As globalization deepens and market competition intensifies, supply chain networks have become increasingly complex and dynamic.

ISSN 2959-6130

Due to the complexity of supply chain networks and the systemic and transmissive characteristics of credit risks, a credit crisis involving any participant in the chain could potentially lead to the breakdown of the entire supply chain. At the same time, considering the maximization of their own interests, enterprises within the supply chain, as independent economic entities, will seek new upstream or downstream partners to meet their needs when faced with risks. This internal competition and pressure within the supply chain can also easily trigger and spread credit crises across industries. Existing literature primarily examines risk contagion issues from the perspective of credit connections within supply chains. For instance, Qian et al. studied the contagion effects of credit risks within supply chains composed of trade credit and bank credit from the perspective of counterparty default risk. Similarly, Xie et al. analyzed how dual-channel financing (trade credit and bank credit) adopted by retailers impacts the contagion effects of credit risks in supply chains through financing channels and costs.

Based on the existing research, this paper focuses on the Chinese automotive industry. Using real transaction data from 2011 to 2020 on business interactions between upstream and downstream enterprises, it constructs an interconnected network of the supply chain market. The study analyzes and describes the topological properties and structure of the supply chain network, with a particular focus on examining the impacts of supply chain network structure and firm heterogeneity on credit risk contagion.

2. literature review

Research on credit risk contagion at home and abroad has primarily focused on subjects such as bank-enterprise networks and corporate groups. From the perspective of influencing factors, existing literature generally identifies counterparty default risk as a major cause of credit risk contagion. Barro and Basso utilized counterparty risks within interdependent corporate networks to describe business relationships among different firms and explored the impact of default contagion on the loss distribution of bank loan portfolios. Similarly, Jorion and Zhang examined the correlation between direct counterparty effects and credit contagion, analyzing the impact of bankruptcy announcements on creditors' wealth through empirical testing. They concluded that counterparty risk serves as an important additional channel for credit contagion. Chen et al. constructed a dual-layer credit risk contagion model based on bank-enterprise counterparty networks and analyzed the mechanisms influencing the evolution of credit risk contagion within these networks. Additionally, networks formed by guarantees, interpersonal relationships, and other connections have also been identified as significant channels for the diffusion of credit risk contagion.

As one of the critical carriers of credit risk contagion, supply chain networks have garnered increasing attention in recent years. In terms of research topics, most existing studies focus on commercial credit financing within supply chains. Boissay and Gropp analyzed how commercial credit networks composed of enterprises propagate risk shocks to upstream and downstream firms. Wang Zhenjie and Wang Zhuquan studied credit risk contagion and working capital structure issues in export-oriented electronic information industries, focusing on commercial credit financing models. Qian and Zhou built a game theory model to elaborate on the mechanisms of credit risk contagion within supply chains, considering the provision of commercial credit by suppliers to retailers.

Although supply chain credit risk has gained increasing attention in recent years, existing research predominantly concentrates on bank networks and corporate groups. Most studies adopt a micro-level perspective, analyzing the factors influencing credit risk contagion based on commercial credit connections within supply chains. Few studies examine the effects of credit risk contagion from the perspective of supply chain network structures formed by business relationships, and there is a lack of research adopting a holistic view of network structures. In terms of methodology, much of the existing literature relies on mathematical modeling and simulation analysis based on hypothetical network structures, with limited empirical data support. This raises questions about the practical applicability of their findings.

In response, this paper first constructs an interconnected supply chain network based on real transaction data between upstream and downstream enterprises. It then analyzes the topological properties and structure of the supply chain network, simulates the risk-bearing capacity of supply chain enterprises under risk shocks, and integrates the analysis of network topology with the simulation results of risk contagion. This approach explores the critical and vulnerable segments of the supply chain, while also analyzing the impact of core enterprise heterogeneity within the supply chain network on credit risk contagion.

