Can Digital RMB Alleviate Financing Constraints for Small and Micro Enterprises? — Based on Evolutionary Game Model and Simulation Analysis

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Abstract

Small and micro enterprises represent one of the most critical drivers of Chinese-style modernization. Digital RMB, with its inclusiveness and accessibility, offers novel approaches to alleviating the financing predicament of small and micro enterprises in China. This article constructs a bank-enterprise game model under information asymmetry, integrating digital RMB payment methods into the computational framework to analyze the alleviating effects of digital RMB on small and micro enterprise financing difficulties, and utilizes numerical simulation to examine how variations in different parameters influence the behavioral paths and equilibrium outcomes of banks and enterprises. The findings indicate that, accounting for the incremental revenue from digital RMB and central bank subsidies, small and micro enterprises' adoption of digital RMB can mitigate the bad debt risk of commercial banks arising from information misalignment, while the central bank' s incentive mechanism transmits to commercial banks, encouraging the implementation of credit concessions to optimize financing for small and micro enterprises. This achieves excess returns for both game participants while simultaneously addressing operational efficiency and financial security. The study recommends that the central bank intensify digital RMB promotion, establish a scientific circulation supervision system, and while expanding digital currency demand, facilitate coordination between small and micro enterprises and commercial banks, thereby leveraging digital finance to ensure high-quality socio-economic development.

Full Text

Can the Digital RMB Alleviate the Financing Dilemma of Small and Micro Enterprises? —Based on an Evolutionary Game Model and Simulation Analysis

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Abstract

Small and micro enterprises constitute one of the most important drivers of China' s modernization, and the digital RMB, with its 普惠性 (inclusive nature) and accessibility, offers a novel approach to alleviating their long-standing financing constraints. This paper constructs a bank-enterprise game model under information asymmetry, incorporating the digital RMB payment method into the analytical framework to examine its mitigating effects on small and micro enterprise financing difficulties. Through numerical simulation, we analyze how changes in different parameters influence the behavioral paths and equilibrium outcomes of banks and enterprises. The findings indicate that, considering the incremental revenue from digital RMB and central bank subsidies, small and micro enterprises' adoption of digital RMB can reduce commercial banks' nonperforming loan risks caused by information misalignment. Simultaneously, the central bank' s reward mechanism transmits to commercial banks, incentivizing them to implement preferential credit policies that optimize financing for small and micro enterprises, thereby achieving excess returns for both parties while balancing operational efficiency and financial security. The study recommends that the central bank strengthen digital RMB publicity, establish a scientific circulation supervision system, expand digital currency demand, and facilitate coordination between small enterprises and commercial banks to ensure high-quality socio-economic development through digital finance.

Keywords: Digital RMB; Small and Micro Enterprises; Financing Dilemma; Evolutionary Game; Simulation Analysis

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1. Introduction

The 2023 Central Financial Work Conference emphasized that finance is the lifeblood of the national economy, which must not only empower economic development through high-quality financial services but also provide safeguards for social progress. Currently, the focus of financial support for economic and social development lies in channeling more resources toward technological innovation, advanced manufacturing, and green development. Small and micro enterprises

serve as vehicles for entrepreneurship and sustainable development, representing the central link in receiving these resource allocations while undertaking competitive breakthrough missions. They are both one of the most important drivers of China' s modernization and the source of resilience for the Chinese economy. As "market gap fillers," these enterprises concentrate on the "long tail" of market segments, pioneering new industries through continuous exploration of niche markets and acting as the most dynamic prospectors in China' s socialist market economy. However, China' s small and micro enterprises have long faced financing difficulties. Capital scarcity and weak financial management lead to the phenomenon of "poor borrowing and poor financial management" that accompanies many enterprises throughout their brief life cycles. Their low risk resistance capacity and severe information asymmetry after financing expose commercial banks to high default risks, creating numerous uncertainties in lending. Consequently, banks must raise interest rates to guard against losses, which in turn causes small enterprises to experience further capital tightening and inability to expand. This vicious cycle makes loan repayment even more difficult. In short, moral hazard and adverse selection under information asymmetry have always shackled small and micro enterprises (Wang Xin, 2015; Liu Manfeng and Zhao Long, 2019).

When small and micro enterprises fail to repay loans on time, commercial banks' liquidity management is adversely affected. When collateral and pledges cannot be liquidated, and guarantees prove illusory or invalid, banks' losses become irrecoverable, forcing them to resort to abnormal measures such as "high-interest deposit attraction" to maintain operations, thereby planting seeds for a "bank run crisis." Over time, these risks transmit and amplify throughout the financial system, potentially igniting systemic risk.

