Article
Dynamic Evolutionary Game Approach for Blockchain-Driven Incentive and Restraint Mechanism in Supply Chain Financing

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Abstract: The sustainability of financing is an important measure in the development of supply chains. However, the difficulty and high cost of financing have always been critical factors hindering the sustainable development of small and medium-sized enterprises (SMEs). Blockchain technology (BT) is an effective tool to relieve the current problem. Based on it, this study aims to establish Blockchain-driven incentives and restraint mechanisms for SME financing using a dynamic game model in which financial institutions (FIs) and new agricultural business entities (NABEs) are regarded as game subjects. By analyzing the impact of key parameters on the equilibrium state of the game for all stakeholders, several findings are drawn as follows. (1) The usage of BT affects FI loan strategies by influencing their cost in supply chain financing. (2) The usage of BT affects NABE’s strategy choice by influencing their loan interest rate. (3) The usage of BT affects NABE’s strategy choice by influencing their default losses. (4) The usage of BT affects NABE’s and FI’s strategy choices by influencing their additional benefits. This study provides decision-making support for optimal strategy decisions under different conditions and serves as a theoretical reference for the government in formulating financing incentive and restraint mechanisms.

Keywords: supply chain financing; optimal strategy decision; Blockchain technology; evolutionary game model; incentive mechanism; new agricultural business entities

1. Introduction

With the rapid growth of urbanization, traditional supply chain finance models face increased inherent risks, which can lead to disruptions in the capital chain for small- and medium-sized enterprises (SMEs) [1]. Supply chain financing primarily involves consolidating transactional and relevant information from financing institutions, core companies, and upstream and downstream businesses [2]. By connecting the resources of these stakeholders’ resources, it breaks down the financing barriers between the real economy and the financial industry and improves the financing ratio of financial enterprises. This, in turn, provides better capital support for the real economy [3]. It indirectly controls the financing risks and facilitates faster provision of financial services for the development of the rural economy.

Since the majority of capital demanders in supply chain finance are SMEs, financial institutions (FIs) encounter challenges in credit identification, transaction supervision, risk control, and other business links associated with supply chain finance. New agricultural business entities (NABEs), as a member of small and medium-sized enterprises (SMEs), also faces these challenges deeply, though it plays an indispensable role in achieving rural revitalization and advancing agricultural and rural modernization [4]. NABEs mainly consist of family farms, farmers’ cooperatives, and agricultural enterprises [5], which can further ensure the safety of grain production and promote the upgrading and optimization
of the industry through the development of modern agriculture [6]. Like other industrial sectors, NABEs indeed need to adopt advanced production technology and equipment, engage in deep processing of agricultural products, expand the industrial chain, expand production scale, and so on, which have a higher demand for funding than ordinary farmers and have strong financial support. This significant funding gap forced by NABEs has compelled them to rely on asset-backed debt financing using agricultural land as collateral [7]. However, with socio-economic development, NABEs encounter profound challenges. On one hand, issues such as highly asymmetric information, weak organizational structures, limited collateral availability, narrow financing channels, lack of guarantee mechanisms, and low financing accessibility [8] pose considerable obstacles that impede NABE development [9,10]. Addressing these challenges is crucial for unlocking the full potential of NABEs and ensuring their sustained growth. On the other hand, with the lack of significant operational scale, limited capacity, and low level of industrialization profits, FI in practice is unable to timely and effectively measure NABE’s operation, repayment ability and other relevant information, which leads to its guarantee financing risk being still at a high level [11]. It has become an emerging trend for FIs to explore efficient and accurate emerging technologies as a means to facilitate the financing of NABEs.

Blockchain technology (BT) has emerged as a transformative force in the financial field, owing to its characteristics of decentralization, distributed ledger, and being tamper-proof [12,13]. This innovative technology has found applications in various sectors, such as its application to digital finance, bank credit investigation, digital currency, logistics, public services, and more [14–17]. By leveraging the distributed ledgers in the Blockchain platform, the multi-party trust mechanism can be established [18], and then a good credit reporting system can also be built. On the one hand, this helps revitalize agricultural assets, optimize organizational structures, and address the issue of high information asymmetry in the financing process [19]. On the other hand, FI can gain deeper insights into the operational dynamics and creditworthiness of NABEs, enabling them to provide robust support in addressing the financing challenges faced by NABEs.

A problem naturally arises: whether BT can be adopted by FI and NABE or not, since it is affected by many factors promoting their willingness to participate. One of the most effective methods is to enable FI and NABE to gain more benefits. Because FI and NABE continuously adjust their strategies based on their decision-making environment, one party’s strategy directly affects the benefit of the other party. There are obvious game characteristics between FI and NABE. The key to evolutionary games lies in designing incentive and constraint mechanisms by analyzing the learning mechanisms and evolutionary strategies of participants to achieve system equilibrium. Based on the analysis above, some questions naturally are raised as follows.

1. What dynamic game relationship does the stakeholders in supply chain financing base on BT?
2. What kind of theoretical model can well characterize the game strategies’ relationship among stakeholders for supply chain financing?
3. How does BT affect the stakeholders’ strategy choices in supply chain financing?

To tackle the aforementioned issues, this study concentrates on NABEs and FIs as the primary game subjects. The main objectives of this study can be summarized as follows: (I) An evolutionary game model will be developed to characterize the game strategies’ relationship between FI and NABE. (II) The main influence factors and the evolutionary trend of the FI’s and NABE’s strategy choices will be identified and simulated, respectively. (III) The incentive and restraint mechanism of the financing risk will be designed according to the influence factors and the FI’s and NABE’s strategies’ evolutionary trend. The main highlights of this study have two aspects: (I) This study selects NABE as the representative of the SMEs in the game process, which broadens the scope of research subjects and provides a broader perspective. (II) This study utilizes the evolutionary game theory to examine the evolutionary trends in investment and financing strategies adopted by FIs and NABEs, thereby enriching existing research findings. Moreover, considering the
widespread prevalence of NABEs globally, the insights of this study can serve as a valuable theoretical reference for governments in diverse contexts when formulating financing incentives and constraint mechanisms.

The remaining sections of this study are structured as follows: Section 2 presents a literature review on supply chain financing, the application of BT, and evolutionary game theory. Section 3 focuses on model formulation, including assumptions, parameters, construction of the evolutionary game model, and an analysis of the model. In Section 4, simulation analysis is conducted covering the impact of initial strategies on the evolution path, the influence of different parameters on the evolution path, and discussions on the results. Finally, Section 5 concludes this study and includes some corresponding strategies and suggestions for future research.

2. Literature Review

This section primarily delves into the theoretical foundations of the study, specifically focusing on supply chain financing, the application of BT, and evolutionary game theory. The knowledge and concepts discussed in this section serve as the fundamental basis for the subsequent analysis conducted in the study.