3. Empirical

3.1 sample selection and data source

This study selects enterprises listed on the Shanghai and Shenzhen Stock Exchanges from 2011 to 2020 that are related to the automotive industry as the initial research sample. To ensure the completeness of the industrial chain data, the classification is conducted according to the "In-

dustry Classification Guidelines for Listed Companies" issued by the China Securities Regulatory Commission in 2012. The supply chain network's relevant sales and procurement data, along with financial data, are sourced from the GTA database. Specifically, the sales network (customer concentration) is constructed using data from the "Top Five Customers Sales Information" table in the GTA "Listed Company Supply Chain Information" dataset. Similarly, the procurement network (supplier concentration) is built using data from the "Top Five Suppliers Procurement Information" table in the same dataset.

3.2 data process and net-built

Before constructing the supply chain network, this study first excluded samples with incomplete supply chain information, such as missing supplier and customer names or data. By matching the stock codes of Chinese listed companies, complete automotive supply chain information was obtained, resulting in a total of 2,327 valid data points, including 1,042 procurement records and 1,285 sales records.

Using a matrix model, the network construction was based on procurement relationships within the supply chain network. Sellers in the procurement and sales data were designated as source nodes, while buyers were designated as target nodes to establish relationships. By slicing the data year by year, separate sales and procurement networks were constructed. These were further combined to create a unified supply chain network.

The matrix model assumes that the automotive supply chain system is closed. Different nodes within the network represent distinct enterprises in the supply chain, and the edges between nodes represent business relationships between enterprises. The weight of an edge indicates the amount of funds involved in the business relationship. The interactions among the upstream and downstream businesses of n automotive supply chain enterprises form an n*n matrix X .

$$X=\begin{pmatrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ ? & \ddots & ? & \ddots & ? \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ ? & \ddots & ? & \ddots & ? \\ x_{n1} & \cdots & x_{nj} & \cdots & x_{nn} \end{pmatrix}$$

Here, x_{ij} represents the actual transaction amount between automotive enterprise i and enterprise j, which is the value of goods sold by enterprise i to enterprise j. In the procurement network, x_{ij} refers to the amount spent by the enterprise on procurement, while in the sales network, it refers to the revenue obtained from selling goods.

The total revenue of automotive enterprise i is represented as $\sum_{j=1}^{n} x_{ij} = a_i$. The total expenditure of automotive enterprise j is represented as $\sum_{i=1}^{n} x_{ij} = c_j$.

3.3 Analysis of Network Topological Properties

This study uses metrics such as nodes, edges, connected components, and clustering coefficients to describe the relational characteristics of the supply chain network.

Nodes: Nodes are one of the fundamental components of a network and can represent individuals, organizations, or even nations. In this study, nodes in the supply chain network refer to all upstream and downstream enterprises involved in automotive supply chain activities. Each node may have one or both roles as a supplier or customer.

Edges: Edges represent the connections between nodes. The network in this study is a weighted directed network, where weights represent the transaction amounts in the automotive supply chain, and directions indicate the flow of goods within the supply chain—from the supplier (seller) to the customer (buyer). These edges illustrate the relationships between upstream and downstream enterprises in the automotive supply chain.

Connected Components: Connected components are used to identify small communities within the automotive supply chain network. The study calculates the number of connected components, the size of the largest connected component, and the number of supply chains at different scales to analyze the risk contagion outcomes within the network.

Clustering Coefficient: The clustering coefficient of a node measures the ratio of actual connections among its neighboring nodes to the maximum possible connections. It reflects the degree to which vertices in the network form tightly-knit groups. The average clustering coefficient of the network is used in this study to evaluate the degree of group cohesion in the automotive supply chain. A higher average clustering coefficient indicates better connectivity among enterprises.

By leveraging these metrics, the study provides a detailed analysis of the structural properties of the automotive supply chain network, which is critical for understanding its resilience and vulnerability to risk contagion.