Addressing the financing dilemma of small and micro enterprises, scholars from different disciplines have proposed various solutions targeting different actors, such as adjusting guarantee models (Feng Xiaofei and Zhang Lin, 2020), tax and fee reductions (Wang Weitong et al., 2020), targeted reserve requirement cuts (Kong Dongmin et al., 2021), and bank-tax interaction (Chen Biao et al., 2021). Beyond these approaches, adapting to change is the task assigned to academia in the "new era." In recent years, the booming digital economy has created new conditions for alleviating financing constraints on small and micro enterprises (Yu Ping and Dou Junxia, 2020). Financial big data can screen demand using massive information, leveraging internet externalities and economies of scale to seek optimal strategies for filling financing gaps. However, solutions from the digital finance perspective remain limited to theoretical construction, lacking application value (Zhou Guangyou et al., 2020). Meanwhile, illegal token financing risks disrupting markets, requiring the "capable government" to maintain its position as a "structural transformer" in digital finance practice, using government functions to communicate with markets and crack the crux of the problem through structural adjustments at various levels. Currently, as the People' s Bank of China vigorously promotes the digital RMB, whether it can improve financing for small and micro enterprises constitutes the research

focus of this paper.

Central bank digital currency (CBDC), issued by the central bank as digital cryptocurrency, represents an important tool for the capable government to solve these problems. Since the turn of the century, digital currency derived from technological revolutions has been considered promising under new productive forces, but related discussions have been limited to qualitative issues such as whether it should be privatized, cashless, and decentralized (Hu Qiuling and Zhang Chenghu, 2003). From the 13th to the 14th Five-Year Plan periods, cashlessness has been largely achieved through mobile payment popularization, while privatization may lack institutional foundations. In other words, inclusive finance construction requires participation from a "capable government," otherwise true "inclusiveness" cannot be realized. In fact, the digital RMB was developed partly to counterbalance private digital currencies, not to blindly pursue decentralization, but rather to strive for inclusive development (Ba Shusong and Yao Shunda, 2021; Yuan Zeng, 2022). The Bank for International Settlements Committee on Payments and Market Infrastructures (CPMI) report identifies three key characteristics of CBDC: electronic, non-liability, and peer-to-peer network exchange, distinguishing it from traditional currency' s physical form and liability attributes (Zhou Chenxi and Cao Junxin, 2017). However, it does not represent a disruptive change in influencing factors or control methods and can be effectively utilized as a policy tool by the capable government. The CPMI also emphasizes that CBDC is significant for monetary policy and financial stability, and its potential to solve small and micro enterprise financing difficulties urgently requires proof through Chinese practical experience.

The digital RMB, developed by the People' s Bank of China as an electronic encrypted RMB with Chinese characteristics, provides a new monetary policy tool that balances protection and supervision as a retail CBDC, representing an outcome of digital economic development (He Dexu and Yao Bo, 2019; Peng Xushu, 2020; Tang Song et al., 2020; Liu Kai et al., 2021; Sanches and Keister, 2021). The digital RMB is both a legal sovereign currency with complete monetary functions and a credit currency with important policy value. The "central bank-commercial bank" two-tier centralized management system facilitates government management, including the People' s Bank' s use of qualification, interest rate, and scale indicators to ensure its impact on the banking system and financial structure is controllable (Qi Yudong and Chu Xi, 2019; Yao Qian, 2019; Peng Xushu, 2020). Experts and scholars have corroborated these arguments from different perspectives, suggesting that the digital RMB, as both a macro policy tool and micro financing instrument, can effectively achieve inclusive finance empowerment for small and micro enterprise development through its information transparency advantages (Yang Yanchao, 2020; Feng Sixian and Yang Jing, 2021).

Therefore, this paper establishes an evolutionary game model from the perspective of efficiency and security to study the alleviating effect of digital RMB on small and micro enterprise financing difficulties. The potential marginal contri-

butions of this research are threefold: First, it closely links digital RMB as a policy tool with small and micro enterprise financing problems, providing new ideas and pathways for alleviating their capital difficulties. Second, it enriches the scientific theory analyzing the operational foundation of CBDC from a micro perspective, expanding substantive research focusing on the mechanisms through which digital RMB affects enterprises and banks. Third, based on critical acceptance of the bounded rationality hypothesis for bank-enterprise actors, it introduces an evolutionary game model to simulate dynamic bank-enterprise decision-making, analyzing strategies and path choices for small and micro enterprises and commercial banks before and after digital RMB adoption. Additionally, while strengthening understanding of small and micro enterprises and commercial banks from the capable government perspective, it adds methods and perspectives for studying micro-object behavior in game contexts.

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2. Theoretical Mechanisms

When small and micro enterprises rely on traditional payment methods, the degree of information asymmetry encountered by both banks and enterprises is relatively high. The issuance of digital RMB introduces a new option for enterprise transaction settlement, generating significant benefits for small and micro enterprises through three major layers: improved payment efficiency, reduced payment costs, and enhanced risk prevention and control. Synchronized with dynamic enterprise payment choices, commercial banks also derive convenience, reducing credit risk, operational risk, and market risk while improving information transparency. This reliable security guarantee enhances confidence and efficiency in execution and decision-making. Under the incentive of targeted reserve requirement cut policies, commercial banks match credit strategies according to enterprise scale, ownership nature, and corporate governance, offering certain preferential terms to enterprises with lower risk and higher transparency.

