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Construction and Stability Analysis of Evolutionary Game Model for Green Agricultural Production under the Leadership of Village Committees

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Abstract

The promotion of agricultural green production is mired in a governance dilemma characterized by policy implementation challenges and farmer reluctance, rooted in the complex strategic interactions among micro-level stakeholders. Leveraging the dual role of village committees as both a policy transmission hub and a cornerstone of rural society, this paper constructs an asymmetric evolutionary game model to analyze the behavioral interactions between village committees and agricultural producers. By defining the strategy sets and payoff matrices for both parties, the replicator dynamics of the system are derived, and local stability analysis is conducted using the Jacobian matrix to identify key Evolutionary Stable Strategies(ESS). The findings reveal that the system's evolutionary trajectory does not converge to a unique equilibrium but is critically dependent on cost-benefit parameters. The optimal equilibrium (1,1)—where village committees promote green production and farmers adopt it—requires a stringent benefit distribution mechanism, driven by factors such as the village committee's revenue share coefficient e, product price premium P,and collaborative returns R_s. Conversely, the Pareto-inefficient equilibrium (1,0)—where village committees promote green production but farmers refuse to participate—stems from specific cost structures. Numerical simulations further verify that the system tends to converge toward a cooperative equilibrium when the benefit distribution coefficient e falls within an appropriate interval. Both government subsidies S_f and environmental synergistic benefits R_s significantly promote cooperation. This study is the first to reveal the ”dual-threshold effect” of the benefit distribution coefficient, providing a micro-level theoretical foundation and quantitative evidence for addressing bottlenecks in agricultural green cooperation. The policy implications include implementing targeted interventions, designing incentive-compatible distribution mechanisms, and integrating economic incentives with the cultivation of social norms to advance sustainable cooperation in grassroots green governance.

Keywords: Rural Revitalization; Evolutionary Game; Village Committee; Green Production; Stability Analysis

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

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1 Introduction

In 2025, the Central Document No. 1, *Opinions on Comprehensively Promoting Rural Revitalization and Accelerating Agricultural and Rural Modernization,"* was officially released. The terms "agricultural green development," empowerment through science and technology, and "food security" once again emerged as core keywords. The rural revitalization strategy serves as the overall framework for addressing issues related to agriculture, rural areas, and farmers in the new era. Ecological revitalization, as a vital component of rural revitalization, constitutes a crucial path toward achieving sustainable agricultural and rural development (1). With the increasing progress in the construction of ecological civilization in China, green agricultural production has become the central focus for driving ecological revitalization. However, the traditional agricultural production model, which relies heavily on high inputs and high consumption, has led to increasingly prominent issues such as resource waste, environmental pollution, and ecological degradation, creating an urgent need to transition to a green, low-carbon and circular development model. In recent years, the central government has enacted a series of policies to facilitate agricultural green development and ecological revitalization. The *Strategic Plan for Rural Revitalization (2018-2022)"* explicitly calls for strengthening the prevention and control of agricultural non-point source pollution and promoting agricultural green development. The *Opinions on Innovating Institutional Mechanisms to Promote Agricultural Green Development"* emphasize the establishment of a green agricultural technology system and the promotion of clean production methods. These policies provide institutional safeguards and practical guidance for green agricultural production. According to the *China Agricultural Green Development Report (2024)*, the green product supply index increased by 0.05 compared to the previous year. Although this indicates progress, a gap persists when compared with developed countries. This disparity underscores the urgency of investigating the micro-level decision-making mechanisms of agricultural producers in China. Therefore, studying how these producers make decisions regarding green production, and exploring how policies and technologies can foster synergies between ecological and economic benefits, holds significant theoretical and practical relevance. Unlike previous studies that primarily emphasize the importance of 'incentive compatibility,' this paper seeks to quantify the specific conditions for achieving it. We will, for the first time, reveal and demonstrate that in the green production cooperation between village committees and farmers, there exists a dual-threshold interval concerning the benefit distribution coefficient e. The significance of this finding lies in its transformation of a complex governance principle into a quantifiable tool. This tool can guide concrete contract design, facilitate policy diagnosis, and enable targeted intervention, thereby providing a new micro-foundation for resolving grassroots cooperation dilemmas.