2.1. Supply Chain Financing

Supply chain financing is a comprehensive financing model that relies on the collaborative efforts of core enterprises and their associated upstream and downstream supporting businesses, functioning as a unified entity [3]. By leveraging transaction relationships and industry characteristics within the supply chain, it establishes an integrated financial solution that emphasizes the control of cargo rights and cash flow. Supply chain financing serves to alleviate the challenges encountered by upstream and downstream enterprises in accessing financing and guarantees. Furthermore, it aids in reducing supply chain financing costs and enhances the competitive advantage of both core enterprises and their supporting counterparts [20].

Currently, research on supply chain financing has gained substantial momentum and has been practically implemented in various domains. Wu et al. [21] analyzed the impact of carbon emission reduction on supply chain operations and financing decisions considering financial constraints. Huo et al. [22] highlighted the significance of addressing financial risk control and financing pricing issues within the context of supply chain financing involving multiple stakeholders. Wang et al. [23] conducted a study to identify crucial driving factors and corresponding results in supply chain finance decision making by constructing a comprehensive model for supply chain finance adoption. Yang et al. [24] emphasized that agricultural supply chain finance represents a novel financial model, with the central challenge lying in the effective management and control of supply chain financial risks. To achieve the transformation from the current agricultural supply chain to a green agricultural supply chain, adequate financial support and enhanced consumer recognition are crucial. Building upon this premise, Zhang and Syed Abdul [25] devised a financing system that involves the participation of agricultural suppliers and urban residents, and they analyzed the impact of this system on agricultural supply chain financing. Li et al. [26] utilized grey correlation analysis and the entropy method to investigate the impact of agricultural supply chain finance on rural economic development. Through an analysis of financing strategies employed by SMEs, Yan et al. [27] discovered that the financing rate, effort cost, and profit all exert influence on the financing strategies of agricultural supply chains. By using fuzzy set qualitative comparative analysis, Duan et al. [28] investigated the linkage effects of technology, organization, and environmental conditions on the performance of SMEs in improving supply chain financing. Additionally, Xu et al. [29] emphasized that information asymmetry of all parties involved in the supply chain has become the primary problem hindering its development, and BT presents an effective solution to overcome this problem of information silo, so as to facilitate the information sharing of the supply chain. Wang and You [30] highlighted that the integration of BT into the financial sector of the agricultural
value chain has the potential to alleviate the financing bottleneck faced by the development of the agricultural supply chain. The adoption of agricultural supply chain finance requires advanced information technology support and financial attractiveness. Additionally, it is important to seek collaboration with various entities [31]. Furthermore, some companies have already implemented financing mechanisms to incentivize sustainable practices among their suppliers and improve their supply chain efficiency through different payment terms [32].

New agricultural business entities (NABEs), as significant contributors to the development of agricultural and rural economies, mainly refers to educated, skilled, operated farmers and agricultural business organization with large-scale operations and more intensive degree and market competitiveness [4,10,33]. Since only modern agriculture can make a significant contribution to economic growth [34], NABE can only provide power for the development of the modern agricultural business mode. Soto [35] found that the lack of a formal certificate of property title is the reason for the low financing ability of rural residents in developing countries. Townsend and Yaron [36] believed that the government seeks to promote agricultural credit, which will increase rural financial risk and decrease efficiency in the absence of risk management. McCord and Osinde [37] found that micro-insurance institutions in rural areas are often in a state of continued loss due to small-scale businesses and high operating costs. According to Zhu et al. [10], the financing challenges faced by NABEs have emerged as a significant obstacle, limiting their development potential. Zhang and Fan [38] employ the back propagation (BP) neural network to develop a predictive model for farmers’ formal credit availability. The study also examines formal credit demand and identifies factors influencing the availability of formal credit for NABEs.

Based on the aforementioned analysis, the existing research primarily concentrates on supply chain finance operations and financing decisions, driving forces, and their impact on economic development. However, relatively less research emphasizes the influencing factors from specific groups, such as NABEs, and their financing mechanisms for incentives and constraints. Therefore, this study focuses on the unique category of NABE to provide tailored decision-making references for their financing, which broadens the existing scope of research.

2.2. Application of Blockchain Technology

BT has emerged as a significant player in the financial industry, primarily driven by its decentralized nature, distributed ledger system, and tamper-proof features [39,40]. With these distinctive attributes, the Blockchain platform has the potential to address challenges such as information asymmetry, positioning itself as a crucial strategic tool for future business deployments by financial institutions [40].

At present, scholars have carried out rich research using BT. Liu et al. [41] believed that Blockchain, as a distributed ledger, has been applied to a wide range of scenarios beyond cryptocurrency, such as the Internet of things, health care, and insurance. Yermack [42] pointed out that Blockchain is a new application of cryptography and information technology in solving the problem of financial record keeping, which may lead to profound changes in corporate financial governance.

The integration of science and technology into the financial sector has the potential to optimize resource allocation and drive economic development. BT serves as a data infrastructure that facilitates the advancement of big data analysis. Through its consensus algorithm mechanism, BT enables the creation of a trusted network where data can be securely transmitted among nodes. This fosters the distribution and sharing of information, thereby reducing information asymmetry [19]. Relevant research conducted by Mishkin [43] highlighted how Internet finance can address the issue of information asymmetry. Song et al. [44] discussed the cost of its application and the long-term impact of sustainable benefits when implementing BT in cooperation, offering novel insights for governance in traditional sectors from a technology-driven perspective. Regarding the research on BT empowerment, Niu et al. [45] conducted research on incentive mechanisms by
constructing a two-stage supply chain, which examined how BT affects incentive alignment opportunities among supply chain members. Similarly, Shen et al. [46] designed incentive mechanisms based on Blockchain smart contracts to encourage active participation in information sharing by enterprises. Zhu et al. [47] integrated BT with supply chain finance platforms and analyzed the impact of changes in incentive parameters on subject strategies using an evolutionary game model. Meanwhile, Deng et al. [48] also pointed out that the field of supply chain finance is still in its early stages, with limited research on optimal incentive contracts for empowering BT. And, to address this gap, they employed principal-agent theory and incentives theory to investigate the incentive mechanism between supply chain platforms and banks. Overall, BT plays a pivotal role in promoting the development of various application fields seen today.

2.3. Application of the Evolutionary Game Theory

Classical game theory [49] operates under the assumption that participants are perfectly rational, meaning their strategic behavior evolves in the game and automatically leads to equilibrium through introspection. However, in reality, it is challenging for participants to be entirely rational, and reaching equilibrium instantaneously is equally difficult. To overcome these limitations, evolutionary game theory has been introduced. In evolutionary game theory, the concept of Nash equilibrium represents a dynamic process rather than an instant equilibrium. Participants continuously adjust their decisions in response to their respective environments, ultimately reaching equilibrium [40].