2.1 Theoretical Mechanism for Small and Micro Enterprises in the Bank-Enterprise Game When using traditional payment methods, financing constraint theory suggests that information asymmetry and agency problems cause external financing costs to exceed internal financing costs, thereby constraining enterprise investment decisions (Myers and Majluf, 1984; Bernanke and Gertler, 1989; Kaplan and Zingales, 1997) and affecting small and micro enterprise operations. Financing constraints are further influenced by macro environments and enterprise characteristics, with enterprise scale being a major factor. Due to constraints from management capabilities, organizational structure, and bankruptcy risk, small and micro enterprises face higher information asymmetry and greater investor risk, resulting in widespread financial discrimination (Beck and Demirguc-Kunt, 2006).

When interest rate marketization is underdeveloped, commercial banks prefer lending to giant enterprises, compounded by their responsibility to support state-

owned enterprises. Small and micro enterprises must therefore endure this "discrimination," and their corporate strategies cannot be implemented due to high interest rate constraints, making their decision-making and execution processes extremely precarious (Lin Yifu and Li Yongjun, 2001; Liu Chang et al., 2017; Zhu Wuxiang et al., 2020). Since risk and return are often equivalent, enterprises lacking entrepreneurial spirit cannot grow and inevitably suffer in fierce market competition, eventually facing bankruptcy risk when unable to repay loans normally.

When choosing payment methods, the core advantages of digital RMB mainly manifest in three aspects: improved payment efficiency, reduced payment costs, and enhanced risk prevention and control. First, compared with Alipay and WeChat Pay, digital RMB as central bank legal tender breaks payment restrictions and improves payment efficiency (Yao Qian and Tang Yingwei, 2017). Digital RMB users rely on national credit to achieve payment-as-settlement more quickly through a loosely coupled account system, improving capital utilization efficiency. Additionally, digital RMB' s compatibility enables interoperability between banks and payment institutions, breaking payment barriers and broadening transaction channels (Calle and Eidan, 2020). Second, compared with physical currency, digital RMB eliminates transfer or exchange needs, reducing payment costs. Compared with traditional third-party payments, digital RMB reduces small and micro enterprises' exchange-in and exchange-out fees, further streamlining service procedures (Feng Sixian and Yang Jing, 2021; Ba Shusong and Yao Shunda, 2021). Third, digital RMB alleviates information mismatch between small and micro enterprises and commercial banks, strengthening external risk prevention and control capabilities and effectively assisting enterprises in loans, financial management, and reasonable operations. In digital RMB financing activities, the currency flow and information flow of small and micro enterprise financing can be supervised by the central bank under confidentiality (Ba Shusong and Yao Shunda, 2021).

After small and micro enterprises integrate digital RMB through commercial banks, relevant cash flows are recorded and stored in the central bank's database, making central bank access to small and micro enterprise risk information simple and effective (Wang Weixuan, 2023). According to the People' s Bank of China' s "White Paper on the Research and Development Progress of China' s Digital RMB," as a new retail payment instrument, digital RMB features controllable anonymity—small amounts remain anonymous while large amounts are traceable according to law. With permission to track small and micro enterprise risk and financial information, big data can be used to prevent capital chain risks while ensuring financial privacy protection.

2.2 Theoretical Mechanism for Commercial Banks in the Bank-Enterprise Game Previously, due to adverse selection and moral hazard caused by information asymmetry, commercial banks faced credit risk, operational risk, and market risk when lending to small and micro enterprises

(Stiglitz and Weiss, 1981). Credit risk includes reckless investment and gambling; operational risk involves human error; market risk arises from changes in market factors such as interest rates, exchange rates, and prices. According to "firm reputation theory," due to incomplete information in imperfectly competitive markets, price selection and incentive effects lead commercial banks to prefer higher interest rate pricing. "Menu costs" make banks' capital pricing (i.e., interest rates) sticky, changing very slowly under state-dependent and time-dependent rules, with banks reluctant to reduce prices. Compared with price adjustments, banks prefer quantity adjustments, such as credit scale (Ball and Romer, 1989). Additionally, considering provisions for bad and doubtful debts, bank credit strategies tend toward conservatism, exacerbating small and micro enterprise financing difficulties. The "adverse selection" theory demonstrates that excessively cautious interest rates are also detrimental to commercial banks, as conservative strategies actually damage their risk management. This market clearing failure represents a multiple equilibrium state of market mechanism failure, requiring appropriate government intervention to ensure market health and sustainability.

Although affecting bank profitability in the short term, digital RMB can profoundly influence bank credit decisions and play a significant role in monetary policy and financial stability (Bindseil, 2019). Regarding credit risk, digital RMB as cryptocurrency cannot be forged, while its restrictions on cash withdrawal and asset transfer reduce potential risks of post-loan gambling and reckless investment by actual controllers, ensuring funds truly flow toward business operations (Bank for International Settlements, 2020). For operational risk, its transparent information and efficient feedback on commercial bank information systems provide operational traceability, reducing financial transaction complexity while optimizing costs and protecting privacy. Concerning market risk, during continuous exploration of innovative application models, digital RMB' s payment convenience dilutes exchange rates, interest rates, or transaction fees, enabling senders and receivers to synchronize processes at the same rate, thereby avoiding interest rate and market risks (Chiu et al., 2019). After digital RMB popularization, through data transparency and continuous algorithm optimization, commercial banks can efficiently grasp small and micro enterprise financing information under central bank guidance based on CBDC' s inclusiveness and accessibility. This allows effective tracking of actual capital flows before crises erupt and timely formulation of countermeasures when facing bad debt risks.

