Hindawi
Discrete Dynamics in Nature and Society
Volume 2019, Article ID 3646097, 6 pages
https://doi.org/10.1155/2019/3646097

Research Article

Analysis of Signal Game for Supply Chain Finance (SCF) of MSEs and Banks Based on Incomplete Information Model

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Received 30 November 2018; Accepted 3 February 2019; Published 26 March 2019

Academic Editor: Lu Zhen

The signal gaming model based on incomplete information is used to analyze the decisions of commercial banks and medium-sized and small enterprises (SMEs) in supply chain finance business. It is found that the returns of banks are closely relied on the probability of good SMEs join which is proportional to θ (the probability of "good" SMEs in the market) and p (the probability of "good" SMEs chosen to join the supply chain finance) in supply chain finance business, and the default cost is an important constrain for determining the strategies adopted by the SMEs and the banks. To achieve higher returns, SMEs and banks should make effects to create a better supply chain finance business environment to achieve the separation equilibrium.

1. Introduction

As a new financing mode, supply chain finance has played an increasingly important role in supply chain operational and financial practices and greatly improved the current situation of financing difficulties for medium-sized and small enterprises (SMEs) [1, 2]. For banks, supply chain finance has reduced the cost of evaluating enterprises, effectively circumvented some of the credit risks, and established close ties with supply chain companies to increase the business volume. However, the issue of "information asymmetry" has also brought certain obstacles to MSE and banks.

A signaling game model based on incomplete information is established to analyze the game revenue and game process between banks and enterprises. Then, numerical simulation is utilized to analyze the interaction between variables and the influence of variables on the profits of the bank. Harsanyi [3] defined the incomplete information situation as "each player will receive only partial information about the outcome and the values of these parameters". some participant may find in his self-interest to impair the interests of other supply chain members in an incomplete information status. Claude d'Aspremont et al. [4] imposed compatibility condition to solve the incentive problem.

Stemmler [5] finds that the key characteristic of Supply Chain Finance (SCF) is the integration of financial flows into the physical supply chain, and SCF can be characterized as an essential part of supply chain management. Hofmann [6] describes SCF as located at the intersection of logistics, supply chain management, and finance and defines it as an approach for two or more organizations in a supply chain, including external service providers, to jointly create value by planning, steering, and controlling the flow of financial resources on an interorganizational level. The financing model of supply chain finance in practices mainly includes accounts receivable financing mode, prepaid account financing mode, and inventory financing mode. This paper analyzes the receivable category which refers to the financing mode in which the enterprise pledges to the commercial bank with its own accounts receivable and serves as the source of the first repayment.

Game analysis method used in many supply chain finance research [7], Cai, Zhang, & Zhang [8], evaluated the impact of price discount contracts and pricing schemes on the dual-channel supply chain competition. Esmaeili, Aryanezhad, and Zeephongsekul [9] proposed a Stackelberg model to analyze the relationships between seller and buyer based on noncooperative and cooperative games scenes.

Table 1: Bank-MSE game matrix under complete information.

		MSE	
Bank		Pay back	not pay back
	Loan	$\frac{\alpha Lr - c}{1-\delta}, \frac{\alpha\beta L - \alpha Lr}{1-\delta}$	$-L - c, \alpha\beta L + L$
	No loan	0,0	0,0

Milgrom and Roberts [10] researched the influence of pre-entry prices limit on established firm base on signal game; Friedman [11] defines the basic concept of "fitness" in evolutionary game theory and analyzed the relationship between evolutionary stability state and static equilibrium state of fitness function. Lee and Rhee [12] considered the forms of supply chain financing mechanisms like supply chain contracts.

2. Model

2.1. Bank-MSE Gaming Based on Complete Information. We assume that a MSE (labeled m) needs to loan L for a project, the success rate of the project is α $(0 < \alpha < 1)$, and the return rate of project is β. The MSE borrows from the bank and the expected project revenue is $\alpha\beta$L. Assume that the bank's credit cost (including evaluation costs, supervision costs, etc.) is c, the bank's loan interest rate is r, and the bank's loan interest income is αLr. Assume that the transaction cost between banks and enterprises is 0, and the discount rate is $\delta(0 < \delta < 1)$, and δ is constant. The game matrix is as Table 1.

