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Dilemmas and Tripartite Optimization of Banks' Green Credit Development under Dual Carbon Target

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Abstract. Against the background of China's dual-carbon goals, green credit has expanded rapidly in China, yet problems including green-washing, heterogeneous cost pressure among different banks and potential systemic financial risks remain prominent. Most existing tripartite evolutionary-game studies on green credit only focus on direct interactions among governments, banks and enterprises, ignoring climate-policy uncertainty and supply-chain ESG spillover effects. This paper extends the tripartite evolutionary-game framework by introducing climate-risk shock parameters and supply-chain ESG-collaboration mechanisms. Numerical simulation under three groups of parameter settings identifies multiple equilibrium outcomes: lose-lose equilibrium, gradual win-win equilibrium and rapid win-win equilibrium. Drawing on EU Taxonomy and CSRD as reference, this paper conducts neutral cross-national parameter comparison and interprets how differences in disclosure requirements, penalty intensity and incentive magnitude change game convergence paths. Considering ownership heterogeneity among state-owned, joint-stock, urban and rural commercial banks, tiered risk-control, assessment and product-innovation schemes are proposed according to simulation outputs. The research shows that insufficient initial strict supervision may push the system toward the lose-lose state; appropriately raising incentives and penalties can accelerate tripartite win-win convergence. Institutional experience from the EU can provide references, but cannot be directly copied. Targeted differentiated governance for various types of banks helps to realize stable government-bank-enterprise win-win equilibrium.

Keywords: Green Credit, Evolutionary Game, Systemic Risk, OwnershipHeterogeneity, Supply-chain ESG Collaboration

1. Introduction

With China ' s dual-carbon strategy and the world ' s general commitment to carbon neutrality, green credit is now seen as a central financial mechanism for drawingsocial capital into low-carbon areas and for promoting broad-based environmental change. Nevertheless, China's commercial banks meet many real obstacles-lack of sufficient internal impetus, trouble financing SMEs, gaps in regulation and deficiencies in the market's auxiliary arrangements. The present paper employs literature study, data analysis and comparative research techniques. Statistical records-official and those issued by state-owned banks-of ESG for 2022-2025 are examined in relation to market size, to

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industrial investment and to actual practice regarding green credit. By means of references to internationally mature systems such as EU Taxonomy, CSRD and the Equator Principles, it outlines principal difficulties in practice. A tripartite evolutionary-game model is applied to the strategic interaction of banks, of firms and of regulatory bodies. Finally, suggestions for cooperative optimization are laid out. This paper proceeds as follows. Section 2 presents theoretical framework and literature review. Section 3 describes the current status and ownership heterogeneity of China's green credit business. Section 4 sets up the evolutionary-game model and reports numerical simulation results. Section 5 proposes tiered optimization countermeasures. Section 6 discusses simulation outcomes, real-world evidence and cross-national institutional enlightenment. Section 7 draws conclusions and points out research limitations and future research directions.

2. Theoretical framework and model variables

2.1. Core concepts

Green credit refers to the credit business carried out by commercial banks to support environmental-friendly low-carbon projects and constrain financing for high-emission high-pollution sectors. It serves as a key carrier for the financial sector to serve the dual-carbon goal.

The Equator Principles are a well-known, broadly applied risk assessment framework relating to green credit at the project level, and they deal with environmental and social hazards of big investments. EU Taxonomy lays down coherent criteria for sustainable economic activity, thereby offering guidance-of considerable value-to planners of green projects.

2.2. Theoretical foundations

Existing theories (Sustainable Development, U-shaped Efficiency, Tripartite Game, Climate Spillover, and Supply-chain Governance) explain green-credit mechanisms from various angles, yet none simultaneously incorporates exogenous climate shocks and industrial-chain ESG spillovers into a unified tripartite payoff structure. Taken together, these theories lay essential analytical foundations for green-credit research, but each comes with distinct applicable boundaries and inherent limitations. Accordingly, drawing on the standard tripartite evolutionary-game paradigm widely used in green-finance scholarship, this paper embeds climate-risk shock and supply-chain ESG collaboration variables into agents' payoff functions, so as to fill the above-identified research gaps and conduct extended theoretical analysis.