Therefore, digital RMB can create conditions for preferential credit, facilitating credit relationships between banks and enterprises.

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3. Model Construction and Strategy Analysis

Considering that information asymmetry and its resulting adverse selection and moral hazard problems reduce banks' lending propensity toward small and micro

enterprises, thereby causing financing difficulties, this paper introduces digital finance to construct an evolutionary game model between banks and enterprises. The digital RMB payment method is incorporated into the model framework to analyze commercial banks' credit strategy choices and digital RMB' s alleviating effect on small and micro enterprise financing constraints.

3.1 Game Strategy Construction 1. Small and Micro Enterprise Strategies

Small and micro enterprises have two choices: traditional payment methods or digital RMB payment. When choosing traditional methods, general income is set as ep, while costs vary due to commercial banks' credit strategies. When preferential credit is implemented, enterprise cost is set as $3ce$; when not implemented, it is $4ce$. Since digital RMB does not accrue interest, the current deposit interest generated when enterprises do not use digital RMB is set as i. If choosing digital RMB, additional income is set as $ep\Delta$. Costs vary according to bank strategies: when preferential credit is implemented, enterprise cost is $1ce$; when not implemented, it is $2ce$. Due to switching costs and privacy costs (Jia Pengfei, 2024), the cost of using digital RMB exceeds that of traditional payment, and due to financing constraints, the additional cost without credit preference exceeds that with credit preference, so $2 > 1$. Additionally, subsidies from the central bank for digital RMB usage are set as s.

2. Commercial Bank Strategies

Commercial banks have two choices: implement credit preference (low interest rates) or not implement credit preference (conservative interest rates). When not implementing credit preference, banks' general income is bp and cost is cb. When implementing credit preference and enterprises use digital RMB, banks generate additional income $bp\Delta$. The additional cost from interest rate reduction is $cb\Delta$. When implementing credit preference, banks receive policy benefits cr such as targeted reserve requirement cuts and reduced rediscount rates. Variable symbols for the bank-enterprise evolutionary game model are shown in Table 1 .

Table 1 Symbol Definitions

Symbol	Meaning and Description
x	Probability of small and micro enterprises choosing digital RMB payment, $x \in (0,1)$
$1-x$	Probability of not choosing digital RMB
y	Probability of commercial banks implementing credit preference (low interest rates), $y \in (0,1)$
$1-y$	Probability of not implementing credit preference
ep	General income of small and micro enterprises when choosing traditional payment

Symbol	Meaning and Description
bp	General income of commercial banks when not implementing credit preference
$1ce$	Cost for enterprises using digital RMB when banks implement credit preference
$2ce$	Cost for enterprises using digital RMB when banks do not implement credit preference
$3ce$	Cost for enterprises using traditional payment when banks implement credit preference
$4ce$	Cost for enterprises using traditional payment when banks do not implement credit preference
cb	Cost for commercial banks when not implementing credit preference
s	Subsidy from central bank to incentivize digital RMB usage
cr	Policy benefits when banks implement credit preference
i	Current deposit interest when enterprises do not use digital RMB
Δep	Additional income for enterprises using digital RMB
Δbp	Additional income for banks when enterprises use digital RMB
Δcb	Additional cost for banks implementing credit preference

Note: Based on relevant economic meanings, all parameters are assumed to be greater than 0.

Based on fundamental assumptions and bank-enterprise behavioral choices, the game strategy construction yields the payoff matrix for commercial banks and small and micro enterprises under different behavioral choices, as shown in Table 2 .

Table 2 Decision and Payoff Matrix for Small and Micro Enterprises and Commercial Banks

	Digital RMB Payment	Traditional Payment
Credit Preference (Low Interest)	$ep + \Delta ep - 1ce + s$, $bp + \Delta bp - cb - \Delta cb + cr$	$ep - 3ce$, $bp - cb + cr$
No Credit Preference (Conservative Interest)	$ep + \Delta ep - 2ce + s$, $bp - cb$	$ep - 4ce$, $bp - cb$

3.2 Evolutionary Stable Strategy and Equilibrium Point Analysis Let x be the probability of small and micro enterprises choosing digital RMB, and $1-$

x the probability of not choosing it. Let y be the probability of commercial banks implementing credit preference, and $1-y$ the probability of not implementing it. The expected payoff for enterprises choosing digital RMB, the expected payoff for not choosing it, and the average expected payoff are respectively:

$$U_{11} = y(ep + \Delta ep - 1ce + s) + (1 - y)(ep + \Delta ep - 2ce + s)$$

$$U_{12} = y(ep - 3ce) + (1 - y)(ep - 4ce)$$

$$\bar{U}_1 = xU_{11} + (1 - x)U_{12}$$

Similarly, the expected payoffs for commercial bank strategies are:

$$U_{21} = x(bp + \Delta bp - cb - \Delta cb + cr) + (1 - x)(bp - cb + cr)$$

$$U_{22} = x(bp - cb) + (1 - x)(bp - cb)$$

$$\bar{U}_2 = yU_{21} + (1 - y)U_{22}$$

According to the Malthusian replication dynamic principle, the replication dynamic equations for bank-enterprise game strategy selection are:

$$\frac{dx}{dt} = x(1-x)(U_{11}-U_{12}) = x(1-x)[y(2ce-1ce-3ce+4ce)+\Delta ep+s+4ce-3ce]$$

$$\frac{dy}{dt} = y(1 - y)(U_{21} - U_{22}) = y(1 - y)[x(\Delta bp - \Delta cb + cr) - cr]$$

The system of equations (7) and (8) constitutes the replication dynamic system of the asymmetric bank-enterprise game, revealing the evolutionary trends of both parties' strategy selection probabilities over time.

