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Quantitative Research on "Blockchain+Supply Chain" Financing Based on Game Theory Modeling

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Abstracts:

In the 21st century, with globalization and the "Belt and Road" economic activities. As an important financial means, supply chain financing plays a key role in trade transactions between enterprises. Supply chain financing refers to providing financial support and services to different participants in the entire supply chain through financial instruments to meet the financial needs of their production and trade activities. To address the issue of "blockchain+supply chain" financing, specifically in the traditional supply chain, the downstream of the SMEs financing difficulties has been one of the factors plaguing its development. Still, also one of the constraints on the overall supply chain operational efficiency, we use the principles of game theory to establish a game theory model between financial institutions and SMEs and use Matlab software to solve the simulation data. We use the principle of game theory to establish a game theory model between financial institutions and MSMEs, use Matlab software to solve the simulation data and analyze the financial institutions to adopt the "blockchain+supply chain" financing strategy, and MSMEs to adopt the trustworthy strategy so that the two sides can maximize the benefits, and also maximize the benefits for the whole supply side. In addition, the research process and results can provide references for relevant state departments and various social enterprises and organizations.

Keywords: "Blockchain+Supply chain" Financing; Game theory model; Financial Institutions; MSMEs

Introduction

In today's globalized business environment, supply chain financing, as an important financial instrument, plays a key role in trade transactions among enterprises. Supply chain financing refers to providing financial support and services to different participants in the entire supply chain through financial instruments to meet the financial needs of their production and trading activities. This form of financing not only covers the enterprise's own financing needs but also focuses on the upstream and downstream partners of the supply chain[1,2] and realizes the flexible management of capital flow through financial tools.

Its advantages speak for themselves. First, supply chain financing helps optimize supply chain operations, accelerates the flow of funds, and reduces the financial pressure in enterprise operations. It provides a more effective way of capital management, promoting the smooth conduct of the production link and enhancing the efficiency and competitiveness of the whole supply chain. Secondly, supply chain financing can reduce the financial risks in the supply chain link, and it provides flexible financing channels and capital protection for enterprises through financing tools for accounts, inventories, and so on. Most importantly, this kind of financing not only focuses on the enterprise itself but also on the whole supply chain ecosystem, which helps to enhance the overall efficiency of each participant in the supply chain.

Supply chain financing has significant application prospects in the Belt and Road Initiative[3]. The initiative covers several countries and regions spanning Asia, Europe, and Africa, and supply chain financing has multiple advantages. First, it helps promote cross-border trade among participating countries and regions and facilitates the convenient conduct of trade activities. Secondly, the provision of cross-border financing services can reduce the financial risks of the participating parties in cross-border trade and provide more reliable financing guarantees for enterprises in different countries and regions. Most importantly, supply chain financing can help strengthen the economic ties between countries and regions along the Belt and Road, promote the cross-border flow of resources, technology, and capital, and provide solid support for the comprehensive development of the Belt and Road Initiative.

Therefore, supply chain financing, as an important financial instrument[4], is significant in inter-enterprise trade transactions and plays an indispensable role in promoting

global economic cooperation and cross-border trade and investment[5]. In-depth exploration and utilization of the potential of supply chain financing will provide strong support and guarantee for cross-border trade and regional economic development.

2. Literature review

Xie Xun[6] (2018) suggests that online banking opens a new trade era with unlimited convenience. However, the problem of capital security is highlighted. The solution: improve user authentication, strengthen regulatory constraints, and reduce investment risks. Internet banking is crucial to e-commerce and needs to protect consumer rights and interests and asset security.

Rebiya Tursun et al. [7] (2021) study the direct impact of supply chain concentration on corporate innovation through secondary data and focus on the mediating role of exogenous financing. The shortcomings are that secondary data may lead to inaccurate measurement of innovation and a lack of breakdown of the mediating role of exogenous financing. This can enhance the study's accuracy by increasing the sample size and examining other indicators in depth.

Wang Bo et al.[8] (2022) elaborated on the key role of supply chain finance in enhancing the financing efficiency of science and technology-based SMEs. Not only highlighting the positive impact of supply chain finance on financing efficiency but also examining the impact of its influence channels and the quality of accounting information on efficiency from different perspectives, they suggest that SMEs strengthen their internal management to optimize the efficiency of supply chain financial services and reduce risks.