Notable studies have employed an evolutionary game approach in different contexts. Based on an evolutionary game approach, Toda et al. [50] proposed a dynamic model utilizing first-order differential equations to analyze the decision-making process of miners and assess the stability of equilibrium points within their model. Additionally, Xu et al. [51] developed a four-party evolutionary game model involving SMEs, banks, guarantee agencies, and the government. They found that enhancing supervision for defaulting SMEs and collaborating with financial institutions were crucial in improving the credit ratings of SMEs. Moreover, Kang et al. [52] established a two-level supply chain consisting of a retailer and a manufacturer. They employed the Stackelberg game approach to determine low-carbon strategy combinations for the retailer and manufacturer. Their findings indicated that reducing the financing interest rate for retailers could lead to an equilibrium state within the supply chain system. Yan et al. [53] developed a tripartite evolutionary game model encompassing a bank, core enterprise, and SME. Their results demonstrated that the lending rate set by the bank and the reputation loss suffered by defaulting core enterprises impacted the equilibrium state of the tripartite evolutionary game. Overall, evolutionary game theory aims to design incentive and constraint mechanisms by analyzing participants’ learning mechanisms and evolutionary strategies to achieve equilibrium. Its application enables a deeper understanding of complex systems and facilitates the development of effective strategies. The summary for a portion of the relevant literature is listed in Table 1.

Through the analysis of the existing literature, it can be concluded that the key to evolutionary games lies in analyzing the learning mechanisms and evolutionary strategies of participants to achieve the equilibrium of the system. The decision-making process of Fis and NABEs, continuously adapting their strategies based on their respective decision-making environments, aligns perfectly with the learning mechanism and evolutionary strategy advocated by evolutionary game theory. Compared to the existing literature, firstly, they primarily concentrate on the influence of NABEs on farmers’ employment while giving relatively less consideration to addressing the challenge of sluggish financing in their operations. Secondly, the current research predominantly relies on qualitative analysis and case studies, and few studies explore the innovative mechanisms and financing model diffusion of NABEs from a dynamic evolutionary perspective. Additionally, it is wise to incorporate BT and establish a financing incentive and restraint mechanism to solve the difficulty and slow financing for NABEs. Based on the existing research, the evolutionary game theory and the advantages of BT would be applied to study the financing risk
reduction mechanism of NABEs so as to provide policy reference for reducing the financing risk of NABEs.

Table 1. Summary of the relevant literature.

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Objective</th>
<th>Methodology</th>
<th>Research Perspective</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The impact mechanism of supply chain financing / Incentive mechanism for information sharing among supply chain enterprises</td>
<td>/</td>
<td>Key driving factors for supply chain financing decision-making</td>
<td>[21,23,54]</td>
</tr>
<tr>
<td>2</td>
<td>The impact of BT on the optimal incentive contract in supply chain finance</td>
<td>Evolutionary game theory</td>
<td>Encourage participants to use BT</td>
<td>[45–47]</td>
</tr>
<tr>
<td>3</td>
<td>Incentive mechanism for using BT in retailer inventory games</td>
<td>Principal-agent model and incentive theory</td>
<td>The impact of BT maturity on participants</td>
<td>[48]</td>
</tr>
<tr>
<td>4</td>
<td>Incentive and Restraint Mechanism in Supply Chain Financing</td>
<td>Sequential games</td>
<td>The impact of demand uncertainty on subjects adopting BT</td>
<td>[55]</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>Evolutionary game theory</td>
<td>This paper</td>
<td></td>
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</tbody>
</table>

3. Model Formulation

3.1. Assumptions and Parameters for Model

In general, NABEs are at a relatively inferior position in the financing process. The lack of self-identity ability makes it difficult for NABEs to obtain a large amount of financing from FI. However, BT is an emerging technology with the characteristics of openness, transparency, non-tampering of data, and decentralization. It can facilitate information sharing between FIs and NABEs within the supply chain, promoting high credibility and low-cost exchanges. Previously, assessing the creditworthiness of NABEs was challenging for FIs due to disparities in storing land information, warehouse details, and other relevant data, as well as the absence of regulations and standards. Nevertheless, with the integration of BT, credit and financing information can be efficiently transmitted across multiple layers of the supply chain, effectively enabling the creditworthiness of NABEs. During the financing process, by utilizing Blockchain technology platforms, FIs can obtain real-time updates on the production and operational status of NABEs, facilitating prompt evaluation and supervision while curbing opportunistic behavior. Furthermore, following the completion of financing, repayment-related information can be linked, establishing a virtuous self-circulation of credit.

Therefore, to ensure the smooth financing process, FI and NABE are regarded as two game subjects in this study, and FI will supervise the repayment behaviors of NABEs. Here, there are two behavior choices for FI in the supervise process. One is that the Blockchain platform is used to realize the automated audit and supervise the NABE’s behaviors, and the other is the supervision of NABE using the traditional supervised mean (TSM). Additionally, there are also two behavior choices for NABEs. One is the repayment on time, and the other is that NABE cannot repay the loan funds due to certain reasons, such as reinvesting. Specifically, when FI selects the Blockchain platform to supervise the NABE’s strategies and behaviors, it will obtain additional benefits if the NABE chooses the repayment strategy. Meanwhile, the cost brought by the BPSM for FI should be paid. Additionally, the cost of credit checks brought by the TSM for FI also does not need to be paid. Otherwise, if the TSM is selected, the FI will not get additional benefits and has to pay the cost of credit checks. Moreover, it is assumed that, if the loan can be paid to the FI, the NABE will obtain additional benefits. On the contrary, the NABE will pay the default losses, and its default losses are different under the FI’s different supervision strategies. These issues can be illustrated in Figure 1.
Based on the mention above, to construct the game model, some assumptions are given as follows:

**Assumption 1.** Assume that FI and NABE are the two main game subjects, and both of them are bounded rationality.

Since FI and NABE are the main stakeholders in the game process, the purpose of their decision-making is to maximize their interests, and they adjust their strategies gradually based on their learning abilities and game outcomes. Thus, Assumptions 2 and 3 are given as follows:

**Assumption 2.** Assume that FI has two behavior choices: Blockchain platform supervised mean (BPSM) and TSM, respectively. And, the probabilities of selecting BPSM and TSM for FI are \( x \) and \( 1 - x \), respectively.

**Assumption 3.** Assume that NABE has two behavior choices: repayment and default, respectively. And the probabilities of selecting repayment and default for NABE are \( y \) and \( 1 - y \), respectively.

Obviously, there are two strategies for FI, the costs brought by them are different, and the default losses are also different for NABEs selecting different strategies.