Setting $\frac{dx}{dt} = 0$ and $\frac{dy}{dt} = 0$, solving the system yields equilibrium points: $(0, 0)$, $(1, 0)$, $(0, 1)$, $(1, 1)$, and (x^*, y^*).

However, equilibrium points of replication dynamic equations do not necessarily stabilize the system. According to Friedman' s method, the evolutionary stable strategy of the group dynamic system described by differential equations can be obtained through local stability analysis of the system's Jacobian matrix. Taking derivatives of the replication dynamic system yields matrix J, with equilibrium point values calculated as shown in Table 3 .

In formula (9) matrix, the determinant and trace are:

$$Det(J) = (1-2x)[y(2ce-1ce-3ce+4ce)+\Delta ep+s+4ce-3ce]\times(1-2y)[x(\Delta bp-\Delta cb+cr)-cr]-x(1-x)y(1-y)(2ce-1ce-3ce+4ce)(\Delta bp-\Delta cb+cr)$$

$$Tr(J) = (1-2x)[y(2ce-1ce-3ce+4ce)+\Delta ep+s+4ce-3ce]+(1-2y)[x(\Delta bp-\Delta cb+cr)-cr]$$

Table 3 Equilibrium Point Values

Equilibrium Point	$Det(J)$	$Tr(J)$
$(0, 0)$	$(\Delta ep + s + 4ce - 3ce) \times (-cr)$	$(\Delta ep + s + 4ce - 3ce) + (-cr)$

Equilibrium Point	$Det(J)$	$Tr(J)$
$(0,1)$	$(\Delta ep + s + 2ce - 1ce) \times (-cr)$	$(\Delta ep + s + 2ce - 1ce) + (-cr)$
$(1,0)$	$-(\Delta ep + s + 4ce - 3ce) \times (\Delta bp - \Delta cb)$	$-(\Delta ep + s + 4ce - 3ce) + (\Delta bp - \Delta cb)$
$(1,1)$	$-(\Delta ep + s + 2ce - 1ce) \times (\Delta bp - \Delta cb + cr)$	$-(\Delta ep + s + 2ce - 1ce) + (\Delta bp - \Delta cb + cr)$
(x^*, y^*)	0	0

At point (x^*, y^*), we have $\partial x^*/\partial \Delta ep + \partial y^*/\partial \Delta ep = 0$, with matrix trace less than 0, thus it is not an evolutionary equilibrium point.

As shown in Table 4 , under the condition $2ce - 1ce - 3ce + 4ce > 0$, five categories of different equilibrium points and nine potential stability conditions are identified, which can be divided into two major categories: deterministic strategies and uncertain strategies. Among them, $(0,0)$ represents enterprises not using digital RMB and banks not implementing credit preference; $(1,0)$ represents enterprises using digital RMB while banks do not implement credit preference; $(0,1)$ represents enterprises not using digital RMB while banks implement credit preference; $(1,1)$ represents enterprises using digital RMB and banks implementing credit preference.

The stability conditions exhibit three characteristics, representing differential comparisons calculated by various theoretical formulas. First, the comparison between enterprises' additional digital RMB income, central bank subsidies, current deposit interest benefits, and banks' additional costs. Second, the comparison between banks' relative policy benefits from credit preference and additional business costs. Third, the comparison between banks' excess benefits from credit preference when enterprises use digital RMB and relative costs.

Table 4 Stability Conditions for Equilibrium Points

Equilibrium Point	Stability Conditions
$(0,0)$	$\Delta ep + s + 4ce - 3ce < 0$ and $-cr < 0$
$(0,1)$	$\Delta ep + s + 2ce - 1ce < 0$ and $-cr < 0$
$(1,0)$	$-(\Delta ep + s + 4ce - 3ce) < 0$ and $\Delta bp - \Delta cb < 0$
$(1,1)$	$-(\Delta ep + s + 2ce - 1ce) < 0$ and $\Delta bp - \Delta cb + cr < 0$
Uncertain	$(\Delta ep + s + 4ce - 3ce) \times (\Delta bp - \Delta cb) > 0$ or $(\Delta ep + s + 2ce - 1ce) \times (\Delta bp - \Delta cb + cr) > 0$

4. Simulation Analysis

To verify the impact of key parameters such as costs, subsidies, policy benefits, and digital RMB additional income on the evolutionary paths and final equilibrium outcomes of small and micro enterprises and commercial banks under different strategies in the above game model, we conduct simulation analysis using MATLAB software. This simulates scenarios where stable strategies emerge and factors influencing both parties' decisions, examines specific decision trends under different stability conditions, and explores changes in strategy selection under stable strategies.