Wang Ying et al.[9] (2023) used small and medium-sized enterprises and financial institutions as participants in the financial system, introduced blockchain technology into online credit evaluation services, and constructed an evolutionary model for financial institutions to provide credit financing to small and medium-sized enterprises. They compared the changes in system equilibrium before and after the introduction of blockchain technology, analyzed its mechanism, and conducted numerical simulation analysis.

Han Pu et al.[10](2023) first constructed an evolutionary game model for government departments, blockchain service providers, and third-party regulatory agencies to explore the behavioral tendencies of multiple stakeholders in government data sharing from the perspective of rewards and punishments. Secondly, they explored the equilibrium conditions of the three-party evolutionary game through model stability analysis.

3. quantitative research on blockchain and supply chain financing based on game theory modeling

3.1 Model preparation and hypotheses

This model focuses on the game between financial institutions and MSMEs[11,12] in the supply chain. Game Theory, also known as Countermeasure Theory (Game Theory), is a new branch of modern mathematics and an important discipline in operations research. Game Theory focuses on the interactions between formulated incentive structures and is a mathematical theory and methodology for studying phenomena of a combative or competitive nature. Game theory considers individuals' predicted and actual behavior in a game and studies their optimization strategies. Biologists use game theory to understand and predict certain outcomes of evolution.

Model Assumption: 1. The financing company can either fulfill the agreement or not fulfill the agreement at the financing term date. 2.MSMEs apply for financing from the financing company by the receivable claims. 3. All parties to the game are rational and will make decisions to maximize their interests under incomplete information.

3.2 Game Model of Financial Institutions and MSMEs

3.2.1 Interpretation and Setting of Variables (Parameters)

Table 1 Game parameters and their interpretation

Parameter name	Alphabetic variables corresponding to parameters
The probability of financial institutions choosing to use the "blockchain + supply chain" financing model	P_{f1}
The probability that a financial institution chooses a traditional financing model	P_{f2}
The probability that a financial institution chooses the coexistence of the two financing models	$1-P_{f1}-P_{f2}$
Probability of trustworthiness of MSMEs	P_{e1}
Probability of default for MSMEs	$1-P_{e1}$

In addition to the parameters we set in Table 1, the game theory model we built also uses the following variables:

D is the accounts receivable claims of MSMEs, MA is the marginal credit review cost of financial institutions, R_d is the pledge rate of financial institutions, R_s is the reinvestment yield of MSMEs after accounts receivable financing, T_1 is the default loss of MSMEs after choosing "blockchain + supply chain" financing model, T_2 is the default loss of MSMEs after choosing traditional financing model, and T_3 is the default loss of MSMEs after choosing hybrid financing model. " T_1 is the default loss of MSMEs after choosing "blockchain+supply chain" financing mode, T_2 is the default loss of MSMEs after choosing traditional financing mode, and T_3 is the default loss of MSMEs after choosing mixed financing mode. R_i is the lending rate of financial institutions, C_1 is the enhanced revenue of MSMEs after choosing the "blockchain+supply chain" financing model[13], and C_2 is the enhanced revenue of MSMEs after choosing the hybrid financing model.

3.2.2 Modeling and Analysis

In the game between financial institutions and MSMEs, the game strategy of financial institutions is to choose "blockchain+supply chain" or "traditional financing mode," and MSMEs may choose "trustworthy," "default," or "half trustworthy" after obtaining financing. After obtaining financing, MSMEs may choose to "keep their word," "default," or "half keep their word."

In any case, the amount of loan that MSMEs can get is the product of MSMEs' accounts receivable claim (D) and the financial institution's financing pledge rate (R_d), i.e., the financial institution grants loans to MSMEs in the supply chain. When the financial institution chooses the strategy of "blockchain + supply chain" financing mode, if the MSME chooses to repay the loan "in good faith," the financial institution can obtain the product of the loan amount and the loan interest rate (R_i), i.e., $R_d * D * R_i$.