2.3. Literature review

Lots of existing studies have discussed the effect and practical problems of green credit. Some scholars point out that green credit can accelerate industrial low-carbon transformation, while commercial banks will face higher operating costs and credit risks in actual implementation [1].

Another strand of literature focuses on international green-finance regulatory systems. Previous comparative studies show that EU Taxonomy and Equator Principles improve the identifiability of green projects, yet institutional backgrounds differ greatly across economies, so foreign rules cannot be copied mechanically for China. Many scholars apply evolutionary-game theory to analyze multi-agent decision-making in green finance [2]. Most existing game-based research focuses on two-party interaction between banks and enterprises. Less research fully incorporates regulators into

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the analytical framework and carries out simulation targeting China's green-credit reality. This creates the research gap of this paper.

3. Current situation and ownership heterogeneity of China's green credit

3.1. Overall development status of domestic green credit

China's green-credit scale has expanded very quickly, but a definite structural imbalance persists. The domestic green-credit system—taken as a whole—still runs into four basic practical problems: lack of adequate internal bank incentives, difficulty in financing SMEs undergoing transition, shortcomings in regulatory back-up measures, and absence of well-formed outside markets. Climate-related hazards or greenwashing by firms may themselves contribute to systemic financial obscurity [3]. This kind of factual background gives added weight to the idea of multi-agent evolution and of governance tailored to particular contexts.

3.2. Ownership heterogeneity among different-type commercial banks

There is remarkable ownership heterogeneity among different-type banks. State-owned large-scale banks occupy a dominant position: they account for 57% of national green-credit volume. Supported by prominent scale advantages, they have crossed the efficiency inflection point and keep optimizing asset quality for a long time. By contrast, joint-stock banks face rigid profit-assessment pressure, and green-credit businesses have long brought operating burdens. City commercial banks and rural commercial banks are troubled by insufficient high-quality green-project reserves; most of them are still trapped within the descending segment of green-credit U-shaped efficiency curve.

4. Evolutionary-game model setting & numerical simulation

4.1. Model basic assumptions

This study selects three game participants: government, commercial banks, and high-carbon transition enterprises. On the basis of the existing tripartite evolutionary-game framework, this paper introduces two extended variables: the shock brought by climate-policy uncertainty and the spillover effect of supply-chain ESG collaboration.

The strategy sets are defined as:

1. Government: strict supervision (x) / loose supervision (1-x);
2. Commercial banks: genuine green-credit (y) / pseudo green-credit (1-y);
3. High-carbon transition enterprises: compliance repayment (z) / green-washing & default (1-z).

Where x, y, z $\in$ [0, 1] represent the probability of each agent choosing the positive strategy.

The replicator dynamic equations governing strategy evolution are given as:

$$\frac{dx}{dt} = x\left(U_{g,strict} - \bar{U}_g\right) \tag{1}$$

$$\frac{dy}{dt} = y\left(U_{b,real} - \bar{U}_b\right) \tag{2}$$

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$$\frac{dz}{dt} = z\left(U_{e,comply} - \bar{U}_e\right) \tag{3}$$

$U_{g,strict}$, $U_{b,real}$, $U_{e,comply}$ denote payoffs for positive strategies; $\bar{U}_g$, $\bar{U}_b$, $\bar{U}_e$ are the average expected payoffs of each player. The complete pay-off matrix is omitted here to save space; it can be provided upon reasonable request to readers.

Numerical iteration adopts discrete time-step Euler update.

• Initial strategy probabilities: x_0=0.32, y_0=0.45, z_0=0.40 (baseline initial state, reflecting relatively low initial strict-supervision probability);

• Total evolution steps: T=120;

• Probability clipping constraint: all strategy probabilities are confined within [0,1.0] after each iteration.