The complex network evolutionary game model is well-suited to capturing the influence of interactions among agents on their decision-making. In the context of agricultural green production, the interactions between village committees and groups of agricultural producers are neither fully coupled nor entirely random in reality; their strategic choices are significantly shaped by the system's topological structure. At its core, this represents an evolutionary game process on complex networks, where individual strategies co-evolve with changes in the network environment and structure (2; 3).Extending this analytical lens, several studies have employed game-theoretic frameworks to examine stakeholder behaviors in related rural and environmental governance contexts. For instance, Yang Xue et al. (4) argue that stakeholders' behavioral choices are critical for utilizing collectively-owned commercial construction land and fostering sustainable rural industrial development, specifically exploring the impacts of government support and village-enterprise cooperation. Weersink and Livernois (5) highlight the cost-effectiveness of economic instruments in achieving environmental objectives, noting their superior applicability for managing agricultural non-point source pollution compared to point-source controls. From a governance perspective, Chu, Vivian H.Y. et al. (6) propose collaborative governance as a key framework for addressing rural decline, constructing a theoretical linkage from institutional design to resilience enhancement through multi-stakeholder collaboration. Focusing on micro-level decision mechanisms, Bayramoglu and Chakir (7) used structural econometric methods to analyze how grain price hikes influence fertilizer inputs in French agriculture, revealing farmers' cost-benefit calculations in market settings. Similarly, Wang, Linlin et al. (8) developed a tripartite evolutionary game model involving the central government, local governments, and farmers. Their study reveals the dynamic nature of policy effectiveness, which depends on the actors' perceived benefits and constraints, and suggests that altering incentive structures through political accountability and fiscal constraints is more effective than mere institutional design. In green supply chain management, Zhu, Qinghua and Dou, Yijie (9) concluded that government subsidies and penalties directly affect the cost-benefit calculus of core enterprises, which is central to game outcomes. Recent applications further demonstrate the versatility of evolutionary game theory. Sun, Yong et al. (10) systematically analyzed the drivers and barriers in agricultural digital transformation. By modeling the game between digital technology service providers and agricultural operators under government influence, they explained the interactive mechanisms among these stakeholders. Hu, Qifan et al. (11) developed a tripartite evolutionary game model based on prospect theory, involving logistics enterprises, farmers, and consumers. Through stability analysis and numerical simulation of risk and payoff parameters, they proposed feasible recommendations for marketing green agricultural products.To elucidate the decision-making mechanisms of multiple stakeholders in environmental governance under the context of urbanization, Ding Qianxing et al. (12) constructed a tripartite evolutionary game model involving local governments, polluting enterprises, and the public. By solving for evolutionary stable strategies (ESS) and conducting numerical simulations, key influencing factors and their dynamic effects were identified. The simulation results further confirmed that by adjusting relevant parameters, the system can evolve toward an ideal stable state. This provides a theoretical basis for environmental collaborative governance in the process of new-type urbanization.

However, existing research predominantly focuses on macro-policy design by central or local governments or simplifies the game to a direct interaction between the government and farmers. This perspective overlooks a crucial institutional reality in China's rural governance: the dual role played by village committees as the "last link" of state power and the "hub" of rural society. In promoting green production, village committees are not merely policy conduits; they function as integrated governance intermediaries, acting as policy translators, interest coordinators, and community mobilizers. Therefore, unraveling the strategic interaction between village committees and farmers in green production serves as a key to unlocking the micro-foundations of the dual dilemma of policy stagnation and farmer reluctance. This study aims to construct an evolutionary game model embedded in this institutional reality to clarify their interactive logic and conditions for cooperation.

2 Construction and Analysis of the Evolutionary Game Model

2.1 Analysis of Game Agents and Behavioral Logic

Rural ecological revitalization involves multiple stakeholders, including the government, villagers, enterprises, and village committees. As a crucial link between state power and rural society, the village committee plays a dual role: implementing policies and representing villagers' interests. Its strategic choices directly affect policy effectiveness and shape agricultural producers' perceptions and willingness to adopt green technologies. As micro-level decision-makers, agricultural producers weigh the costs and benefits of greening their production practices. Their decisions are simultaneously embedded in rural social networks, which are often led by village committees. The strategic interaction between village committees and agricultural producers thus reflects the complex state-society dynamics in contemporary Chinese rural environmental governance. Modeling this dyadic relationship captures the hierarchical transmission of policies—from national strategies to village-level implementation and then to farm-level practices—as well as the moderating role of informal institutions in green technology diffusion. Crucially, their interaction forms a positively reinforcing governance feedback loop. Active facilitation by the village committee increases farmers' adoption willingness, while widespread farmer participation, in turn, strengthens the committee's governance legitimacy. This co-evolutionary mechanism offers a theoretical key to overcoming the dual dilemma of policy ineffectiveness and farmer reluctance.