When $\Pi_{c1} \geq \Pi_{c2}$, that is $(\alpha\beta L - \alpha Lr)/(1-\delta) \geq \alpha\beta$L+L, the MSE will choose to "pay back" the loan, under this situation, $\alpha \geq (1-\delta)/(\beta\delta - r)$, which can be interpreted as when the project success rate α is greater than or equal to $(1-\delta)/(\beta\delta - r)$, the MSE will choose to "pay-back" the loan; otherwise it will "not pay back" the loan. Based on completed information, the bank can get the success rate of the project and use this as a basis to decide whether to lend to the MSE. But in real life, information is asymmetrical, banks cannot get all needed information, and such Nash equilibrium is hard to produce. In this reality, the emergence of supply chain finance has provided new ideas for SME loans.

2.2. Supply Chain Finance and Bank-MSE Signal Game Based on Incomplete Information. Managers often need to make decisions under uncertainty [13]. It is found that the project success rate α will affect the MSEs pay back strategy, so we divide the MSEs into two types according to the difference in project success rate α: if $\alpha \geq (1-\delta)/(\beta\delta - \mathrm{r})$, the company will pay back a loan is defined as a "good" company; if $\alpha < (1-\delta)/(\beta\delta - r)$, the company will not pay back a loan is defined as a "bad" company. On the other hand, all the MSEs can decide to "join" or "not join" in a supply chain finance business. The core enterprise of a supply chain is equivalent to providing guarantees for MSEs in the supply chain finance business. Therefore, if the MSE do not repay the loans, the core enterprises will have the responsibility to compensate for the losses of the banks, and the MSE will be punished if it does not pay back the loan. In the supply chain finance mode, the signal game model is used to analyze the game between banks and MSE.

For simplicity, we given some necessary notations as follows.

(1) "Join" enterprises participate in supply chain finance, and the cost of obtaining core enterprise guarantee is S, and the default cost is F (such as the penalty imposed by core enterprises and banks, the credit loss of non-repayable loans, etc.). In the "join" mode of supply chain finance, the bank obtains the enterprise information set as f; if it does not participate in the supply chain finance, that is, the "no join" mode, the bank obtains the enterprise information set as i. The success rate of a good enterprise project is α_1, and the success rate of a bad enterprise project is α_2. Good companies are marked as C1; bad companies are marked as C2; banks are marked as b.

(2) Priori probability: P(join|C1)= p; P(not join | C1)=1-p.

(3) Priori probability: P(join | C2)= q; P(not join |C2)=1-q.

(4) The probability of being a good company in all enterprises is θ, and the probability of a bad business is 1-θ.

(5) Posterior probability: P(C1 | join)= m_1; P(C2 | join)=1 − m_1; according to Bayes' rule, you can get the following:

$$\begin{aligned} \mathrm{P}(\mathrm{C1} \mid \mathrm{join}) = m_1 &= \frac{\mathrm{P}(\mathrm{join} \mid \mathrm{C1})\,\mathrm{P}(\mathrm{C1})}{\mathrm{P}(\mathrm{join})} \\ &= \frac{p \times \theta}{p \times \theta + (1-\theta) \times q} \end{aligned} \tag{1}$$

(6) Posterior probability: P(C1| not join)= m_2; P(C2 | not join)=1 − m_2. According to Bayes' rule, you can get the following:

$$\begin{aligned} \mathrm{P}(\mathrm{C1} \mid \mathrm{not\ join}) = m_2 &= \frac{P(\mathrm{not\ join} \mid \mathrm{C1})\,P(\mathrm{C1})}{P(\mathrm{not\ join})} \\ &= \frac{(1-p) \times \theta}{(1-p) \times \theta + (1-q) \times (1-\theta)} \end{aligned} \tag{2}$$

(7) The cost of joining the supply chain finance is small and set to be negligible. At the same time, for good companies, when the benefits of "joining" and "not joining" are very similar, good companies will prefer to "join" in order to maintain stable trade income and maintain stable trade targets.