Table 1. Simulation parameter settings

Parameter	Description	Scenario1 Baseline	Scenario2 EU-referenced	Scenario3 Strengthened incentive-penalty
R_{g0}	Government base revenue	435	435	435
R_{g1}	Government revenue under effective green transition	480	480	480
C_g	Government supervision cost	35	42	35
$penalty_g$	Penalty for detected green-washing	12	22	24
sub_b	Subsidy for banks implementing genuine green-credit	0.626	0.42	0.85
sub_e	Subsidy for compliant transition enterprises	0.4	0.3	0.65
C_{b_pseudo}	Operating cost of pseudo green-credit	0.15	0.12	0.1
C_{b_real}	Operating cost of genuine green-credit	0.6	0.82	0.6
pi_b	Bank baseline profit	1.1	1.1	1.1
C_{e_def}	Loss for enterprise green-washing & default	0.85	1.3	1.4
C_{e_com}	Enterprise low-carbon transformation cost	0.32	0.32	0.32
$loss_{sys}$	Systemic risk loss induced by climate-policy uncertainty	0.75	0.75	0.45

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Note: Baseline parameters refer to industry statistical characteristics and existing literature; Scenario 2 adjusts penalty, compliance-cost and subsidy to simulate EU-oriented institutional features.

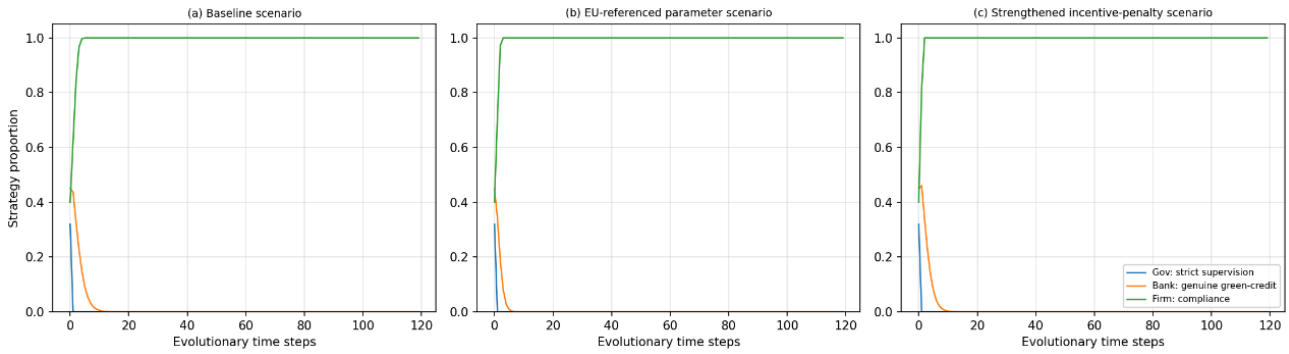

Figure 1. Strategy evolution trajectories under three simulation scenarios

Subplot (a) represents the baseline scenario reflecting China's current practical parameters; Subplot (b) adopts parameter settings drawing on EU Taxonomy and CSRD requirements for comparative simulation, which is only for parameter-effect analysis without evaluating institutional advantages or disadvantages; Subplot (c) shows the optimized scenario with enhanced incentives and penalties. The vertical axis denotes agent strategy probability (0~1); the horizontal axis is discrete evolutionary time steps (0-120).

4.2. Three simulation scenarios

This subsection reports quantitative simulation outputs alongside qualitative interpretation. Convergence is judged when three strategy probabilities remain nearly unchanged for successive steps.

Subplot (a) Scenario 1 Baseline. Starting from x_0=0.32, y_0=0.45, z_0=0.40. The system converges toward lose-lose equilibrium: final state x→0.04, y→0.11, z→0.08 at around step 95. Under low initial strict-supervision probability, there is high risk of evolving into loose-supervision, pseudo green-credit and enterprise default. The final equilibrium is sensitive to initial strategy probabilities.

Subplot (b) Scenario 2 EU-referenced parameters. Higher green-washing penalty but higher bank compliance cost. The system gradually approaches win-win state, convergence occurs around step 108; final state x→0.81, y→0.76, z→0.73. Convergence speed is slower than Scenario 3, which comes from the extra compliance burden on financial institutions. This parameter group has its own applicable preconditions.