2.2 Model Assumptions and Parameter System

Let the strategic choice space for the village committee be $S_1 = \{\text{Facilitate Green Production, Not Facilitate}\}$, and for agricultural producers be $S_2 = \{\text{Adopt Green Production, Not Adopt}\}$. To enhance the model's analytical rigor and practical relevance, we propose the following assumptions and establish a corresponding parameter system (Table 1):

H1: Both players are boundedly rational and aim to maximize their own expected payoffs.

H2: Among agricultural producers, the proportion that adopts green production is denoted by x; among village committees, the proportion that facilitates green production is denoted by y.

H3: Green production generates an environmental synergy benefit, Rs. This benefit is realized as additional economic value through a market-based product premium.

H4: Facilitation by the village committee incurs costs for promotion and training. The committee's payoff is tied to the final output of the agricultural producers.

Table 1: Game model parameters and their meanings.

Agent	Parameter	Meaning
Village Committee	c	The promotion and training cost coefficient required for the dissemination of clean production technology, $0 < c < 1$
	e	The proportion of benefits gained when promoting green production among agricultural producers and it is adopted, $0 < e < 1$
	R_S	Synergistic benefits arising from environmental improvement, $R_S > 0$
	R_L	Fixed income, $R_L > 0$
Agricultural Producer	C_f	The production cost per unit of agricultural product, $C_f > 0$
	C_p	Unit selling price of agricultural products, $C_p > 0$
	W	Quantity of waste per unit in the agricultural production process, $W > 0$
	P_W	Unit cost of waste disposal for agricultural producers who do not adopt green production strategies, $P_W > 0$
	R_W	Unit cost of waste disposal for agricultural producers who adopt green production strategies, $R_W > 0$
	b	Adoption rate of green production technology, $b > 0$
	f	Cost coefficient for agricultural producers to independently implement clean production strategies, $f > 0$
	d	Waste reduction coefficient, $0 < d < 1$
	Q	Scale of agricultural production, $Q > 0$
	S_f	Subsidies for agricultural production provided by the local government, $S_f > 0$
	a	Product premium coefficient after adopting green production technology, $a > 0$

2.3 Analysis of the Game Model

Based on the above assumptions, the mixed-strategy payoff matrix between agricultural producers and the village committee is derived, as presented in Table 2.

Table 2: Payoff Matrix of the Evolutionary Game

Producer Committee	**Adopt** (x)	**Not Adopt** $(1-x)$
Promote (y)	$U_f^{FA} = \pi_1$ $U_c^{FA} = \pi_3$	$U_f^{FN} = \pi_2$ $U_c^{FN} = \pi_4$
Not Promote $(1-y)$	$U_f^{NA} = \pi_5$ $U_c^{NA} = \pi_7$	$U_f^{NN} = \pi_6$ $U_c^{NN} = \pi_8$

Note: Payoffs are presented as (Farmer payoff U_f, Committee payoff U_c).
Superscript notation: FA = Facilitate-Adopt, FN = Facilitate-Not adopt,
NA = Not Facilitate-Adopt, NN = Not Facilitate-Not adopt.

Symbol definitions:

$$
\begin{aligned}
&\pi_1 = (1-e)\big[(1+a)P - b^2 C_f\big]Q - (1-d)WR_wQ + S_f,\\
&\pi_2 = (P - C_f)Q - WP_WQ,\\
&\pi_3 = e\big[(1+a)P - (1+c)b^2 C_f\big]Q + R_L + R_s,\\
&\pi_4 = R_L - cC_fQ,\\
&\pi_5 = e\big[(1+a)P - (1+f)b^2 C_f\big]Q - (1-d)WR_wQ + S_f,\\
&\pi_6 = (P - C_f)Q - WP_WQ,\\
&\pi_7 = R_L + R_s,\\
&\pi_8 = R_L.
\end{aligned}
$$

All parameters are defined in Table 1.