3. Equilibrium Analysis

3.1. Mixed Equalization Analysis. Under the definition of mixed equilibrium, both good and bad SMEs choose the same strategy as (join, join) or (not join, not join). There are two strategies that banks can choose from "loans" or "no loans".

(1) SMEs Choose (Join, Join) Strategy. When a bank chooses to lend a loan, the proceeds are as follows:

$$\Pi_{b1}^{f} = \mathrm{m}_1 \times \frac{\alpha_1 Lr - c}{1-\delta} + (1 - \mathrm{m}_1) \times (\alpha_2 Lr - c) \tag{3}$$

Table 2: Summary of mixed equalization.

Mixed equalization strategy	Strategy of SMEs	(join, join)
	Strategy of Bank	(loan, no loan) When MSE joins supply chain finance, the bank chooses the loan; when MSE does not join the supply chain finance, the bank chooses not to lend.
Equilibrium condition	(1) P(C1 | not join)=m_2, $m_2 \leq \frac{L + c - \delta L - \delta c}{\alpha_1 Lr + L}$. (2) Default cost $F < \alpha_2 \beta L + L - S$.	
Returns	Returns of bank	$m_1 \times \frac{\alpha_1 Lr}{1-\delta} + (1 - m_1) \times (\alpha_2 Lr - c)$
	Returns of good MSE	$\frac{\alpha_1 \beta L - \alpha_1 Lr}{1-\delta} - S$
	Returns of bad MSE	$\alpha_2 \beta L + L - S - F$
Description	Under the condition of mixed equilibrium, the income of enterprises "joining" is higher. Both good and bad companies will choose to join supply chain finance. Banks will be willing to believe that the enterprises in supply chain finance are probable of good enterprises and lend to supply chain finance. SMEs. When the company joins, the bank is willing to lend to the enterprises in the supply chain finance because the guarantee of the core enterprise can share the risk of the non-repayable loan of some bad enterprises.	

When a bank chooses a "no loan" strategy, the revenue of bank is $\Pi_{b2}^{f} = 0$. $(\alpha_1 Lr - c)/(1-\delta)$ and $\alpha_2 Lr - c$ are obviously bigger than 0, then $m_1 \times (\alpha_1 Lr - c)/(1-\delta) + (1-m_1) \times (\alpha_2 Lr - c) > 0$, so $\Pi_{b1}^{f} > \Pi_{b2}^{f}$. That means the bank will get a better return if it chooses a "loan" strategy whether the MSE is a good company or a bad company. Under this situation, the return of good company which chooses to "join" is $(\alpha_1 \beta L - \alpha_1 Lr)/(1-\delta) - S$, and the return of "bad" company which chooses to "join" is $\alpha_2 \beta L + L - S - F$; the return of good company which chooses to "not join" is $(\alpha_1 \beta L - \alpha_1 Lr)/(1-\delta)$, and the return of bad company which chooses to "not join" is $\alpha_2 \beta L + L$.

(2) SMEs Choose (Not Join, Not Join) Strategy. The analysis process is similar to the (join, join) situation. The summary of mixed equalization is shown in Table 2.

3.2. Separation Equilibrium Analysis. In the context of separation equilibrium, there may be two situations: good companies that choose to "join" and bad companies to choose "do not join"; good companies choose "not to join" and bad companies to choose "join".

(1) Good SME and Bad SME Choose (Join, Not Join) Strategy. "Good" companies choose to "join", while bad companies choose "not to join". At this time, p=1, q=0. The two sets of information for the bank are both on the equilibrium path. The optimal strategy of bank is "loans" to good SME, and the return is $(\alpha_1 Lr - c)/(1-\delta)$, the optimal strategy of bank is "no loans" to "bad" SME, and the optimal income of banks is 0. In summary, the optimal response of banks is (loans, no loans). The return of "good" SME is $\Pi_{c1}^{f} = (\alpha_1 \beta L - \alpha_1 Lr)/(1-\delta) - S$; the return of "bad" SME is $\Pi_{c2}^{i} = 0$.