**Assumption 4.** Assume that FI will obtain the additional benefit selecting BPSM and pay cost brought by the usage of the BPSM. Meanwhile, the cost of credit checks will be paid if FI selects TSM. Therefore, the additional benefit and the cost due to the usage of BPSM are denoted as \( G \) and \( C \), respectively, and the cost of credit checks for FI selecting TSM is denoted as \( c \).

**Assumption 5.** Assume that the default losses paid by the NABE under the FI’s BPSM and TSM strategies are different, and the NABE will receive additional benefit if it chooses the repayment strategy. Therefore, the NABE’s default losses under FI’s different strategies are denoted as \( M \) and \( m \), respectively, and the additional benefit for the NABE selecting repayment strategy is denoted as \( g \).

According to the aforementioned assumptions, for convenience’s sake, the parameters and their explanations used in the construction of the game model are set in Table 2.

### 3.2. Construction of the Evolutionary Game Model

From the assumptions and parameters mentioned above, FI has the behavior strategy of BPSM or TSM, while NABE can choose the behavior strategy of repayment or default. The FI’s income mainly relies on the loan interest from NABE, and the NABE’s profits primarily come from investment income. Meanwhile, the strategies of BPSM and repayment can bring more incomes for FI and NABE, respectively. Therefore, the construction of the evolutionary game model is mainly analyzed from two cases. One is that the FI selects the BPSM strategy. If the NABE prefers to repay on time, then the FI’s income is \( aRt - C + G \),

**Figure 1.** Supply chain finance program with BT integration.
which is the sum of the loan interest from NABE, the cost and the additional income of the FI brought by its BPSM behavior. Meanwhile, the NABE’s income is $aR(r-i) + g$, which is the sum that includes the difference between investment income and loan interest and the additional income brought by its repayment strategy. On the contrary, if the NABE selects the default strategy, then the FI’s income is $-aR - C$ and the NABE’s income is $aR(1+i) - M$. The other case is that FI selects the TSM strategy. If the NABE prefers to choose a repayment strategy, then the FI’s income is $aR - c$ and the NABE’s income is $aR(r-i)$. Meanwhile, if the NABE chooses the default strategy, the FI’s and NABE’s incomes are $-aR - c$ and $aR(1+i) - m$, respectively.

Table 2. Parameters and their descriptions.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>The probability using the BPSM for FI</td>
</tr>
<tr>
<td>$y$</td>
<td>The probability of the repayment on time for the NABE</td>
</tr>
<tr>
<td>$r$</td>
<td>The financial income rate for the NABE</td>
</tr>
<tr>
<td>$i$</td>
<td>The loan rate from FI</td>
</tr>
<tr>
<td>$M, m$</td>
<td>The NABE’s default losses when the FI chooses BPSM and TSM, respectively</td>
</tr>
<tr>
<td>$G$</td>
<td>The FI’s additional benefits when it chooses the BPSM strategy</td>
</tr>
<tr>
<td>$R$</td>
<td>The appraise of collateral for NABE</td>
</tr>
<tr>
<td>$g$</td>
<td>The NABE’s additional benefits when it chooses the repayment strategy</td>
</tr>
<tr>
<td>$a$</td>
<td>The loan-to-value rate determined by FI</td>
</tr>
<tr>
<td>$C$</td>
<td>The FI’s cost choosing the BPSM supervision</td>
</tr>
<tr>
<td>$c$</td>
<td>The cost of credit checks when the FI selects TSM supervision</td>
</tr>
</tbody>
</table>

Table 3. The income matrix of the game for the FI and NABE.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>NABE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSM ($x$)</td>
<td>$aRi - C + G, aR(r-i) + g$</td>
</tr>
<tr>
<td>TSM ($1-x$)</td>
<td>$aRi - c, aR(r-i)$</td>
</tr>
<tr>
<td>Default ($1-y$)</td>
<td>$-aR - C, aR(1+r) - M$</td>
</tr>
</tbody>
</table>

3.3. Analysis of the Evolutionary Game Model

This section will carry out the analysis of the evolutionary game model, which includes the evolutionary equilibrium analysis for FI and NABE and their evolutionary equilibrium mixed analysis.

3.3.1. The Evolutionary Equilibrium Analysis for FI

If $U_{11}$ and $U_{12}$ are denoted as the FI’s expected incomes obtained by its usage of BPSM and TSM, respectively, and $\overline{U}_1$ as the average income of them, then according to the income matrix of the game shown in Table 3, they are obtained as follows:

$$U_{11} = y(aRi - C + G) + (1 - y)(-aR - C),$$

$$= yaRi + yG - aR + aRy - C,$$

$$U_{12} = y(aRi - c) + (1 - y)(-aR - c),$$

$$= yaR(1+i) - aR - c,$$
\[ U_1 = xU_{11} + (1 - x)U_{12} = yaR(1 + i) - aR - c - xC + xc + xyG. \]  

Then, the replicated dynamic equation (RDE) can be obtained accordingly as follows:

\[ C_1(x) = \frac{dx}{dt} = x(U_{11} - U_1) = x(1 - x)(yG - C + c). \]  

Let \( C_1(x) = 0 \); it can be seen that \( x = 0, x = 1 \), and \( y_0 = (C - c) / G \) are the alternative stable points. And, the probability of the FI adopting BPSM is in a stable state when the stable point satisfies the conditions \( C_1(x) = 0 \) and \( C'_1(x) = dC_1(x)/dx < 0 \).

**Proposition 1:** When \( y > y_0 \), adopting BPSM is an evolutionary stability strategy for FI; when \( y < y_0 \), adopting TSM is an evolutionary stability strategy for FI; when \( y \neq y_0 \), there does not exist an evolutionary stability strategy for FI.

From the proof of Proposition 1 appearing in Appendix A, it is shown that the cost and the benefit from the chosen supervision mean for the FI plays a critical role in its strategy choices. FI will choose the TSM strategy due to the too high cost from the usage of BPSM. And, FI will prefer to select a BPSM strategy if this strategy brings a relatively higher benefit.

3.3.2. The Evolutionary Equilibrium Analysis for NABE

If \( U_{21} \) and \( U_{22} \) are denoted as the NABE’s expected incomes obtained by its repayment and default strategies, respectively, and \( \overline{U}_2 \) as the average income of them, then according to the income matrix of the game shown in Table 3, they are obtained as follows:

\[ U_{21} = x(aR(r - i) + g) + (1 - x)(aR(r - i)), \]

\[ = aR(r - i) + xg, \]

\[ U_{22} = x(aR(1 + r) - M) + (1 - x)(-aR(1 + r) - m), \]

\[ = aR(1 + r) - xM + xm - m. \]

\[ \overline{U}_2 = yU_{21} + (1 - y)U_{22} = yaR(r - i) + yxg + (aR(1 + r) - xM + xm - m)(1 - y). \]

And then, the RDE can be obtained accordingly, as follows:

\[ C_2(y) = \frac{dy}{dt} = y(U_{21} - \overline{U}_2) \]

\[ = y(aR(r - i) + xg - yaR(r - i) - yxg - (aR(1 + r) - xM + xm - m)(1 - y)) \]

\[ = y(1 - y)(xg - aRi - aR + xM - xm + m). \]

Let \( C_2(y) = 0 \); it can be seen that the alternative stable points are \( y = 0, y = 1 \) and \( x_0 = \frac{aRi + aR - m}{g + M - m} \). And, the probability of the NABE adopting the repayment strategy is in a stable state when the stable point satisfies the conditions \( C_2(y) = 0 \) and \( C'_2(y) = 0 \).