In the traditional financing model, due to the existence of MA, the financial institution's income also needs to remove this part of the cost. MSMEs can get the reinvestment income after financing the loan, after deducting the interest, plus the enhanced income (C_1) of MSMEs after choosing the "Blockchain + Supply Chain" financing model, i.e., $R_d * D * (R_s - R_i) + C_1$: If the MSME chooses to default on the loan, the financial institution loses the loan principal and interest $-R_d * D * R_i$ and the MSME loses the loan principal and interest $-R_d * D * R_i$ and the MSME loses the loan interest $-R_d * D * R_i$, while MSMEs can get the sum of financing principal and reinvestment income $R_d * D * (1 + R_s)$ minus the default loss of MSMEs after choosing the "blockchain + supply chain" financing model (T_1). In addition, MSMEs may have a coexistence of compliance and default. Similarly, under the traditional financing model, the revenue of MSMEs is $R_d * D * (1 + R_i) - T_2$. In summary, the payoff matrix of the game between financial institutions and MSMEs is shown in Table 2 below:

Table 2 Benefits matrix of the game between financial institutions and MSMEs

The two sides in a game	Small, Medium, and Micro Enterprise(MSME)		
Financial institution		P_{e1}	$1 - P_{e1}$
	P_{f1}	$R_d * D * R_i$, $R_d * D * (R_s - R_i) + C_1$	$-R_d * D * R_i$, $R_d * D * (1 + R_s) - T_1$
	P_{f2}	$R_d * D * R_i - MA$, $R_d * D * (R_s - R_i)$	$-R_d * D * R_i - MA$, $R_d * D * (1 + R_s) - T_2$
	$1 - P_{f1} - P_{f2}$	$R_d * D * R_i - \alpha MA$, $R_d * D * (R_s - R_i) + C_2$	$-R_d * D * R_i - \alpha MA$, $R_d * D * (1 + R_s) - T_3$

Table 2 shows the weight parameters. Through the analysis, it can be seen that, no matter what strategy is chosen by MSMEs, the benefit of financial institutions choosing the "blockchain+supply chain" financing mode is always larger than that of mixed financing mode and larger than that of traditional financing mode. Therefore, the preferred strategy of financial institutions in the game is the "blockchain+supply chain" financing mode, so the preferred strategy of financial institutions is the "blockchain+supply chain" financing mode. Supply chain" financing model. When financial institutions choose the "blockchain+supply chain" financing mode, the equilibrium strategy that prompts MSMEs to choose a trustworthy strategy is that the benefit of trustworthiness is greater than or equal to the benefit of default, as shown in the following (1)(2):

$$R_d * D * (R_s - R_i) + C_1 \geq R_d * D * (1 + R_s) - T_1 \qquad (1)$$

Simplify to:

$$D \leqslant \frac{C_1 + T_1}{R_d * (1 + R_i)} \tag{2}$$

As shown in equations (1) and (2), the lower the lending interest rate R_i of financial institutions, the greater the improved return C_1 of MSMEs after choosing the "blockchain+supply chain" financing mode, and the greater the default loss of MSMEs after choosing "blockchain+supply chain" financing mode, the greater the possibility of MSMEs choosing to keep their word at equilibrium. The greater the default loss of the enterprise, the greater the probability that the MSME will choose to keep its word in equilibrium. It is generally believed that the lending interest rate of financial institutions will not be zero, so 1+i>0. Therefore, the smaller the receivable claim D of MSMEs is, the more likely that MSMEs will choose the trustworthy strategy in the game's equilibrium.

Suppose

a financial institution chooses a mixed financing model. In that case, it can rely on the weighting parameter α to mediate the relationship between the size of the benefits between the financial institution and the MSME, and a good choice can maximize the total benefits, as shown in the following equations (3) (4) (5):

$$R_d * D * (R_s - R_i) + C_2 = R_d * D * (1 + R_i) - T_3 \tag{3}$$

Substitution of weighting parameter α:

$$R_d * D * (R_s - R_i) + (1 - \alpha) * C_1 = R_d * D * (1 + R_s) - (1 - \alpha) * T_1 - \alpha * T_2 \tag{4}$$

Simplify to:

$$\alpha = \frac{D * R_d * (1 + R_s) - T_1 - C_1}{T_2 - T_1 - C_1} \tag{5}$$

It can be concluded that the lower the financial institution's lending rate R_i, the greater the SMEs' enhanced return C_1 after choosing the "blockchain+supply chain" financing model, and the greater the SMEs' default loss \[{}_{}\]after choosing the "blockchain+supply chain" financing model, the smaller the SMEs' default loss T_2 after choosing the traditional financing model, and the greater the α, the higher the probability of SMEs' trustworthiness, and the greatest the total benefit of SMEs and financial institutions.