Based on the assumptions, good SME will prefer to "join". The bad SME's income at this time is $\Pi_{c2}^{f} = \alpha_2 \beta L + L - S - F$; at this time, we need to compare Π_{c2}^{f} and Π_{c2}^{i} size; when $\Pi_{c2}^{f} < \Pi_{c2}^{i}$, bad SMEs will choose "do join" strategy; otherwise they will choose "join" strategy that means $\alpha_2 \beta L + L - S - F < 0$, $F > \alpha_2 \beta L + L - S$. In this case, the bad SME "not join" will get a higher income, which constitutes separation equilibrium of [(join, not join), (loan, no loan)]. When $F < \alpha_2 \beta L + L - S$, bad SME "join" gains higher income, and bad companies choose "join". At this context, the separation equalization does not exist.

(2) Good SME and Bad SME Choose (Not Join, Join) Strategy. The analysis process is similar to the (join, not join) situation; the conclusion is that when SME strategy is (not join, join), the separation equalization does not exist.

3.3. Quasi-Separation Equilibrium Analysis. Quasi-separation equilibrium refers to that when one type of signal issuer chooses a strategy, another signal sender randomly chooses between two strategies. In our research, we assume that "good" SME chooses "join", and then the "bad" SME can choose "join" or "not join" randomly.

Based on definition of Quasi-separation equilibrium, we set the probability of good SME in which "join" to supply chain is P=1 and the probability of bad SME is q (choose "join" strategy) or 1-q (choose "not join" strategy). According to Bayes' rule, the following is available:

$$\mathrm{P}(\mathrm{C1} \mid \mathrm{join}) = m_1 = \frac{\mathrm{P}(\mathrm{join} \mid \mathrm{C1})\,\mathrm{P}(\mathrm{C1})}{\mathrm{P}(\mathrm{join})} = \frac{p \times \theta}{p \times \theta + (1-\theta) \times q}$$

$$\begin{aligned} \mathrm{P}(\mathrm{C1} \mid not\ \ join) &= m_2 = \frac{P(\text{not join} \mid \mathrm{C1})\, P(\mathrm{C1})}{P(\text{not join})} \\ &= \frac{(1-p)\times\theta}{(1-p)\times\theta + (1-q)\times(1-\theta)} \\ \mathrm{m}_2(\text{good SME, not join}) &= 0. \end{aligned} \tag{4}$$

When q tends to 0, the probability of bad SME choosing to join tends to 0, bad SME will hardly be confused with good SME, and banks infer P (C1 | not joined) = m_2 = 0. When a bad SME chooses "not to join" and thus can be separated from a good SME, the probability of good SME is equal to zero in "not join" group.

When the bad SME choose to "join", and mix with good SME, P (join | C2) = q, q tends to 1; P (not join | C1) = p = 0. When q tends to 1, p = 0, so the bank infers that m_1 tends to a priori infer θ.

To a "bad" SME, the gain that will be obtained in the "not joined" state is $\Pi_{c2}^{i} = 0$, in the context of mixed equilibrium, $\Pi_{c2}^{f} = \alpha_2\beta L + L - S - F$, to make $\Pi_{c2}^{f} = \Pi_{c2}^{i}$, then $\Pi_{c2}^{f} = \alpha_2\beta L + L - S - F = 0$; $F = \alpha_2\beta L + L - S$. Therefore, if there is a quasi-separation equilibrium, the bad SME will have a return of 0 regardless of whether it chooses to "join" or "not join" strategy.

To a bank, when receiving the signal of "not joining", the probability that the bank thinks it is a good SME is equal to 0 in the "not join" group. The good SME is naturally separated from the bad SME. If the bank's loan income is (-L-c), it must be negative. Therefore, the bank's strategy is not to lend to the "not join" SME with an income 0. When the bank faces the "join" situation of the bad SME, the probability of the good SME in the "join" group enterprise is inferred to be m_1, because the hypothesis is p= 1; then m_1 tends to the prior probability θ; at this time, the bank "loan" income is

$$\Pi = \theta \times \frac{\alpha_1 Lr - c}{1-\delta} + (1-\theta)\times(\alpha_2 Lr - c) \tag{5}$$

At this situation, bank will make a "loan" decision because Π must bigger than 0.