4. Analysis of Credit Risk Contagion in the Network

This section focuses on examining the impact of supply chain structure and firm heterogeneity on credit risk contagion, further exploring the core and weak links in supply chain credit risk contagion, as well as the varying influ-

ISSN 2959-6130

ence intensity of different enterprises within the chain.

4.1 Analysis of Credit Risk Shock Results in the Automotive Supply Chain

This study conducts annual credit risk simulation shocks on the automotive network from 2011 to 2020. By tracking changes in the network structure and total trade volume during disruptions in the supply chain, it observes the credit risk contagion effects resulting from the bankruptcy of supply chain enterprises. The results reveal that most listed companies in the automotive supply chain network cause a single round of direct impact on credit risk propagation. After one round of contagion, the supply chain system typically terminates. However, a minority of companies survive and continue to propagate credit risks in a second round of indirect impact until the supply chain system ceases to function. This indicates that the longer the supply chain structure, the more complex and concealed the credit risk contagion becomes. Analysis shows that in 2012, 2016, and 2019, certain companies caused second-round contagion effects, generating indirect impacts. Thus, these three years are analyzed in detail. Companies are ranked based on three key indicators: the number of contagion rounds, the number of companies affected, and the total trade discrepancy caused by bankruptcy. Enterprises meeting all three criteria and ranking in the top 20 are identified as key players in the automotive supply chain network, occupying central positions and exhibiting strong risk contagion capabilities. The details are summarized in the table below.

Chart 1 Credit Risk Contagion Effects during Bankruptcy Shocks in the Automotive Supply Chain Network in 2012 Unit: 100 million RMB

Year	Company	Round	Trade balance Ranking	Ranking of Total Number of Bankruptcies Caused	1- Number of Companies	1-Trade balance	2- Number of Companies	2- Trade balance	Total Number of Bankruptcies Caused	Total trade balance
2012	Huayi Auto	2	3	2	6	25.19	4	17.80	10	42.99
2012	Dongfeng Motor Corporation Limited	1	4	3	9	42.51	0	0.00	9	42.51
2012	Wanxiang Qianchao Co., Ltd.	1	6	2	10	32.38	0	0.00	10	32.38
2012	Offcn Education Technology Co., Ltd.	1	8	2	10	27.89	0	0.00	10	27.89
2012	Zongshen Power Machinery Co., Ltd.	1	10	1	11	24.04	0	0.00	11	24.04
2012	Beijing Bus Media Co., Ltd.	1	12	2	10	20.45	0	0.00	10	20.45
2012	Ankai Automobile Co., Ltd.	1	15	3	9	17.26	0	0.00	9	17.26
2012	Dongfeng Motor Co., Ltd.	2	17	4	5	12.28	3	3.04	8	15.32
2012	WKW Automotive Parts Co., Ltd.	1	19	3	9	14.79	0	0.00	9	14.79

Chart 2 Credit Risk Contagion Effects during Bankruptcy Shocks in the Automotive Supply Chain Network in 2016 Unit: 100 million RMB

Year	Company	Round	Trade balance Ranking	Ranking of Total Number of Bankruptcies Caused	1- Number of Companies	1-Trade balance	2- Number of Companies	2- Trade balance	Total Number of Bankruptcies Caused	Total trade balance
2016	BMW AG	2	1	1	9	70.98	7	48.98	16	119.96
2016	Huaxiang Electronic Co., Ltd.	1	1	4	9	119.96	0	0.00	9	119.96
2016	Jiangling Motors Co., Ltd.	1	2	3	10	68.96	0	0.00	10	68.96
2016	Offcn Education Technology Co., Ltd.	1	3	5	8	53.77	0	0.00	8	53.77
2016	Wanxiang Qianchao Co., Ltd.	1	5	5	8	36.44	0	0.00	8	36.44
2016	Yunnei Power Co., Ltd.	1	6	3	10	30.33	0	0.00	10	30.33
2016	Jiangnan Mould & Plastic Technology Co., Ltd.	1	7	4	9	30.30	0	0.00	9	30.30
2016	WKW Automotive Parts Co., Ltd.	1	8	4	9	26.39	0	0.00	9	26.39
2016	Beijing Bus Media Co., Ltd.	1	10	4	9	20.43	0	0.00	9	20.43
2016	Zhejiang Century Huatong Group Co., Ltd.	1	12	4	9	19.76	0	0.00	9	19.76
2016	Chuangying Xinzhi Technology Co., Ltd.	1	16	2	11	14.15	0	0.00	11	14.15