4.1 Simulation Analysis of Bank-Enterprise Game Behavior Under Deterministic Strategies 1. Simulation Analysis When Commercial Banks Do Not Implement Credit Preference

(1) Simulation Analysis When Enterprises Do Not Use Digital RMB

At equilibrium point $(0,0)$, solving differential equations under different stability conditions yields three game evolution trends as shown in Figure 2 [Figure 2: see original paper], with different conditions illustrated in Figures 2(a), 2(b), and 2(c). Here, $(0,0)$ is the evolutionarily stable strategy, where choosing not to use digital RMB and not to implement credit preference becomes the dominant choice for both parties.

Further simulation of individual behavioral paths yields three results shown in Figure 3 [Figure 3: see original paper], with three stability conditions illustrated in Figures 3(a), 3(b), and 3(c).

Case 1: When $\Delta ep + s + 4ce - 3ce < 0$ and $-cr < 0$, assume $1ce = 3$, $3ce = 4$, $\Delta ce = 0.8$, $ep = 0.9$, $i = 0.3$, $cr = 0.8$, $cb = 3$, $\Delta bp = 0.7$, $x = 0.3$, $y = 0.9$. The evolution trend is shown in Figure 2(a) and behavioral paths in Figure 3(a). As evolutionary steps increase, commercial banks tend not to implement preferential credit, while small and micro enterprises are unwilling to use digital RMB, with both strategy probabilities eventually dropping to 0. When enterprises have weak awareness of digital transactions, the central bank implements no appropriate incentives or penalties, and commercial banks cannot achieve excess returns, the switching costs for enterprises and menu costs for banks become too high in repeated game cycles. Under state-dependent rules, price stickiness prevents interest rate reduction, banks cannot implement credit preference, enterprises choose traditional methods due to path dependence, digital RMB remains abandoned, and both parties fail to achieve ideal welfare.

Case 2: When $\Delta ep + s + 4ce - 3ce < 0$ and $\Delta bp - \Delta cb < 0$, assume $1ce = 3$, $3ce = 4$, $\Delta ce = 0.8$, $ep = 0.9$, $i = 0.3$, $cr = 0.7$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.3$, $y = 0.9$. The evolution trend is shown in Figure 2(b) and behavioral paths in Figure 3(b). As evolutionary steps increase, commercial banks initially show

tendency to implement credit preference, but enterprises show no digital RMB adoption tendency, with both probabilities eventually dropping to 0. When enterprises lack interest in digital RMB due to weak awareness or excessive operational risk making disclosure difficult, even if banks can obtain excess returns from credit preference, without enterprise support and cooperation, banks eventually accumulate risks. Considering banks' inherent preference for conservative rates, mismatched risk-return profiles cause them to abandon credit preference strategies.

Case 3: When $\Delta ep + s + 4ce - 3ce > 0$ and $\Delta bp - \Delta cb < 0$, assume $1ce = 3$, $2ce = 4$, $3ce = 10$, $\Delta ce = 0.7$, $ep = 0.9$, $i = 0.3$, $cr = 0.7$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.3$, $y = 0.9$. The evolution trend is shown in Figure 2(c) and behavioral paths in Figure 3(c). As evolutionary steps increase, enterprise digital RMB adoption probability first rises then falls, while bank credit preference probability continuously declines, both eventually dropping to 0. Although enterprises and the central bank attach some importance to digital RMB and enterprises show some adoption preference, if rewards are insufficient, banks maintain conservative rates (i.e., the maximum legal rate for small enterprises), preventing credit relationship formation and causing enterprises to abandon digital RMB. This demonstrates that central bank macro-control and bank profitability after implementing credit preference are major drivers of digital RMB development.

(2) Simulation Analysis When Enterprises Use Digital RMB

When $\Delta ep + s + 4ce - 3ce > 0$ and $\Delta bp - \Delta cb > 0$, assume $1ce = 3$, $2ce = 4$, $3ce = 10$, $\Delta ce = 0.7$, $ep = 0.9$, $i = 0.3$, $cr = 0.7$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.2$, $y = 0.8$. Solving the differential equations yields the evolution trend shown in Figure 4 [Figure 4: see original paper] and behavioral paths in Figure 5 [Figure 5: see original paper], where $(1, 0)$ is the evolutionarily stable strategy—enterprises use digital RMB while banks do not implement credit preference. Figures 4 and 5 show that as evolutionary steps increase, bank credit preference probability declines to 0 while enterprise digital RMB adoption probability rises to 1. In this scenario, enterprises sufficiently value digital RMB, whose security, convenience, and inclusiveness improve their efficiency, while central bank subsidies stimulate active adoption. However, banks cannot achieve additional returns from credit preference strategies. Considering menu costs and sticky prices, despite enterprise preference for digital RMB, sticky interest rates trap banks in adverse selection again.