3.4. Comparison among Mixed Equalization, Separation Equilibrium, and Quasi-Separation Equilibrium Analysis

(1) Equilibrium Constrains. The summary of equilibrium constrains is shown in Table 3.

The value of m_1 is needs to be stint to meet the mixed equilibrium condition when the numerical simulation of bank income is in the next step. We let L=100, r=2.5%, c=1, α_1=0.9, δ=0.71, then $m_2 \le 0.29$, that is, the probability of good SMEs which "not join" in supply chain finance in the market is less than 0.29; the Mixed equalization is established. m_1 is Posterior probability:

$$m_1 = \frac{p\times\theta}{p\times\theta + (1-\theta)\times q} \tag{6}$$

Table 3: Equilibrium constrains.

	Equilibrium constrains
Mixed equalization	$m_2 \le \dfrac{L + c - \delta L - \delta c}{\alpha_1 Lr + L}$ $F < \alpha_2\beta L + L - S$
Separation equilibrium	$F > \alpha_2\beta L + L - S$
Quasi-separation equilibrium	$F = \alpha_2\beta L + L - S$

Table 4: The effect of θ on m_1.

θ	p	q	m_1
0	0.8	0.2	0
0.1	0.8	0.2	0.307692308
0.2	0.8	0.2	0.5
0.3	0.8	0.2	0.631578947
0.4	0.8	0.2	0.727272727
0.5	0.8	0.2	0.8
0.6	0.8	0.2	0.857142857
0.7	0.8	0.2	0.903225806
0.8	0.8	0.2	0.941176471
0.9	0.8	0.2	0.972972973
1	0.8	0.2	1

We first analyze the value of m_1, then adjust the value of p, θ and q, and observe the impact on m_1. We let p=0.8, q=0.2, adjusting the value of θ from 0 to 1, the effect of θ on m_1 is as follows. The effect of θ on m_1 is shown in Table 4.

We found that the values of θ and m_1 are positively correlated which means that the more the good SME in the market, the greater the probability of good SME in the "joined" SME group. Similarly, the values of p and q can be analyzed, values of p and m_1 are positively correlated, and q and m_1 are negatively correlated. The establishment of the mixed equalization requires $m_2 \le 0.29$. Since m_1, m_2 are affected by value of p, q, θ, $m_2 \le 0.29$ is required. In order to compare the value range of m_1 with m_2, we set the same group of p, q, θ. The effect of θ on m_2 is as follows. The effect of θ on m_2 is shown in Table 5.

To make $m_2 \le 0.29$, when=0.8, q=0.2, $\theta \le 0.6$, then $m_1 \le 0.857142857$, which means that the value of $m_1$is 0 to 0.857142857 in this case.

(2) Returns of Bank. Summary of returns of bank is shown in Table 6.

We can find that the difference of returns is based on the posterior probability m_1 (separation equilibrium m_1 =1; quasi-separation equilibrium m_1=θ); what follows, we use a few sets of data for a simple comparison.

In the previous section, we have conducted some relation of m_1 and θ using numerical simulation in which p=0.7,q=0.5, and the mixed equalization model requires $m_1 \le 0.8$. Now, we let L=100, r=2.5%, β=0.5, c=1, α_1=0.9, α_2=0.2, δ=0.71; m_1 is adjusted between 0 and 1; the change of returns of banks is shown in Table 7.

Table 5: The effect of θ on m_2.

θ	p	q	m_2
0	0.8	0.2	0
0.1	0.8	0.2	0.027027027
0.2	0.8	0.2	0.058823529
0.3	0.8	0.2	0.096774194
0.4	0.8	0.2	0.142857143
0.5	0.8	0.2	0.2
0.6	0.8	0.2	0.272727273
0.7	0.8	0.2	0.368421053
0.8	0.8	0.2	0.5
0.9	0.8	0.2	0.692307692
1	0.8	0.2	1

Table 6: Returns of banks.

