

Research on Stakeholder Behavior Strategy in Green PPP Project Financing

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Abstract. In the context of green development, while promoting green industry and sustainable development, green PPP faces the challenge of financing difficulties. Based on the evolutionary game theory of bounded rationality and taking government, social capital and financial institutions as the game players, this paper constructs an evolutionary game model for the behavioral decision-making of stakeholders in green PPP project financing. Using MATLAB software, we simulate and analyze the key factors affecting the behavioral strategies of each game player. The results indicate that: (1) The additional income obtained from participation in green PPP projects is a key factor affecting the decision-making of social capital and financial institutions, so it is necessary to improve the reasonable return mechanism of green PPP projects and attach importance to the construction of reputation mechanism; (2) Government subsidies can effectively encourage social capital and financial institutions to participate in green PPP projects, but the amount of subsidies should be within a reasonable range; (3) The government's reward and punishment intensity is a significant factor affecting the decision-making of social capital behavior. To this end, it is imperative for the government to enhance the performance evaluation system for green PPP projects and establish a balanced reward and punishment mechanism. This paper puts forward some suggestions on the decision-making of stakeholders in the financing process of green PPP projects, and provides references for the policy formulation of encouraging social capital and financial institutions to participate in green PPP projects.

Keywords: Green PPP; PPP Project Financing; Stakeholders; Evolutionary Game.

1. Introduction

Green development is a crucial concept that impacts the overall development of the country and serves as a significant guarantee for achieving sustainable development. Since green industries are typically public in nature, the majority of funding is provided by the government, which places significant financial pressure on the government. Public-Private Partnership (PPP) can introduce social capital into green industries and help solve the problem of insufficient government investment. Furthermore, encouraging social capital to participate in the construction of green projects through the PPP model will help integrate the advantages of both the government and the market, ultimately enhancing the quality and efficiency of public goods. This has provided new impetus for the development of green industries.

In recent years, The State Council, the Ministry of Finance and the National Development and Reform Commission have issued a number of important documents to promote the PPP model to develop green industries, which has provided a favorable policy environment for the development of green PPP projects [1]. However, due to the long investment return period and low yield rate of green PPP projects, green PPP still faces financing difficulties. Therefore, how to coordinate the interests of all parties, promote the cooperative behavior of core stakeholders, and ultimately facilitate successful financing for green PPP projects needs to be studied.

2. Literature Review

Green PPP projects refer to the cooperation between the government and private capital to provide green technology facilities and services to the public in order to meet social development and public



demand. A more specific description is provided by the Government and Social Capital Cooperation Center of the Ministry of Finance: PPP projects that aim to support pollution prevention and control, as well as promote a green and low-carbon economic structure [2]. There have been researches on the key success factors of green PPP projects [3], risk management [4-6], financing model [7-10], incentive mechanisms and implementation [11, 12], as well as existing problems [13], etc. However, there are limited researches on the financing of green PPP projects.

Evolutionary game theory takes the behavior of finite rational groups as the research object [14], and pursues the maximization of its own interests by constantly adjusting the strategy, and finally reaches the equilibrium state of the system. At this point, the strategy is considered evolutionarily stable [15]. Zheng and lu [16] analyzed the behavioral strategies involved in improving government and social capital performance. Lu and Chen [17] studied the payment mechanism of PPP projects and considered the influence of different reward and punishment systems on the behavior strategies of the government and social capital. Wang et al. [18] included the public as one of the game players and examined the establishment of a credit mechanism during the operation of PPP projects. For green PPP projects, scholars mainly focus on government incentives and social capital participation. Gao and Zhao [19] constructed an evolutionary game model between the government and investors for PPP projects involving new energy power construction, and examined the impact of key factors on the strategic stability of these projects. Yang and Zhang [20] as well as Yang et al. [21] analyzed the strategic changes of the government and investment groups on green transformation behavior. Wang et al. [22] studied the behavioral evolution path of government and social capital's participation in construction waste recycling projects, and evaluated the impact of reward and punishment intensity as well as subsidy amounts. Chen et al. [23] analyzed the behavioral evolution process of local governments and social investors in land renovation PPP projects, and suggested establishing a reverse constraint mechanism.