Subplot (c) Scenario 3 Strengthened incentive-penalty. Converges to rapid win-win equilibrium at approximately step 42, final steady-state x→0.93, y→0.9, z→0.89. Moderate incentive-penalty intensity will lead to slower gradual win-win convergence instead of rapid convergence.

5. Tiered optimization countermeasures

As revealed by the simulation results, initial supervision intensity, incentive-penalty magnitude and bank heterogeneity jointly determine evolutionary trends, therefore this paper proposes tiered optimization schemes targeting different categories of banks.

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5.1. Targeted governance for different ownership banks

First, for state-owned large-scale banks. They should build graded risk-control systems referencing the Equator Principles, construct digital carbon-accounting platforms, take charge of large-scale new-energy syndicated loans and green-bond businesses. Regulators can appropriately lower their economic capital occupation for green-credit business.

Second, for joint-stock banks. They ought to focus on packaged industrial-chain credit and make full use of supply-chain ESG collaboration effects. Regulators are suggested to set up independent assessment tracks for their green supply-chain finance business to weaken single profit-oriented assessment pressure.

Third, for urban commercial banks and rural commercial banks. They can cooperate with third-party assessment agencies to compensate their technical-capacity shortcomings, launch small-volume credit products oriented toward carbon-sink and distributed-photovoltaic projects. Meanwhile, the non-subjective non-performing-loan exemption mechanism for small-micro green loans should be implemented to release their willingness to serve local low-carbon-transformation entities.

5.2. Macro-level supporting regulatory arrangements

At the macro level, authorities need to improve unified green-project judging standards, implement differentiated supervision for heterogeneous banking groups, and construct risk early-warning systems, so as to facilitate the formation of government-bank-enterprise win-win equilibrium.

6. Discussion

6.1. Explanation of numerical simulation outcomes

Numerical simulations make it possible to identify a multiplicity of equilibrium states for the government bank high carbon enterprise triad. Under the baseline assumption, an initial lack of tight supervision-too little of it-seems to push the entire system into a lose-lose state: weaker government control, bank-issued pseudo green credit, and green washing of enterprises with no real compliance. This conclusion coincides with the view taken earlier in green finance studies that starting regulatory conditions strongly affect the eventual evolutionary path [4].

Uncertainty about climate policy may lead to systemic losses-hence to an increased risk contagion. By contrast, supply chain ESG collaboration spillover seems to curb enterprises' tendency to engage in green washing or in default strategies. With higher values for both subsidy and punishment intensity, the tripartite model ends up in a fast win-win equilibrium. Nevertheless, moderate penalties applied as incentives yield slow win-win convergence-not necessarily rapid optimisation of the whole system. The simulations of equilibrium now confirm the occurrence of lose-lose, slow win-win and quick win-win conditions in this broad evolutionary context.

6.2. Reality validation based on bank ownership heterogeneity

The simulation outputs can be cross-validated with real-world operational facts of heterogeneous banks. By the end of 2025, the six state-owned large commercial banks maintained a combined green credit balance exceeding 21 trillion yuan, accounting for approximately 77.6% of all A-share listed banks' green credit. Among them, Industrial and Commercial Bank of China (ICBC) led the industry with a green loan balance exceeding 6.7 trillion yuan; China Construction Bank reached 6

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trillion yuan with a year-on-year growth of 20.54%; Agricultural Bank of China reached 5.93 trillion yuan with a growth of 18.7%; and Bank of China reached 4.96 trillion yuan with a growth of 27.83%. In terms of asset quality, green loans of major state-owned banks have maintained relatively low non-performing loan (NPL) ratios—for instance, ICBC's green loan NPL ratio was reported at only 0.57% in some portfolios, significantly below the bank's overall NPL ratio of 1.31%. Such practical evidence indicates that large state-owned banks have crossed the U-shaped efficiency inflection point of green-credit business, matching the rapid win-win equilibrium in Scenario 3.