Following the payoff matrix and evolutionary game theory, the expected payoffs and replicator dynamics equations for both players are derived. Let E_1 and E_2 denote the expected payoffs of agricultural producers when adopting and not adopting green production, respectively, and let $\bar{E}$ be the corresponding average expected payoff. Similarly, let H_1 and H_2 represent the expected payoffs of the village committee when promoting and not promoting green production, respectively, with $\bar{H}$ being the average expected payoff. The model construction and stability analysis for the two players proceed as follows:

2.3.1 Strategy of Agricultural Producers

The expected payoff to agricultural producers from adopting green production is:

$$\begin{aligned} E_1 &= y\pi_1 + (1-y)\pi_5 \\ &= y\left((1-e)\left((1+a)P - b^2C_f\right)Q - (1-d)WR_wQ + S_f\right) \\ &+(1-y)\left(e\left((1+a)P - (1+f)b^2C_f\right)Q - (1-d)WR_wQ + S_f\right) \end{aligned} \tag{2.1}$$

The expected payoff to agricultural producers from not adopting green production is:

$$E_2 = y\pi_2 + (1-y)\pi_6 = y\left(\left(P - C_f\right)Q - WP_wQ\right) + (1-y)\left(\left(P - C_f\right)Q - WP_wQ\right) \tag{2.2}$$

The average expected payoff is:

$$\bar{E} = xE_1 + (1-x)E_2 \tag{2.3}$$

The replicator dynamics for agricultural producers is:

$$f(x) = x\left(E_1 - \bar{E}\right) = x(1-x)\left(A_f y + B_f\right) \tag{2.4}$$

where $A_f = Q\left(C_f b^2(-1+2e+ef) + P(1+a)(1-2e)\right), B_f = Q(P(e(1+a)-1) + C_f\left(1 - e(1+f)b^2\right)) + S_f + W\left(P_W - (1-d)R_w\right)Q$.

Taking the first derivative of the replicator dynamics equation of agricultural producers:

$$df(x)/dx = (1-2x)\left(A_f y + B_f\right) = (1-2x)G(y) \tag{2.5}$$

According to the stability theorem of differential equations, for the agricultural producers' strategy choice to be in a stable state, the following conditions must be satisfied: $f(x) = 0$, $df(x)/dx < 0$. Given tha $\partial G(y)/\partial y = A_f$, we have G(y)=0 when $y = -B_f/A_f$. The stability at this point is indeterminate. Let us denote this critical value as $y* = -B_f/A_f (0 < y* < 1)$. The stability analysis proceeds as follows:

Case 1: If $A_f > 0, B_f < 0$, then $G(y)$ is an increasing function. When y $< y*$, $G(y) < 0$, and $df(x)/\left.dx\right|_{x=0} < 0$. In this scenario, non-adoption of green production is the stable strategy; when $y > y*, G(y) > 0$, ang $df(x)/\left.dx\right|_{x=1} < 0$. In this scenario, adoption of green production is the stable strategy.

Case 2: If $A_f < 0, B_f > 0$, then $G(y)$ is a decreasing function. When $y < y*$, $G(y) > 0$, and $df(x)/\left.dx\right|_{x=1} < 0$. In this scenario, adoption of green production is the stable strategy; when $y > y*, G(y) < 0$, and $df(x)/\left.dx\right|_{x=0} < 0$. In this scenario, non-adoption of green production is the stable strategy.

2.3.2 Strategy of Village Committees

The expected payoff to a village committee from promoting green production among agricultural producers is:

$$\begin{aligned} H_1 &= x\pi_3 + (1-x)\pi_4 \\ &= x\left(e\left((1+a)P - b^2C_f - cb^2C_f\right)Q + R_L + R_s\right) \\ &+(1-x)\left(R_L - cC_fQ\right) \end{aligned} \tag{2.6}$$

The expected payoff to a village committee from not promoting green production among agricultural producers is:

$$H_2 = x\pi_7 + (1-x)\pi_8 = x\left(R_L + R_s\right) + (1-x)\left(R_L + R_s\right) \tag{2.7}$$

The replicator dynamics for village committees is:

$$f(y) = y\left(H_1 - \bar{H}\right) = y(1-y)\left(A_v x + B_v\right) \tag{2.8}$$

where $A_v = Q\left(e(1+a)P - e(1+c)b^2C_f + cC_f\right), B_v = -cC_fQ$.

Taking the first derivative of the replicator dynamics equation of village committees:

$$f(y)/dy = (2y-1)\left(A_vx + B_v\right) = (2y-1)J(x) \tag{2.9}$$

According to the stability theorem of differential equations, the probability of village committees choosing to lead being in a stable state must satisfy: $f(y) = 0$, $df(y)/dy < 0$. $\partial J(x)/\partial x = A_v$, when $x = -B_v/A_v, J(x) = 0$, and the stable state cannot be determined at this time. Let $x* = -B_v/A_v(0 < x* < 1)$.