3.2.3 Model solving and analyzing

Table 3 is close to the actual set of simulation game parameters. The following parameters are substituted into the game model of financial institutions and MSMEs, and Matlab software is used to program the solution: the results obtained are shown in Table 4.

Table 3 Simulation game parameter settings

Parameter variable	Parameter value
D	10000
MA	100
R_d	0.8
R_i	0.05
R_s	0.3
T_1	8000
T_2	7500
T_3	7800
C_1	150
C_2	130
P_{f1}	1/3
P_{f2}	1/3
P_{e1}	0.5
α	0.5

Table 4 The payoff matrix of the solved game

The two sides in a game	Small, Medium and Micro Enterprise (MSME)		
Financial institution		P_{e1}	$1 - P_{e1}$
	P_{f1}	400, 2150	-400, 2400
	P_{f2}	300, 400	-500, 2900
	$1 - P_{f1} - P_{f2}$	350, 2130	-450, 2600

Therefore, it can be concluded from Table 4 that the financial institutions choose to select the "blockchain + supply chain" financing mode strategy, and the MSMEs choose to abide by the strategy, which can be concluded that the total benefit is the greatest. It is of great benefit to the development of the society.

In the traditional supply chain, the downstream of the MSME financing difficulties has been one of the factors that plagued its development, but also one of the constraints on the overall supply chain operational efficiency. In the traditional financing model, financial institutions are out of the control of financing risk considerations for the financing needs of the main body of the financing credit. There are a lot of constraints to solving the financial institutions financing risk is to improve the key to the difficulties of the MSME financing. The "blockchain + supply chain" financing model can effectively reduce the financing risk of financial institutions, and the improvement of the financing efficiency of MSMEs means that compared

with the traditional financing model, it is easier for MSMEs to get financing, and they will also get the reinvestment income after financing. The game theory model analysis shows that when the financial institutions choose the "blockchain + supply chain" financing mode after the MSMEs improve, the greater the benefits, in equilibrium, the greater the possibility of MSMEs choosing to abide by the letter.

In addition, the lower the financial institution's lending rate R_i, the greater the SME's profit after choosing the "blockchain+supply chain" financing model, the greater the probability that the SME will choose to keep its word in the equilibrium. The two sides can finally form a win-win cooperation and equilibrium game result.

In addition, the lower the financial institution's lending rate\[{}_{}\], the greater the SME's profitability\[{}_{}\]. After choosing the "blockchain + supply chain" financing model, the probability that the SME will choose to keep its word in equilibrium is greater. The two sides can finally form a win-win cooperation and equilibrium game result.

Conclusion

This paper focuses on the blockchain and supply chain financial institutions and MSMEs under the "Belt and Road" background. It discusses the game theory model of "blockchain and supply chain" financing mode from theory to practice[14]. It is found that the traditional financing mode of financial institutions has many constraints on the financing credit of the main financing demand for the consideration of controlling the financing risk, and solving the financing risk of financial institutions is the key to improving the financing difficulties of MSMEs. The "blockchain + supply chain" financing model can effectively reduce the financing risk of financial institutions. Improving the financing efficiency of MSMEs means that it is easier for them to get financing than the traditional financing model. They will also get the reinvestment income after financing. Simulation validation shows its effectiveness in the actual context, providing an important reference for establishing a reliable cooperative relationship between financial institutions and MSMEs.

In this paper, a game theory model is developed, and simulation data is used for exploration, but there are some limitations. Due to the more obvious artificial effects of the simulation data, it can be somewhat different from the real data[15]. Despite some limitations, there is still great potential to inspire future research. More comprehensive and accurate metrics can be explored to assess corporate innovation, such as the number of patent applications and new product development[16]. In addition, focusing on the impact of other supply chain structural characteristics on innovation is expected to enrich the research results and improve the understanding of innovation in MSMEs. Future research can move in these directions to fill existing research gaps and expand the understanding of the relationship between supply chains and MSME innovation.

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