Chart 3 Credit Risk Contagion Effects during Bankruptcy Shocks in the Automotive Supply Chain Network in 2019 Unit: 100 million RMB

Year	Company	Round	Trade balance Ranking	Ranking of Total Number of Bankruptcies Caused	1-1- Number of Companies	1-Trade balance	2- Number of Companies	2- Trade balance	Total Number of Bankruptcies Caused	Total trade balance
2019	Huaxiang Electronic Co., Ltd.	1	1	5	7	91.26	0	0.00	7	91.26
2019	FAW Auto Parts Co., Ltd.	1	2	4	9	82.71	0	0.00	9	82.71
2019	Jiangling Motors Co., Ltd.	1	3	3	10	69.72	0	0.00	10	69.72

ISSN 2959-6130

2019	Wanxiang Qianchao Co., Ltd.	1	5	3	10	41.08	0	0.00	10	41.08
2019	Beijing Bus Media Co., Ltd.	1	7	2	11	34.13	0	0.00	11	34.13
2019	Xinquan Automotive Trim Co., Ltd.	1	8	4	9	28.89	0	0.00	9	28.89
2019	WKW Automotive Parts Co., Ltd.	1	9	6	6	24.14	0	0.00	6	24.14
2019	Berry Genomics Co., Ltd.	1	12	2	11	12.14	0	0.00	11	12.14
2019	Deron Intelligent Technology Co., Ltd.	1	13	3	10	11.95	0	0.00	10	11.95
2019	Pengling Group Co., Ltd.	1	20	4	9	8.91	0	0.00	9	8.91
2019	Shanghai Xumu Supply Chain Co., Ltd.	2	-	1	11	1.60	9	4.40	20	6.01
2019	Tianjin Yuanxinda Trading Co., Ltd.	2	-	1	11	1.22	9	4.79	20	6.01

From further analysis of Tables 1, 2, and 3, it can be observed that among the highly infectious companies under credit risk shocks, a significant proportion are primarily involved in the production of automotive parts. Notably, Beijing Bashi Media Co., Ltd., Beijing WKW Automotive Parts Co., Ltd., and Wanxiang Qianchao Co., Ltd. appeared in all three years under examination and occupied central positions in the network, demonstrating significant influence in credit risk contagion. Additionally, Jiangling Motors Co., Ltd., Ningbo Huaxiang Electronic Co., Ltd., and Offcn Education Technology Co., Ltd. (formerly Asia Automotive) appeared twice, also exhibiting high centrality and impact.

These findings highlight that in the automotive supply chain network, attention should not only be focused on vehicle manufacturers but also on the pivotal role of front-end automotive parts enterprises in credit risk contagion. This is particularly crucial in the context of increased costs and parts shortages faced by the automotive industry since the outbreak of the COVID-19 pandemic. To prevent and mitigate credit risk contagion crises, it is essential to address the issue at its source through targeted management of supplier and customer relationships, particularly for parts suppliers.