	Equations of returns
Mixed equalization	$m_1 \times \frac{\alpha Lr - c}{1-\delta} + (1 - m_1) \times (\alpha Lr - c)$
Separation equilibrium	$\frac{\alpha_1 r - c}{1-\delta}$
Quasi-separation equilibrium	$\theta \times \frac{\alpha_1 Lr - c}{1-\delta} + (1-\theta) \times (\alpha_2 Lr - c)$

Table 7: Simulation of returns of bank.

m_1	Mixed equalization	Separation equilibrium (m_1=1)	Quasi-separation equilibrium
0	-0.5	--	-0.5
0.1	-0.01896552	--	-0.01897
0.2	0.462068966	--	0.462069
0.3	0.943103448	--	0.943103
0.4	1.424137931	--	1.424138
0.5	1.905172414	--	1.905172
0.6	2.386206897	--	2.386207
0.7	2.867241379	--	2.867241
0.8	3.348275862	--	3.348276
0.9	--	--	3.82931
1	--	4.310345	4.310345

It is shown that the returns of bank Π_b increase among the increasing of m_1. The value of m_1 under the separation equilibrium is 1; the bank's income is the largest in a separation equilibrium (join, not join), (loan, no loan) strategy situation with other variables constant.

(3) Returns of SMEs. Summary on returns of "good" SMEs is shown in Table 8.

The returns of good SME are the same among the three equilibrium situations with the strategies of good SME and bank being ("join", "loan").

Summary on returns of "bad" SMEs is shown in Table 9.

Table 8: Returns of "good" SMEs.

Returns of "good" SME	
Mixed equalization	$\frac{\alpha_1 \beta L - \alpha_1 Lr}{1-\delta} - S$
Separation equilibrium	$\frac{\alpha_1 \beta L - \alpha_1 Lr}{1-\delta} - S$
Quasi-separation equilibrium	$\frac{\alpha_1 \beta L - \alpha_1 Lr}{1-\delta} - S$

Table 9: Returns of "bad" SMEs.

Returns of "bad" SME	
Mixed equalization	$\alpha_2 \beta L + L - S - F$
Separation equilibrium	0
Quasi-separation equilibrium	0

In practices, the bad SMEs will automatically choose to leave the supply chain finance business when the cost of default reaches a certain value. The constrains of mixed equalization is $F < \alpha_2 \beta L + L - S$ for "bad" SMEs, which can get higher returns when they join the supply chain finance under the mixed equilibrium situation.

4. Conclusions

The returns of banks closely refer to the probability of good SMEs join in supply chain finance business, denoted as m_1, which is proportional to θ (the probability good SMEs in the market) and p (the probability good SMEs chooses to join the supply chain finance) and is inversely proportional to q (the probability that bad SME chooses to join supply chain finance). That is, with more good SMEs in the market, and more good SMEs choose to join in the supply chain finance business, SMEs and banks can get higher returns from supply chain finance business.

The default cost F is an important constrain for determining the strategies adopted by the SMEs and the banks. From the separation equilibrium, we can find that the higher default cost F can effectively curb the bad SMEs to join the supply chain finance business and then enhance the stability of the supply chain financial business.

In an incomplete information situation, it is particularly beneficial to the bad SME under the mixed equilibrium situation, and the separation equilibrium is beneficial to the banks. Under the separation equilibrium, good SMEs can obtain more loan resources and get better partners among the living of bad SME, and the core enterprises of the supply chain can reduce some of the guarantee risks. So, we suggest that government departments and enterprises jointly adopt appropriate means to create a good financial environment to promote the emergence of separation equilibrium.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Zhang Tao contributed in writing the paper and communication. Xin Li provided the original research idea. Xinquan Liu contributed in the modeling stage. Nana Feng revised the paper.

Acknowledgments

The work was supported by the National Natural Science Foundation of China (no. 71462005) and 2017 Philosophy and Social Sciences Planning Project of Guangxi Zhuang Autonomous Region (No. 17FJY019). The second author was supported in part by the National Natural Science Foundation of China under grant no. 71801233.

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