Case 3: Given that $-B_v > 0$, the condition $J(x) = 0$ can only be satisfied if $A_v > 0$, in which case $J(x)$ is an increasing function. When $x < x^*$, we have $J(x) < 0$ and $df(y)/dy|_{y=0} < 0$; therefore, *non-leadership* by village committees constitutes a stable strategy.When $x > x^*$, we have $J(x) > 0$ and $df(y)/dy|_{y=1} < 0$; therefore, *leadership* by village committees constitutes a stable strategy.

2.3.3 Stability Analysis

Setting the replicator dynamics equations of both game parties to 0, i.e., $f(x) = 0$ and $f(y) = 0$, four pure-strategy equilibrium points exist in the system: $(0,0), (0,1), (1,0), (1,1)$, By solving the Jacobian matrix, the eigenvalues of each point are obtained as shown in Table 3.

Table 3: Eigenvalues of Each Equilibrium Point.

Equilibrium Point	Eigenvalue λ_1	Eigenvalue λ_2
$(0,0)$	B_f	B_v
$(0,1)$	$A_f + B_f$	$-B_v$
$(1,0)$	$-B_f$	$A_v + B_v$
$(1,1)$	$-\left(A_f + B_f\right)$	$-\left(A_v + B_v\right)$

Note: The coefficients A_f, B_f, A_v, and B_v are derived from the replicator dynamics (see Section 2.3.1 and 2.3.2). Here, A_f and B_f govern the strategic dynamics of farmers, while A_v and B_v govern those of the village committee.

According to Friedman's stability criterion, the equilibrium point (0,1) cannot be an evolutionarily stable strategy (ESS) under the condition $-B_v > 0$, the mixed-strategy equilibrium $(x*, y*)$ is a saddle point and therefore unstable.

(1) Stability of $(0,0)$: For $(0,0)$ to be a stable equilibrium, the condition $B_f < 0$ must hold. This implies that the expected payoff to farmers from green production is lower than that from traditional production, rendering adoption insufficiently beneficial.

(2) Stability of $(1,0)$: For $(1,0)$ to be a stable equilibrium, the conditions $B_f > 0$ and $A_v + B_v < 0$ must hold. This corresponds to a scenario where farmers have a positive net incentive to adopt green production $B_f > 0$, while the net payoff to village committees from providing leadership is negative $A_v + B_v < 0$, implying that the costs of leadership exceed the associated benefits.

$B_f > 0$ means that even without the leadership of village committees, farmers can still benefit from adopting green production. The driving factors may include a high government subsidy Sf, a significant savings in waste disposal costs $P_W \gg (1-d)R_w$, a sufficiently high green product premium a, and a high technical efficiency b that makes costs more controllable.

$A_v + B_v < 0$ means that the net benefit of village committees' leadership is negative. The reasons may include that the total income of green products $(1+a)P$ is insufficient to

cover the costs $(1+c)C_f b^2$, the cost coefficient c of village committees' leadership is too high, and although the profit-sharing ratio e is positive, the overall benefit is still negative, and the technical efficiency b is not high enough to achieve a sufficient cost reduction.
(3) Equilibrium $(1,1)$ (Full Cooperation): Achieving and sustaining this ideal, Pareto-efficient outcome requires the more stringent condition that the net incentive terms for both groups are positive: $A_f + B_f > 0$ and $A_v + B_v > 0$.
Condition 1 (Incentive for village committees): Under committee leadership, the requirement for farmers to gain a positive net income from adoption translates into the joint satisfaction of two inequalities:$(1+a)(1-e) > 1$ (guaranteeing a net revenue increase) and $(1-e)b^2 < 1$ (ensuring positive cost savings).
Condition 2 (Incentive for agricultural producers):For the leadership of village committees to be financially viable, the total revenue generated must cover the total cost incurred. This profitability condition is given by $(1+a)P > (1+c)C_f b^2$, which essentially requires that the economic efficiency of green production (captured by the premium a,price P, and cost parameters) is sufficiently high.
The interplay of these conditions underscores a double-threshold effect for e. An excessively small e undermines the committee's incentive ($A_v + B_v$ falls), while an excessively large e undermines the farmers' incentive ($A_f + B_f$ falls). Thus, a mutually acceptable, cooperative outcome is feasible only within a bounded interval of e. This interval defines a Pareto-optimal bargaining space, offering a concrete theoretical tool for designing policies that are both incentive-compatible and distributionally fair.