**Proposition 2.** When \( x > x_0 \), adopting repayment is an evolutionary stability strategy for NABE; when \( x < x_0 \), adopting default is an evolutionary stability strategy for NABE; when \( x \neq x_0 \), there does not exist an evolutionary stability strategy for NABE.

From the proof of Proposition 2 appearing in Appendix A, it is shown that the NABE’s principal and interest of loans are two important factors for NABE’s strategy choices. NABE
will a choose repayment strategy if the NABE’s principal and interest of the loans are too low. Conversely, NABE will prefer to choose the default strategy.

3.3.3. Evolutionary Equilibrium Analysis of Mixed Strategies

As mentioned above, the strategies of NABE and FI will vary with their different initial selected strategies. Moreover, it is crucial to highlight that the evolutionary equilibrium point obtained from the RED analysis may not always indicate an evolutionary stable strategy. Assessing the stability of the equilibrium point requires examining the determinant and trace of the Jacobian matrix, which is derived by differentiating the RED \([49]\).

Specifically, if the determinant of the Jacobian matrix is positive and its trace is negative, the equilibrium point associated with these values can be deemed stable \([49]\).

From the analysis as stated above, the initial and equilibrium points are in domain \(\{(x, y) | 0 < x < 1, 0 < y < 1\}\), in which there are five equilibrium points: \((0, 0), (0, 1), (1, 0), (1, 1)\) and \((x_0, y_0)\). Since the equilibrium point \((x_0, y_0)\) needs to satisfy \(0 < \frac{aR(1+i) - m}{g + M - m} < 1\) and \(0 < \frac{C - c}{G} < 1\), the following analysis will be conducted under the cases of \(0 < aR(1 + i) - m < g + M - m\) and \(0 < C - c < G\).

First, the Jacobian matrix is constructed. The Jacobian matrix can be calculated by the RDEs (4) and (8) as follows:

\[
J = \begin{pmatrix}
\frac{\partial C(x)}{\partial x} & \frac{\partial C(x)}{\partial y} \\
\frac{\partial C(y)}{\partial x} & \frac{\partial C(y)}{\partial y}
\end{pmatrix}
= \begin{pmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{pmatrix},
\tag{9}
\]

where

\[
a_{11} = (1 - 2x)(yG - C + c),
\tag{10}
\]

\[
a_{12} = x(1 - x)G,
\tag{11}
\]

\[
a_{21} = y(1 - y)(g + M - m),
\tag{12}
\]

\[
a_{22} = (1 - 2y)(xg - aR(1 + i) + xM - xm + m).
\tag{13}
\]

Second, the stability of the equilibrium points is analyzed. From the judgment conditions of the evolutionary stability strategy, the determinant and trace of the Jacobian matrix \(J\) should be satisfied by the following two conditions \([49]\):

\[
\text{Det}(J) = \begin{vmatrix}
a_{11} & a_{12} \\
a_{21} & a_{22}
\end{vmatrix} = a_{11}a_{22} - a_{12}a_{21} > 0,
\tag{14}
\]

\[
\text{Tr}(J) = a_{11} + a_{22} < 0.
\tag{15}
\]

Therefore, by substituting the equilibrium points into Equations (14) and (15), the stability of the five equilibrium points is analyzed, as shown in Table 4.

Table 4. The stability of the five equilibrium points.

<table>
<thead>
<tr>
<th>Equilibrium Points</th>
<th>Det((J))</th>
<th>Tr((J))</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>A((0, 0))</td>
<td>+</td>
<td>−</td>
<td>stable</td>
</tr>
<tr>
<td>B((1, 0))</td>
<td>+</td>
<td>+</td>
<td>unstable</td>
</tr>
<tr>
<td>C((1, 1))</td>
<td>+</td>
<td>−</td>
<td>stable</td>
</tr>
<tr>
<td>D((0, 1))</td>
<td>+</td>
<td>+</td>
<td>unstable</td>
</tr>
<tr>
<td>E((x_0, y_0))</td>
<td>−</td>
<td>0</td>
<td>saddle point</td>
</tr>
</tbody>
</table>
From Table 4, it is shown that \( A(0, 0) \) and \( C(1, 1) \) are equilibrium points. That is, the strategic choices of both parties in the game process tend to converge to \( A(0, 0) \) and \( C(1, 1) \), and the evolutionary phase diagram of the system’s evolution is shown in Figure 2.

![Figure 2. The evolution phase of strategies for FI and NABE.](image)

From Figure 2, it is clearly seen that the strategic choices of both parties will evolve to the equilibrium point \( C(1, 1) \) when they fall within the region DCBE, and when they fall within the region DABE, their strategic choices will evolve to the equilibrium point \( A(0, 0) \). Taking the region DABE as the analysis object, the probability of the strategy evolution for both parties in the game process is expressed by the area of region DCBE and region DABE [55], where \( S_{DCBE} = \frac{1}{2} (1 - x_0)(1 - y_0) \), \( S_{DABE} = \frac{1}{2} (x_0 + y_0) \). Therefore, the influences of parameters on the FI’s and the NABE’s strategy choices can be obtained through analyzing the influences of parameter changes on the area of the two regions in Figure 2. Based on this, some propositions can be obtained as follows:

**Proposition 3:** If \( S_{DCBE} > S_{DABE} \), then both of the probabilities for the FI’s BPSM strategy and the NABE’s repayment strategy will increase. Conversely, if \( S_{DCBE} < S_{DABE} \), then both of their probabilities will decrease.

**Proposition 4:** There exists a positive relationship between the area of region DABE \( S_{DABE} \) and the cost \( C \).

Proposition 4 shows that using the BPSM strategy can not only simplify the audit process of loans to the NABE for FIs, but also can also improve their lending practices. However, the FI will also hesitant to choose the BPSM strategy due to the cost brought by its usage of the BPSM. To encourage the FI to use BPSM, the government should provide some financial support to indirectly reduce the cost due to the usage of BPSM, and it will make FIs tend to choose the BPSM as well as promote the NABE to choose the repayment strategy.

**Proposition 5:** There exists a positive relationship between the area of region DABE \( S_{DABE} \) and the lending rate \( i \) for NABE.