2. Simulation Analysis When Commercial Banks Implement Credit Preference

(1) Simulation Analysis When Enterprises Do Not Use Digital RMB

When $\Delta ep + s + 2ce - 1ce < 0$ and $-cr < 0$, assume $1ce = 3$, $2ce = 4$, $3ce = 10$, $\Delta ce = 0.7$, $ep = 0.9$, $i = 0.3$, $cr = 0.8$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.3$, $y = 0.8$. Solving yields the evolution trend shown in Figure 6 [Figure 6: see original paper] and behavioral paths in Figure 7 [Figure 7: see original paper]. Here, $(0, 1)$ is the evolutionarily stable strategy—enterprises do not use digital RMB while banks

implement credit preference. Figures 6 and 7 show that as evolutionary steps increase, bank credit preference probability rises to 1 while enterprise digital RMB adoption probability declines to 0. This occurs because enterprises lack deep understanding of digital RMB and, affected by switching costs and path dependence, show weak adoption awareness. Even with central bank digital RMB subsidies, enterprises continue traditional transaction models, resisting digital RMB development. Although central bank rewards such as targeted reserve requirement cuts exceed additional costs, making credit preference profitable even without excess returns, the digital RMB policy still cannot be effectively implemented. Moreover, when policy benefits from credit preference exceed additional costs from interest rate reduction, the central bank bears all additional costs of bank credit preference, contradicting financial security perspectives on central bank subsidy limits.

(2) Simulation Analysis When Enterprises Use Digital RMB

At equilibrium point $(1, 1)$, solving differential equations under different stability conditions yields three game evolution trends shown in Figure 8 [Figure 8: see original paper], with different conditions illustrated in Figures 8(a), 8(b), and 8(c). Here, $(1, 1)$ is the evolutionarily stable strategy.

Further simulation of individual behavioral paths yields three results shown in Figure 9 [Figure 9: see original paper], with three stability conditions illustrated in Figures 9(a), 9(b), and 9(c).

Case 1: When $\Delta ep + s + 2ce - 1ce > 0$ and $\Delta bp - \Delta cb + cr > 0$, assume $1ce = 3$, $2ce = 4$, $3ce = 10$, $\Delta ce = 0.7$, $ep = 0.9$, $i = 0.3$, $cr = 0.9$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.3$, $y = 0.8$. The evolution trend is shown in Figure 8(a) and behavioral paths in Figure 9(a). As evolutionary steps increase, both digital RMB adoption and credit preference probabilities continuously rise, eventually reaching 1. Here, enterprises have strong digital RMB adoption motivation, providing banks with a path to reduce credit rates. Under central bank subsidy incentives, enterprises are willing to forgo current deposit interest. However, excessively high central bank policies eliminate banks' additional costs for credit preference, contradicting financial security perspectives on subsidy limits.

Case 2: When $\Delta ep + s + 2ce - 1ce > 0$ and $\Delta bp - \Delta cb + cr > 0$, assume $1ce = 3$, $2ce = 4$, $3ce = 10$, $\Delta ce = 0.7$, $ep = 0.9$, $i = 0.3$, $cr = 0.9$, $cb = 3$, $\Delta bp = 0.8$, $x = 0.3$, $y = 0.8$. The evolution trend is shown in Figure 8(b) and behavioral paths in Figure 9(b). As evolutionary steps increase, both probabilities continuously rise to 1. Here, enterprises have strong digital RMB awareness, banks have strong social responsibility, and the central bank has high management and macro-control capabilities. Under the "central bank-commercial bank" two-tier centralized management system, subsidy amounts are designed within reasonable ranges. Enterprises are willing to forgo current deposit interest, and banks are willing to reduce credit rates when information asymmetry improves. Both parties' benefits exceed costs, breaking path dependence and achieving an ideal state of positive incentive cycles through tool innovation.

Case 3: When $\Delta ep+s+2ce-1ce<0$ and $\Delta bp-\Delta cb+cr>0$, assume $1ce=3$, $2ce=4$, $3ce=10$, $\Delta ce=0.7$, $ep=0.9$, $i=0.3$, $cr=0.9$, $cb=3$, $\Delta bp=0.8$, $x=0.3$, $y=0.8$. The evolution trend is shown in Figure 8(c) and behavioral paths in Figure 9(c). As evolutionary steps increase, both probabilities continuously rise to 1. Although enterprises and the central bank attach some importance to digital RMB and enterprises show some preference, when bank credit preference rewards are insufficient, enterprises do not actively choose digital RMB. Banks only implement credit preference when central bank rewards are high enough to reduce rates and encourage enterprise adoption. While this achieves coordinated digital RMB usage and credit preference, it again contradicts financial security perspectives on central bank subsidy limits.

4.2 Simulation Analysis of Bank-Enterprise Game Behavior Under Uncertain Strategies When $(\Delta ep+s+4ce-3ce)\times(\Delta bp-\Delta cb)>0$ or $(\Delta ep+s+2ce-1ce)\times(\Delta bp-\Delta cb+cr)>0$, assume $1ce=3$, $2ce=4$, $3ce=10$, $\Delta ce=0.7$, $ep=0.9$, $i=0.3$, $cr=0.7$, $cb=3$, $\Delta bp=0.8$, $x=0.3$, $y=0.8$. Solving the differential equations yields two solutions, representing uncertain strategies. Simulation analysis produces the evolutionary game trend and phase diagram shown in Figures 10 [Figure 10: see original paper] and 11 [Figure 11: see original paper], where equilibrium points are $(0,0)$ or $(1,1)$. The evolutionary equilibrium strategies for small and micro enterprises and commercial banks cannot be determined and require further analysis.