3 Numerical Simulation Analysis

To validate the theoretical analysis and visualize the evolutionary outcomes, this paper employs MATLAB to simulate the strategic interactions between the two stakeholder groups. Numerical simulations are conducted to explore the impact of key parameters.
Case 1: ESS point $(1,0)$, with parameters satisfying $B_f > 0$ and $A_v + B_v < 0$.
Let: $a = 0.3,\ b = 0.6, C_f = 15, P = 5,\ W = 1, P_w = 2, R_w = 1,\ d = 0.3,\ S_f = 8, e = 0.15, c = 0.4, R_L = 30, f = 0.2, R_s = 80, Q = 100$. In this scenario, the leadership cost incurred by the village committee exceeds its revenue.
Case 2: ESS points $(0,0)$ and $(1,1)$, with parameter assignments satisfying $A_f + B_f > 0, A_v + B_v > 0$, and $B_f < 0$. Let : $a = 0.3,\ b = 0.7, C_f = 5, P = 10,\ W = 1, P_w = 2, R_w = 1,\ d = 0.3,\ S_f = 1, e = 0.3, c = 0.3, R_L = 30, f = 0.3, R_s = 80, Q = 100$.
To escape the $(1,0)$ dilemma and steer the system toward the cooperative equilibrium $(1,1)$, the net incentive for village committees must be enhanced. This can be achieved by adjusting key parameters: reducing the production cost C_f, increasing the product price P,lowering the committee's leadership cost coefficient c, while raising both the benefit-sharing coefficient e and the technical efficiency b. The simulation results of this parametric intervention are presented in Figure 3, confirming the theoretical pathway to cooperation.
The simulation results confirm that the evolutionary trends in all three cases align with the theoretical predictions. Using Case 2 as a benchmark, we analyze the strategic interaction by varying parameters related to revenues and costs. The benefit distribution coefficient e is a pivotal factor influencing the payoffs for both players. By systematically varying e, we examine its impact on the game outcomes. As shown in Figure 4, cooperation is most

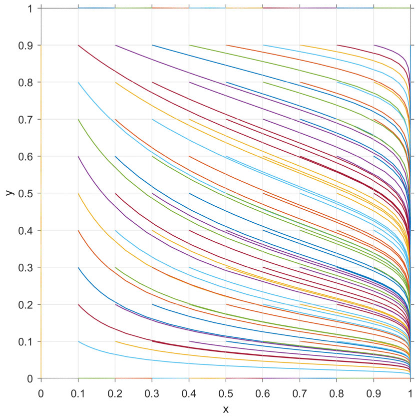

Figure 1: Simulation Results of Case 1

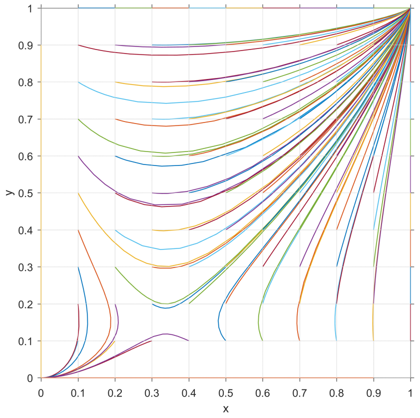

Figure 2: Simulation Results of Case 2

likely when e is moderate. Specifically, the evolutionarily stable point is $(1, 1)$ when $e \in (0.3, 0.7)$. In contrast, non-cooperative outcomes prevail when $e < 0.3$, while the system fails to converge to a stable cooperative equilibrium when $e > 0.7$.

In addition to the income and costs brought by village committees and agricultural producers themselves, there are additional benefits, such as government subsidies for agricultural producers' green production and environmental benefits brought to village committees after green production. Agricultural producers are more likely to reach a cooperative consensus with village committees under appropriate subsidies. The simulation results are shown in Figure 5.

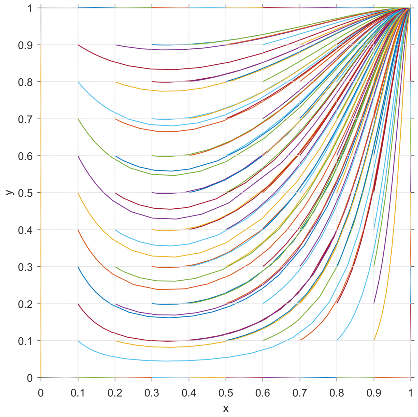

Figure 3: Simulation results of increasing revenue and reducing costs

4 Summary and Conclusion

This study constructs and analyzes an evolutionary game model between village committees and agricultural producers to reveal the micro-motivational roots and potential solutions to the green agricultural production cooperation dilemma. The findings indicate that the system's evolutionarily stable state is highly dependent on cost-benefit parameters, suggesting that simplistic administrative mandates or blanket subsidies are often insufficient to guarantee effective policy outcomes. A key theoretical contribution is the identification of a dual-threshold effectassociated with the benefit distribution coefficient e: system convergence toward the ideal cooperative equilibrium $(1, 1)$—where committees facilitate and farmers adopt green production—is most probable when e within an appropriate interval, whereas values that are too low or too high hinder the attainment of this desirable cooperative state. This quantitative insight provides a novel, actionable foundation for policy design, moving beyond generic recommendations toward targeted intervention.