Proposition 5 shows that, when the interest rate of loans decreases, the NABE’s cost and the FI’s risk from the risk will also decrease. Therefore, the usage of the BT will become a new pattern between FI and NABE, which can affect the equilibrium strategies by affecting the interest rate of loans.

**Proposition 6:** There exists negative relationships between the area of region DABE \( S_{DABE} \) and the additional benefits \( G \) and \( g \).
Proposition 6 shows that, to a large extent, by using the BTSM, the NABE’s enthusiasm for repayment is also high, and the problems of the NABE’s financing difficulties and the FI’s reluctant lending are solved. It is conducive to building a mutual trust mechanism between the FI and the NABE to improve the NABE’s financing environment and the FI’s loan environment simultaneously.

**Proposition 7:** There exists a negative relationships between the area of region $DABE S_{DABE}$ and the default losses $M$ and $m$.

Proposition 7 shows that, when the default losses for NABE increase, the NABE has to choose the repayment strategy. This implies that the FI is more inclined to choose the BPSM strategy as it leads to larger default losses for NABEs compared to the TSM strategy.

In summary, the measures making the system balance include reducing the loan rate, using the BPSM, decreasing the usage cost of the BPSM, increasing the additional income, and increasing the punishment from default. And, the main parameter changes mentioned above can lead to the changes in the position of point $E(x_0, y_0)$, and the FI’s and NBAE’s strategies also change with the changes of this point, and the changes’ trend is as shown in Figure 3.

![Diagram](Figure 3. The diagram of evolution phase for FI’s and NBAE’s strategies.)

### 4. Simulation Analysis

To further analyze the stability of the evolutionary game between FI and NABE, this section will simulate both the influences of the initial strategy and parameter changes on the evolution path based on MATLAB software. One of the key steps in simulation analysis is to assign values to parameters. Combining the practical situation and the existing method in [25,47] used for assigning values to parameters, this section will conduct a numerical simulation from two parts; one is the influence of initial strategy on the evolution path, and the other is the influence of the different parameters on evolution paths.

#### 4.1. The Influence of Initial Strategy on the Evolution Path

According to the above analysis, the main parameters are assigned to values, and then, the simulation analysis is conducted.

First, assume that $c = 80$, $C = 100$, $i = 0.1$, $R = 1000$, $G = 40$, $g = 100$, $a = 0.6$, $g = 100$, $M = 650$, $m = 550$ in Equations (4) and (8), the diagram of the evolution phase with the FI’s and NABE’s different initial strategies is shown in Figure 4. Second, the initial assignment of each parameter remains constant, and their evolution paths are obtained by changing the FI’s and NABE’s different initial strategies $x$ and $y$. The evolution paths with different $x$ and $y$ are shown in Figures 5 and 6, where Figure 5 shows the case that $x$ varies within $[0,1]$ and $y = 0.5$, and the case that $y$ varies within $[0,1]$ and $x = 0.5$ is shown in Figure 6. It is obviously seen that the FI’s and NABE’s initial strategies play a decisive role
in their strategies’ evolution paths. Specifically, when the initial values of the strategies of the FI and NABE are small, the equilibrium evolution trend of the system evolves to the FI’s TSM strategy and the NABE’s default strategy, respectively.

![Image](Figure 4. The diagram of evolution phase with the FI’s and NABE’s different initial strategies.)

Figure 4. The diagram of evolution phase with the FI’s and NABE’s different initial strategies.

![Image](Figure 5. The evolution paths with the FI’s different initial strategies.)

Figure 5. The evolution paths with the FI’s different initial strategies.

![Image](Figure 6. The evolution paths with the NABE’s different initial strategies.)

Figure 6. The evolution paths with the NABE’s different initial strategies.

Meanwhile, it is clearly seen that when the NABE’ enthusiasm of the repayment is too high, it will prefer to make the choice of repayment behavior. Otherwise, it will prefer to choose the default. And, the similar behavior choice can be made for the FI.

### 4.2. The Influence of the Different Parameters on Evolution Paths

As shown in Figure 3, the position of saddle point can affect the final evolution result by affecting the FI’s and NBEA’s initial states. And, the position changes of the saddle point will also affect the evolution paths. Next, the influence of the different parameters on evolution paths will be analyzed by using numerical simulation under the different parameters.

1. The influence of the FI’s cost using the BPSM on evolution paths
When the initial assignment of the other parameters maintains constant, the FI's cost C using the BPSM is reduced from 100 to 90, and the phase diagram is shown in Figure 7. Comparing with Figure 4, with the decreases in the FI's cost using BPSM, the area of the region increases, and the equilibrium point moves toward to the stable point C(1, 1). This indicates that FI can be driven to choose the BPSM strategy by reducing their cost brought by the usage of the BPSM. Consequently, the NABE’s enthusiasm for repayment will also increase, simultaneously.

Figure 7. The evolutionary phase diagram with the FI’s cost C = 90.

(II) The influence of the NABE’s interest rate of loans on evolution path

When the initial assignment of the other parameters remains constant, the NABE’s interest rate for the loans is reduced from 0.1 to 0.05, and the evolutionary phase diagram is shown in Figure 8. Compared with Figure 4, with the decrease in the NABE’s interest rate for the loans, the area of the region will increase, and more and more initial evolution points will also move toward the stable point C(1, 1). This implies that, when the interest rate of the loans decreases, the BPSM should be chosen by FI to help put pressure on the NABE. Simultaneously, NABE will also prefer to choose the repayment strategy that ensures its good profits.

(III) The influence of the FI’s and NABE’s additional benefits on the evolution path

The initial assignment of the other parameters remains constant with the increase in the FI’s additional benefit brought by the usage of the BTSM; the evolutionary phase diagram is shown in Figure 9. Compared to Figure 4, if the FI’s additional benefit G is increased to 70, then many initial evolution points will move toward the stable point C(1, 1) as the area of the region increases. It is seen that the relatively large additional benefit will make NABE have a high incentive to actively choose the repayment strategy. Meanwhile, it will also promote the FI to choose the BPSM strategy for stable and sustainable social benefits.

Figure 8. The evolutionary phase diagram with the interest rate of loans $i = 0.05$. 
Figure 9. The evolutionary phase diagram with the FI's additional benefit \( G = 70 \).

Similarly, when the NABE's additional benefit \( g \) is increased to 130, the evolutionary phase diagram is shown in Figure 10. Similar discussions will not be repeated here. In a word, the relatively higher number of additional benefits will promote the FI and NABE to choose the BPSM and repayment strategies, respectively.

Figure 10. The evolutionary phase diagram with the NABE's additional benefit \( g = 130 \).