The final equilibrium depends on the areas of quadrilaterals $DBOA$ and $DBCA$. When $S_2>S_1$, the system converges to $(1,1)$ with higher probability—i.e., enterprises use digital RMB and banks implement credit preference. The calculation formula is shown in equation (10):

$$S_1=\frac{cr}{\Delta bp-\Delta cb+cr}\times\frac{4ce-3ce-\Delta ep-s}{2ce-1ce-3ce+4ce}$$

$$S_2=1-S_1$$

Equation (10) shows that $1ce$, $2ce$, Δep, s, i, Δcb, Δbp, and cr all have monotonic relationships with S_1 and S_2. When S_1 is large, S_2 increases, and evolutionary strategies develop toward "enterprises use digital RMB, banks implement preferential credit." Area formula analysis reveals that for enterprises, when central bank digital RMB subsidies sufficiently cover switching costs and current deposit interest, and additional income from digital RMB is larger, adoption willingness strengthens and selection probability increases. For commercial banks, the more excess benefits banks obtain from enterprise digital RMB usage that facilitates credit relationships, the higher the probability of implementing credit preference.

4.3 Simulation Results Preliminary theoretical analysis yields five categories of equilibrium points and nine potential stability conditions. However, considering financial security perspectives on central bank subsidy limits, numerical simulation of evolutionary paths reveals only two categories of equilib-

rium points and two stability conditions consistent with hypotheses, forming the conditions for digital RMB to alleviate small and micro enterprise financing difficulties. Commercial banks incentivize credit relationship formation, and enterprise digital RMB usage generates excess benefits that cover additional costs of credit preference. Simultaneously, enterprise additional income must be compared with financing costs under different scenarios. If additional income exceeds the upper limit of additional costs without credit preference, it helps alleviate financing problems. If additional income falls between costs with and without credit preference, enterprises still have probability of obtaining bank loans.

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5. Conclusions and Recommendations

This paper focuses on how digital RMB usage alleviates small and micro enterprise financing difficulties. First, it compares theoretical mechanisms of bank-enterprise behavior under traditional payment methods versus digital RMB scenarios. Second, it constructs an evolutionary game model between small and micro enterprises and commercial banks under information asymmetry, derives stability conditions by solving the game' s differential equations, and uses numerical simulation to examine how parameter changes affect behavioral paths and equilibrium outcomes, systematically exploring stability based on digital RMB adoption and preferential credit implementation.

First, digital RMB usage generates additional benefits for small and micro enterprises through improved payment efficiency, reduced payment costs, and enhanced risk prevention and control. Combined with central bank subsidies, this effectively stimulates digital RMB adoption willingness. Second, digital RMB promotion enables commercial banks to reduce credit risk, operational risk, and market risk while improving information transparency and decreasing bad debt risk. Under central bank incentives such as targeted reserve requirement cuts, banks develop motivation to implement credit preference. Third, within reasonable policy incentive ranges, when digital RMB incremental income exceeds given cost conditions, commercial banks facilitate small and micro enterprise financing development. Both parties obtain excess returns, achieving stable equilibrium and coordinated development of digital RMB and credit preference strategies while balancing efficiency and security.

By solving evolutionary game differential equations and analyzing different stability conditions, simulation results indicate that digital RMB incremental income and reduced information asymmetry are key to increasing digital RMB usage and driving the system toward benign evolution. The study recommends: First, the central bank should strengthen digital RMB publicity, cultivate social awareness of digital RMB transactions, and continuously improve the regulatory system. On one hand, popularize digital RMB transaction knowledge, raise small and micro enterprise cognition levels, and improve digital RMB us-

age. On the other hand, refine incentive rules by reducing rediscount rates and other measures to lower commercial banks' funding costs and promote preferential credit implementation. Relevant departments should provide subsidies to small and micro enterprises using digital RMB to compensate for interest losses, promptly disclose commercial bank credit preference information, and stimulate financing. The central bank should properly utilize digital RMB' s embedded smart contracts, triggered by timing conditions, economic states, loan rates, or flow entities, to ensure funds flow to truly needy small and micro enterprises through "precision drip irrigation." Second, under the "dual-mode" system, the central bank issues digital RMB to commercial bank business vaults and entrusts banks with deposit, withdrawal, exchange, and transfer services. Commercial banks should actively cooperate with the central bank to promote digital RMB, create usage atmosphere, and issue new-form loans dominated by digital RMB to alleviate small and micro enterprise financing difficulties through reasonable pricing. With digital RMB advantages, commercial banks can not only reduce loan rates, extend loan terms, and increase loan efficiency to improve enterprise loan experiences, but also provide feedback to the central bank to strengthen digital RMB product development and innovation.

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Note: Figure translations are in progress. See original paper for figures.