The policy implications derived from the model are structured around four interconnected pillars:

(1) Designing incentive-compatible mechanisms guided by the dual-threshold interval. The identified threshold interval for the benefit distribution coefficient e offers a precise lever for crafting incentive-compatible contracts. Policymakers and local governments should guide village committees to establish benefit-sharing agreements—within cooperatives or for collective green outputs—while consciously maintaining the committee's revenue share within an appropriate range to avoid motivational collapse due to extreme imbalance. Mechanisms can also be designed to adjust e dynamically based on performance metrics such as verified environmental benefits or realized product premiums, thereby encouraging risk-sharing and strengthening incentives.

(2) Implementing classified interventions based on equilibrium diagnosis. Policy interventions must be tailored to a region's diagnosed strategic equilibrium rather than

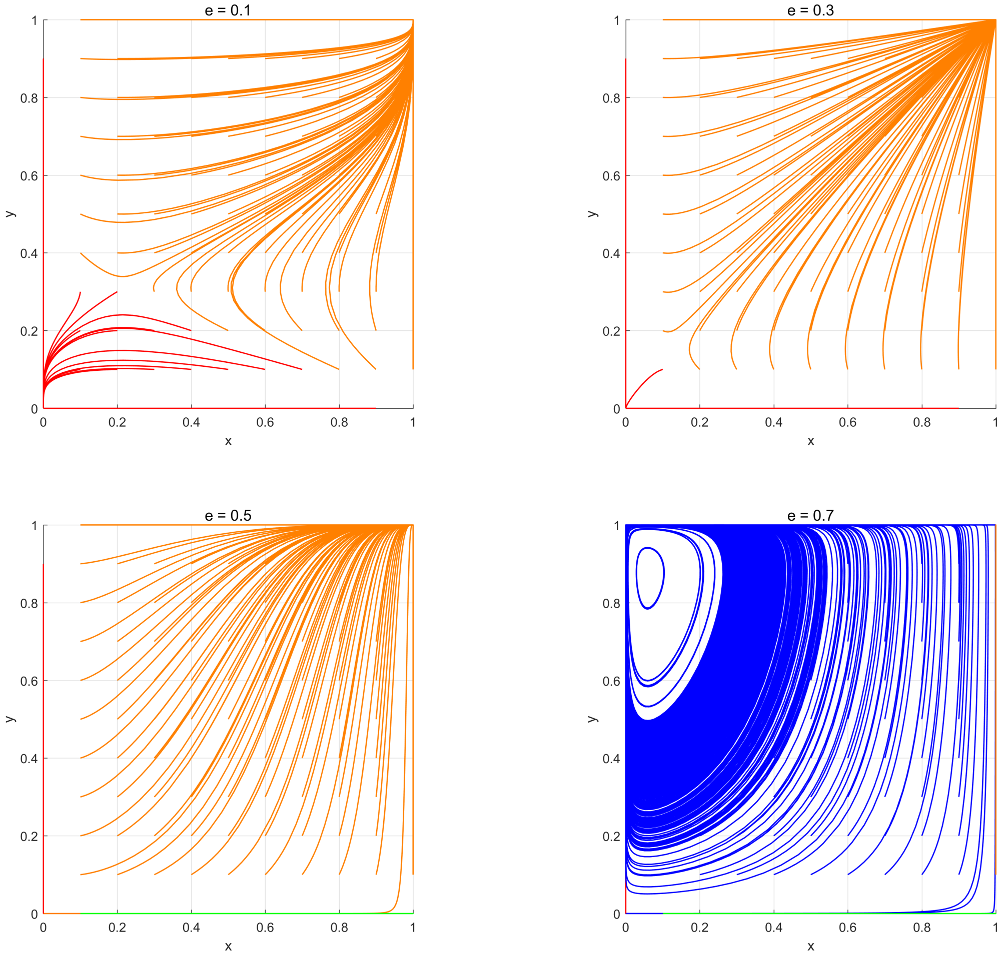

Figure 4: Simulation results of changing benefit distribution

applying uniform approaches.