(IV) The influence of the NABE's default losses on the evolution path

When the initial assignments of other parameters remain constant, with the increase in the NABE's default losses, the area of the region DCBE increases; the evolution phase diagram is shown in Figure 11. Compared to Figure 4, when the default losses increased to 700, the initial points of evolution move toward \( C(1, 1) \) as the area of the region DCBE increases. It can be seen that, with the NABE's default losses increasing, the NABE will be more inclined to choose the repayment strategy to minimize significant losses. Likewise, FI will also prefer to adopt the BPSM strategy to constrain the NABE's repayment behavior.

Figure 11. The evolutionary phase diagram with the NABE's default losses \( M = 720 \).
4.3. Discussions

Based on the conducted simulation and analysis, the results reveal significant insights. Firstly, the initial strategies adopted by FIs and NABEs have a substantial impact on the evolutionary outcomes of the system. It can be seen that when the FIs and NABEs exhibit relatively high initial enthusiasm to choose the BPSM and repayment strategies, respectively, they are more likely to make corresponding behavioral decisions. Second, the loan rate influences the NABE’s financing cost and the evolution trend of the system. The relatively low loan rate increases the probability of the NABE’s repayment and FI’s BTSM strategies. Third, the relatively large additional benefits brought by the usage of the BPSM will promote the FI and NABE to choose the BPSM strategy and repayment strategy, respectively. Finally, the considerable additional benefits derived from using the BPSM promote the choice of BPSM strategy for FIs and the repayment strategy for NABEs, respectively.

Some findings from the results are as follows: (I) The incorporation of BT in the financing process of NABEs can alleviate their financing challenges. Utilizing the Blockchain platform enables the recording of NABEs’ operations, while smart contract technology within the Blockchain can effectively save time in formulating contracts, thereby enhancing NABEs’ financing effectiveness. Additionally, the usage of BT by FIs in the NABEs’ financing process enhances their ability to fulfill promises with a higher probability, further mitigating the financing difficulties faced by NABEs. (II) Incentive mechanisms utilizing BT have the potential to reduce costs, enhance cooperation efficiency, and create a favorable financing environment, ultimately promoting sustainable development. By utilizing the BT platform, both FIs and NABEs experience improved financing efficiency, leading to increased additional income generation. This, in turn, encourages FIs to adopt BT and strengthens the credibility of NABEs, offering a novel solution to their financing challenges. (III) The adoption of BT has partially resolved the financing difficulties for NABEs and enhanced overall financing efficiency. With BT’s implementation, NABEs now have increased incentives to avoid defaults, reducing the risk for FIs when providing loans. Consequently, this encourages FIs to be more willing to lend and take on greater lending risks. By addressing these financing issues, BT contributes to improving the overall financing landscape for NABEs.

5. Conclusions

Supply chain financing represents an innovative breakthrough not only in financing technology, but also in credit management and financial concepts for both financial institutions and enterprises. The introduction of BT into the realm of supply chain financing has the potential to overcome existing barriers and ensure seamless circulation within the supply chain, thereby fostering its development. Therefore, developing the Blockchain-driven incentive and constraint mechanism for supply chain financing is undoubtedly a prudent measure to alleviate the financing challenges faced by SMEs.

The incentive and constraint mechanism in supply chain financing is fundamentally a dynamic game process involving all stakeholders. This study focuses on the financing strategies analysis of all stakeholders by constructing an evolutionary game model within a two-stage supply chain consisting of NABEs and FIs. The results of this study are as follows: (I) The adoption of the BPSM can serve as an incentive for FIs to effectively reduce the costs associated with its implementation. Meanwhile, this fosters an increase in the repayment enthusiasm of NABEs. (II) When loan interest rates decrease, it is prudent for FIs to consider implementing the BPSM to apply pressure on NABEs. Meanwhile, NABEs themselves will be inclined to choose a repayment strategy that ensures favorable profits. (III) The potential for substantial additional benefits will ignite a heightened enthusiasm for NABEs, compelling them to prioritize timely repayment. Meanwhile, FIs will be motivated to adopt the BPSM, driven by their goal of ensuring stable and sustainable social benefits. (IV) With the default losses for NABEs rising, they will have a stronger inclination to prioritize timely
repayment as a means of reducing substantial losses. Based on this, FIs will also be more inclined to adopt the BPSM to exert constraints on NABEs’ repayment behavior.

The contributions of this study are as follows: Firstly, this study designs an evolutionary game model to establish the incentive and restraint mechanism for supply chain financing that encompasses all stakeholders. It provides an important theoretical reference for FIs’ and NABEs’ investment and financing. Secondly, this study provides a comprehensive analysis of the evolutionary strategies adopted by FIs and NABEs during the game process, shedding light on the underlying mechanisms that influence supply chain financing. By framing the incentive and constraint mechanism of supply chain financing as a dynamic evolutionary game problem, this study expands the scope of considerations and approaches to address issues in supply chain financing. Consequently, it offers a novel perspective for advancing the understanding and implementation of effective strategies in supply chain financing.

Meanwhile, some managerial implications are presented as follows: (I) FIs should prioritize the use of “technology” in supply chain financing, embracing the transformative impact of BT in the financial industry. This entails focusing on financial technology talent and expertise, understanding the credit status and financing needs of enterprises, particularly SMEs, and optimizing products and services to attract a wider customer base. By leveraging BT, FIs can effectively serve the real economy. (II) Establishing and strengthening incentive and restraint mechanisms is essential to maximize the potential and advantages of BT. With the innovative features of BT, it is vital to increase the costs of default and additional benefits to enhance financing efficiency. The incentive mechanism using BT reduces costs, enhances cooperation efficiency, fosters a favorable financing environment, and enables the sustainable development of financing for SMEs. (III) Creating a supportive environment for the financial industry’s growth and promoting its diversified development is crucial. Regulatory authorities should consider relaxing financial regulations, advancing market-oriented interest rate reforms, and encouraging healthy competition within the industry. Additionally, implementing reasonable oversight measures will prevent monopolies and facilitate SME financing while ensuring fair practices among large enterprises in finance and commerce.

Although this study has achieved significant results, there are still some limitations to be considered. (I) The impact of supervision using Blockchain platform supervision on NABEs’ financing is analyzed, and other factors, such as the NABEs’ reputation and the uncertainty of the market environment, should also be considered. (II) In the game process, this study mainly focused on a representative FIs and NABEs as the main game subjects, while overlooking the interaction effects within groups of FIs and NABEs regarding financing strategies. Furthermore, designing a dynamic incentive and constraint mechanism that considers uncertainties in the economic environment and potential risks is crucial. Meanwhile, due to the high-speed iteration of technology innovation, FIs have faced problems in insufficient technical investment and weak technical capacity. In future research, to fully leverage the potential of BT and promote the sustainable development of NABEs’ financing, it is essential to address the high costs associated with utilizing the Blockchain platform for FIs. By reducing these costs, FIs can effectively harness the benefits offered by BT, leading to improved efficiency and long-term viability in financing for SMEs.