4.2 Analysis of Core Enterprise Heterogeneity

Based on the aforementioned conclusions, this study collects characteristic data of listed companies to further examine the potential impact of firm-specific traits on credit risk contagion. An in-depth analysis is conducted from the perspectives of enterprise type, number of employees, years of establishment, and regional location to explore factors that may influence the credit risk contagion of core enterprises. The results are shown in the following figure:

Nature of Enterprises: Among the core enterprises with strong credit risk contagion in the automotive supply chain network, private enterprises account for a larger proportion, double that of state-owned enterprises. This indicates that private enterprises have stronger risk contagion capabilities and greater destructive power in the automotive supply chain. This may be because state-owned enterprises generally possess stronger economic strength, advantageous resource access, and more stable operations, making them less likely to face bankruptcy risks.

Employee Scale: Core enterprises with fewer than 5,000 employees account for half of the total, followed by those with 5,000–10,000 employees, which make up one-third. This suggests that among core enterprises with strong

credit risk contagion, smaller employee scale correlates with stronger risk contagion effects. The likely reason is that smaller employee size often indicates smaller company size, which makes such firms more prone to bankruptcy risks, thereby affecting the stability of the entire automotive supply chain.

Years of Establishment: Enterprises established for 20–30 years make up the majority of core enterprises, while only one enterprise has been established for less than 20 years. This indicates that the longer an enterprise has been established, the stronger its role in risk propagation. This phenomenon may arise because longer-established enterprises tend to have more complex business operations and longer supply chains, leading to stronger contagion effects if risks arise.

Geographic Distribution: Core enterprises located in the eastern region account for nearly two-thirds of the total, followed by those in the central region, and finally the western region. This suggests that enterprises in more developed regions have stronger risk destructiveness and contagion effects. The likely cause is that businesses in the eastern and central regions are more interconnected, face fiercer competition, and maintain closer relationships. Consequently, when a credit crisis occurs in one enterprise, its impact on the entire supply chain is more significant.

6. conclusion

As a pillar industry of the national economy, the automotive industry is particularly vulnerable to credit risk contagion within supply chain networks. This study focuses on the Chinese automotive industry and uses real transaction data from 2011 to 2020 on business interactions between upstream and downstream enterprises to construct an interconnected supply chain network. It analyzes the topological properties and structure of the supply chain network, simulates the risk-bearing capacity of supply chain enterprises under risk shocks, and emphasizes the impact of firm heterogeneity on credit risk contagion within the supply chain.

The main findings are as follows: Analysis of the automotive supply chain network structure from 2011 to 2020 reveals that different supply chain network structures exhibit varying levels of risk perception and damage. Longer supply chains lead to more complex and concealed risk propagation.Firm heterogeneity demonstrates varying degrees of influence during credit risk shocks. Privately-owned enterprises, smaller firms, younger companies, and those located in more developed regions exhibit a higher proportion of risks and greater destructive power during such shocks.

7. Reference

[1] Xie, X., Yang, Y., Zhang, F., et al. (2021). The contagion effects of associated credit risk in supply chains under multiple relational linkages. Chinese Management Science, 29(09), 77–89.

[2] Barro, D., & Basso, A. (2010). Credit contagion in a network of firms with spatial interaction. European Journal of Operational Research, 205(2), 459–468.

[3] Jorion, P., & Zhang, G. (2009). Credit contagion from counterparty risk. The Journal of Finance, 64(5), 2053–2087.

[4] Chen, T. Q., Yang, Q. H., Wang, Y. T., et al. (2020). Double-layer network model of bank-enterprise counterparty credit risk contagion. Complexity.

[5] Boissay, F., & Gropp, R. (2007). Trade credit defaults and liquidity provision by firms. ECB Working Paper No. 753. Available at SSRN: https://ssrn.com/abstract=985123.

[6] Wang, Z., & Wang, Z. (2013). Economic crisis, credit risk contagion, and working capital financing structure: An empirical study of export-oriented electronic information industry listed companies. China Industrial Economics, 11, 122–134.

[7] Qian, Q., & Zhou, Z. (2016). Credit risk contagion of supply chain based on trade credit. Procedia Computer Science, 91, 57–64.