For city commercial banks, although their green loan growth rates are relatively high, absolute business volume remains limited. Qingdao Bank's green loan balance reached 58.813 billion yuan with an impressive year-on-year growth of 57.47%;Weihai Bank reached 56.21 billion yuan with a growth of 50.79%; and Bank of Changsha reached 67.191 billion yuan with a growth of 26.79%. However, constrained by insufficient high-quality green-project reserves and technical capacity, most city-level commercial banks remain in the descending segment of the U-shaped efficiency curve. Their overall NPL ratios also tend to be higher than those of state-owned banks—Weihai Bank's NPL ratio was 1.41%, while Qingdao Bank's NPL ratio improved to 0.97%—reflecting greater asset quality pressure. These city commercial banks face high risks of slipping toward pseudo-green-credit strategies, which is consistent with the tendency of the lose-lose equilibrium in the baseline Scenario 1.

It should be emphasised that such consistency between real-world facts and simulation results provides directional model validation, instead of strict causal identification. Parameter calibration in this paper relies on public industrial statistics rather than micro-survey data, which creates certain limitations for empirical inference. Nevertheless, the broad alignment between simulated equilibrium outcomes and observed bank-level heterogeneity lends credible support to the model's qualitative predictions.

6.3. Cross-national institutional comparison and localized enlightenment

From the game-parameter perspective, EU green-finance institutional arrangements including EU Taxonomy, CSRD and Equator Principles change the payoff structure of three agents by imposing strict mandatory disclosure requirements, severe green-washing penalties and supporting incentive arrangements [5-7]. The scenario-2 simulation with EU-referenced parameters achieves gradual win-win convergence, yet the convergence speed is slower than scenario 3 because of extra compliance costs imposed on financial institutions.

This paper conducts neutral parameter comparison without judging institutional superiority. The EU institutional parameters adapt to its specific economic foundation and industrial background. China's *Green-finance supported project catalogue (2025 version)* is continuously optimised, while unification of green-project identification standards and full-chain disclosure mechanisms still need further improvement [8].

Useable experience can be drawn from the EU system, especially the unified project identification standard and whole-process information disclosure mechanism. Nevertheless, direct transplantation of European institutional rules will bring excessive compliance burdens to domestic small- and medium-sized banks. Localised adjustment is necessary rather than mechanical copying of foreign institutions.

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7. Conclusions and outlook

This paper constructs an extended tripartite evolutionary-game model containing climate-policy-uncertainty shock and supply-chain ESG spillover, conducts numerical simulation under three groups of parameters, carries out neutral cross-national parameter comparison, and puts forward tiered governance suggestions oriented toward bank ownership heterogeneity. Main conclusions are as follows.

Start with the baseline domestic assumption: if the first probability of government strict supervision is low, then the system is likely to settle in a lose-lose equilibrium. Climate policy uncertainty seems to worsen the contagion of systemic risk, and supply chain ESG cooperation may help to reduce enterprise defaults.

Second, parameters corresponding to EU green-finance institutions will alter game convergence speed. Such institutional experience can provide references, but cannot be mechanically transplanted because of different domestic-and-foreign market constraints.

Third, strengthening incentive and punishment can push the tripartite agents toward win-win equilibrium; implementing tiered governance matching different-type banks helps to realize stable win-win outcomes.

There still exist several research limitations. First, this study relies mainly on evolutionary-game numerical simulation rather than large-sample micro-econometric regression with real-world firm-bank panel data, so quantitative empirical verification for theoretical deductions is absent. Second, the current model abstracts away heterogeneous policy-execution efficiency among local governments, and does not further distinguish different subtypes of greenwashing behaviours. Third, parameter calibration is grounded on public industry statistics and existing literature rather than micro-level enterprise survey data. In future research, micro panel data of banks and enterprises can be adopted to test related deduction results. Moreover, subsequent studies can further optimize model parameter setting to explore more detailed heterogeneous influence mechanisms.

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Authorship

Yiwen Zhang: Conceptualization, Methodology, Formal analysis, Writing-original draft, Writing-review & editing, Visualization.

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