- For regions near the $(1,1)$ equilibrium, policy should emphasize consolidation and upgrading, e.g., cultivating regional green brands to raise the price premium (a), diversifying market access, and promoting agro-tourism to amplify synergistic benefits (R_s).
- For regions stuck in the $(1,0)$ dilemma—where committees facilitate but farmers resist—the dual aims are to lower farmers' adoption barriers and optimize committee incentives. This can be done by raising targeted subsidies (S_f) to offset transition costs, providing technical assistance to reduce implementation complexity (f), and offering performance-based rewards or recognition to committees to compensate for promotion costs (c).

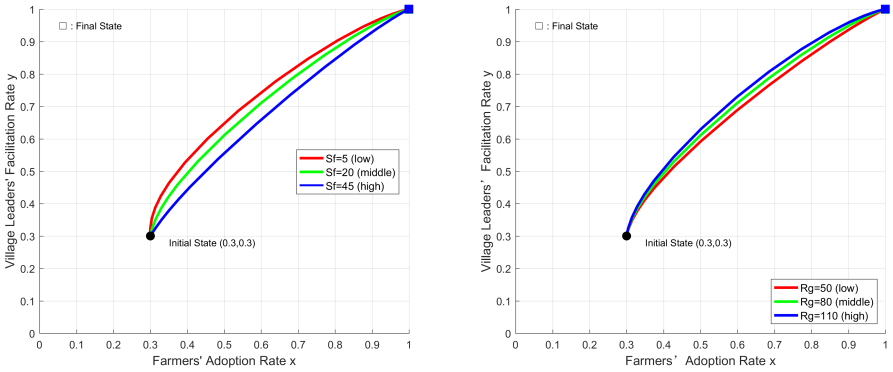

Figure 5: Simulation results for different subsidies and environmental benefits

- For regions in low-level equilibria such as $(0, 0)$, a more fundamental system reset is typically needed, often requiring higher-level government intervention to reconstitute the incentive structure through a mix of fiscal, regulatory, and institutional instruments.

(3) Assessing feasibility, challenges, and the role of non-economic factors. Translating model-based insights into practice involves both opportunities and obstacles.

- Feasibility foundations: Existing rural institutional frameworks—such as township-supervised village financial management (*cunzhang xiangguan*) and registered collective economic organizations—provide a basis for formalizing and monitoring benefit distribution. Pilot experiences from agricultural cooperatives offer practical precedents, while digital governance platforms can facilitate monitoring and dynamic parameter adjustment.

- Major challenges: Practical implementation faces hurdles including the difficulty of monetizing environmental synergies (R_s) and product premiums (a). A viable approach is to develop proxy indicator systems and focus on keeping parameters within a feasible interval rather than targeting a single precise value. Moreover, the model simplifies a multi-actor reality; effective policy must therefore incorporate robust multi-stakeholder negotiation frameworks. The dual role of village committees and market-price volatility (P) introduce additional risks, calling for complementary measures such as enhanced supervision and risk-pooling mechanisms.

- Cultivating social capital: While the model confirms the importance of government subsidies (S_f) and environmental benefits (R_s), sustainable cooperation requires moving beyond purely economic levers. Policy should also foster a sense of identity and honor linked to green production within rural social networks, leveraging social norms and reputation to promote enduring behavioral change.

(4) Limitations and future research directions. This study employs a theoretical model and numerical simulation with parameters set in plausible ranges rather than calibrated to specific empirical data. Future work should:

- Calibrate and test the model using field data from specific regions.
- Extend the framework to multi-agent, dynamic settings to capture more complex interactions.
- Explicitly incorporate network topologies to analyze how social structures influence the diffusion of green strategies, thereby enhancing the practical relevance of the findings.

In summary, advancing the green transformation of agriculture requires a deep understanding of the micro-level incentives of grassroots governance bodies and producers. This study argues for a shift from generic directives toward carefully designed “incentive engineering”, anchored in the dual-threshold logic of benefit distribution. By implementing context-sensitive, classified interventions and complementing them with supportive institutional and social measures, policymakers can foster the emergence of endogenous and sustainable cooperative orders for green production in rural communities.

Disclaimer (Artificial Intelligence)

During the preparation of this manuscript, the authors used ChatGPT (OpenAI, version 4o) for language polishing and grammatical revision. All AI-assisted edits were reviewed and approved by the authors, who take full responsibility for the final content. No AI-generated material was used in the research findings, data analysis, or conclusions.

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