**Author Contributions:** Conceptualization, L.S. and Y.C.; methodology, L.S.; software, Y.C.; validation, L.S. and Y.C.; formal analysis, L.S.; investigation, L.S.; writing—original draft preparation, L.S. and Y.C.; writing—review and editing, L.S. and Y.C.; funding acquisition, L.S. and Y.C. All authors have read and agreed to the published version of the manuscript.

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Abbreviation

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT</td>
<td>Blockchain technology</td>
</tr>
<tr>
<td>FI</td>
<td>Financial institution</td>
</tr>
<tr>
<td>NABEs</td>
<td>New agricultural business entities</td>
</tr>
<tr>
<td>SMEs</td>
<td>Small and medium-sized enterprises</td>
</tr>
<tr>
<td>TSM</td>
<td>Traditional supervised mean</td>
</tr>
<tr>
<td>BPSM</td>
<td>Blockchain platform supervised mean</td>
</tr>
<tr>
<td>RDE</td>
<td>Replicated dynamic equation</td>
</tr>
</tbody>
</table>

Appendix A

Proof of Proposition A1. Let \( H(y) = yG - C + c \), it is obvious that \( H(y) \) is an increasing function with respect to \( y \). Therefore, for the case of \( 0 < C - c < G \), the following cases can be proven.

(I) If \( y > y_0 \), it can be obtained that \( C_1(1) = 0 \) and \( C'_1(1) < 0 \); then, adopting BPSM is an evolutionary stability strategy for FI. That is, \( x = 1 \) is the evolutionary stable point.

(II) If \( y < y_0 \), it can be obtained that \( C_1(1) = 0 \) and \( C'_1(1) < 0 \); then, adopting TSM is an evolutionary stability strategy for FI. That is, \( x = 0 \) is the evolutionary stable point.

(III) If \( y = y_0 \), an evolutionary stability strategy does not exist for FI since \( C'_1(0) = 0 \) and \( C'_1(1) < 0 \). That is, no matter what value of \( x \) is taken, the strategic choice of FI is stable. □

Proof of Proposition A2. Let \( H_1(x) = xG - aRi - aR + xM - xm + m \); it is obviously that \( H_1(x) \) is an increasing function with respect to \( x \). Therefore, for the case of \( 0 < aRi + aR - m < g + M - m \), the following cases can be proven.

(I) If \( x > x_0 \), it can be obtained that \( C_2(1) = 0 \) and \( C'_2(1) < 0 \); then, adopting repayment is an evolutionary stability strategy for NABE. That is, \( y = 1 \) is the evolutionary stable point.

(II) If \( x < x_0 \), it can be obtained that \( C_2(0) = 0 \) and \( C'_2(0) < 0 \); then, adopting default is an evolutionary stability strategy for NABE. That is, \( y = 0 \) is the evolutionary stable point.

(III) If \( x \neq x_0 \), an evolutionary stability strategy does not exist for NABE since \( C'_2(1) = 0 \) and \( C'_2(0) < 0 \). That is, no matter what value of \( y \) is taken, the strategic choice of NABE is stable. □

Proof of Proposition A3. When \( S_{DCBE} > S_{DABE} \), then the point \( E(x_0, y_0) \) moves towards stable point \( C(1, 1) \). That is, the probability of the FI’s BPSM strategy and the NABE’s repayment strategy will increase. Conversely, when \( S_{DCBE} < S_{DABE} \), then the point \( E(x_0, y_0) \) moves towards stable point \( A(0, 0) \). Therefore, the probability of the FI’s BPSM strategy and NABE’s repayment strategy will decrease. □

Proof of Proposition A4. Since the region \( DABE \) is

\[
S_{DABE} = \frac{1}{2}(x_0 + y_0) = \frac{1}{2}\left(\frac{aR(1 + i) - m}{g + M - m} + \frac{c - c}{G}\right),
\]

(A1)

taking the first-order partial derivative with respect to the cost \( C \) in Equation (16), the following equation can be obtained
\[ \frac{\partial S_{DABE}}{\partial C} = \frac{1}{2G} > 0. \quad (A2) \]

It obviously shows that there exists a positive relationship between the area of region DABE and the cost \( C \). That is, with the decrease in reduction of the cost \( C \), the FI’s and NABE’s strategic choices will tend to BPSM and repayment strategies, respectively.

**Proof of Proposition A5.** The similar line as the proof of Proposition 4 is conducted.

Taking the first-order partial derivative with respect to the lending rate \( i \) in Equation (16), the following equation can be obtained:

\[ \frac{\partial S_{DABE}}{\partial i} = \frac{aR}{2(g + M - m)} > 0. \quad (A3) \]

It is shown that there exists a positive relationship between the area of region DABE and the lending rate for the NABE. That is, the area of region DABE will decrease when the lending rate falls. In other words, the smaller the interest rate of loans from the FI is, the more the FI and NABE tend to choose BPSM and repayment strategies, respectively. \( \square \)

**Proof of Proposition A6.** A line similar to the proof of Proposition 4 is conducted.

Taking the first-order partial derivative with respect to the additional benefits \( G \) and \( g \) in Equation (16), the following equations can be obtained:

\[ \frac{\partial S_{DABE}}{\partial G} = -\frac{C - c}{2G^2} < 0, \quad (A4) \]

\[ \frac{\partial S_{DABE}}{\partial g} = -\frac{aR(1 + i) - m}{2(g + M - m)} < 0. \quad (A5) \]

The above equations show that there exist negative relationships between the area of region DABE and additional benefits \( G \) and \( g \). That is, the larger the FI’s additional benefit \( G \) is, the smaller the area of region DABE is, and the FI prefers to choose the BPSM strategy. Similarly, for a larger additional benefit \( g \), the NABE will tend to choose the repayment strategy. \( \square \)

**Proof of Proposition A7.** A line similar to the proof of Proposition 4 is conducted.

Taking the first-order partial derivative with respect to the NABE’s default losses \( M \) and \( m \) in Equation (16), the following equations can be obtained:

\[ \frac{\partial S_{DABE}}{\partial M} = -\frac{aR(1 + i) - m}{2(g + M - m)^2} < 0, \quad (A6) \]

\[ \frac{\partial S_{DABE}}{\partial m} = -\frac{g + M - aR(1 + i)}{2(g + M - m)^2} < 0. \quad (A7) \]

The above equations show that there exist negative relationships between the area of region DABE and default losses \( M \) and \( m \). The more the NABE’s default losses are, the smaller the areas of region DABE are. Specifically, since the default losses will increase when the FI chooses the BPSM strategy, the area of region DABE will also increase. This means that the FI will prefer to choose the BPSM strategy since the NABE’s default losses under the FI’s BPSM strategy is larger than that under the FI’s TSM strategy. \( \square \)
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