Due to the large capital demand and long investment return period of green PPP projects, the participation of financial institutions is particularly important. However, although some scholars have studied the behavioral decisions of government and social capital, few studies have considered financial institutions, much less studied the financing of green PPP projects from the perspective of behavioral decisions. Therefore, based on evolutionary game theory, this paper constructs a three-party evolutionary game model in green PPP project financing, analyzes the behavioral strategy choices of each party and the impact of key factors, which can provide references for motivating social capital and financial institutions to participate in green PPP projects.

3. Methodology

3.1. Assumptions

(1) Government, social capital and financial institutions constitute a complete system. All three parties are bounded rational participants, and their strategy selection gradually evolves and stabilizes to the optimal strategy over time.

(2) The government, as the main participant of a green PPP project, plays the role of supervisor, and its policy set is (incentive policy, non-incentive policy). As an investor, social capital can choose whether to participate in green PPP projects, and its strategy set is (participate in green PPP projects, not participate in green PPP projects). As one of the important capital providers, financial institutions have a set of strategies (provide green loans, not provide green loans). The probabilities associated with the government selecting incentive policies, social capital participating in green PPP projects, and financial institutions providing green loans are denoted as x , y , and z respectively, with $x, y, z \in [0, 1]$.

(3) When social capital does not participate in green PPP projects, the basic income of the government is Rg_1 , and the additional cost of environmental transformation is Cg . When social capital participates in green PPP projects, the additional benefits they can obtain (such as environmental

benefits, good government image, etc.) are Rg_2 . Financial institutions providing green loans can bring Rg_3 to the government. When the government adopts incentive policies, the subsidy amount provided for social capital is B_1 and the supervision cost is S .

(4) The income of social capital participating in ordinary projects is Rs_1 and the basic cost is Cs_1 . Additional benefits such as good reputation gained by social capital participating in green PPP projects are Rs_2 and additional costs are Cs_2 . Additional benefits for social capital when financial institutions provide green loans are Rs_3 . According to the actual results of the project, the social capital is rewarded or punished by the government, and the reward and punishment intensity is k ($k > 0$). The goal of the project is a_0 , and the actual effect is a . The reward is $k(a - a_0)$ when the project reaches the target, and the penalty is $k(a_0 - a)$ when it fails. When social capital participates in green PPP projects, but financial institutions do not provide loans, the loss of social capital is P_1 .

(5) The financial institution's income when providing loans for general projects is Rd_1 and the cost is Cd_1 . The additional cost of providing a loan for a green PPP project is Cd_2 and the additional benefits such as good reputation obtained are Rd_2 . The subsidy and other benefits provided to financial institutions when the government takes incentive measures are B_2 . When financial institutions provide green loans but social capital doesn't participate in green PPP projects, the loss of financial institutions is L_1 . The main parameters of the model are shown in Table 1.

Table 1. Parameter setting of tripartite evolutionary game model

Parameter	Definition	Parameter	Definition
Rg_1	The basic income of the government	Cd_1	Cost when financial institutions provide loans for general projects
Rg_2	Additional benefits for the government when social capital participates in green PPP projects	Cd_2	Additional costs when financial institutions provide green loans
Rg_3	Additional benefits for the government when financial institutions provide green loans	B_1	The amount of subsidy provided to social capital when the government takes incentives
Rs_1	Income when social capital participates in ordinary projects	S	The cost of regulation when the government takes incentives
Rs_2	Additional benefits when social capital participates in green PPP projects	k	The reward and punishment intensity when the government takes incentive measures
Rs_3	Additional benefits for social capital when financial institutions provide green loans	a	The actual results of green PPP projects
Rd_1	Income when financial institutions provide loans for general projects	a_0	The goal that green PPP projects should achieve
Rd_2	Additional benefits for financial institutions when providing green loans	B_2	The subsidy and other benefits provided to financial institutions
Cg	Additional cost of environmental improvement paid by the government when social capital does not participate in green PPP projects	P_1	Additional losses when social capital participates in green PPP projects but financial institutions do not provide loans
Cs_1	Cost when social capital participates in ordinary projects	L_1	Additional losses when financial institutions provide green loans but social capital does not participate in green PPP projects
Cs_2	Additional costs paid when social capital participates in green PPP projects		

3.2. Evolutionary Game Models

Based on the above assumptions, the payment matrix of tripartite evolutionary game model is constructed, as shown in Table 2.

Table 2. Payment matrix of tripartite evolutionary game model Payment matrix under incentive policy (x)

		financing institutions	
		provide green loans(z)	not provide green loans(1-z)
social capital	participate in green PPP projects(y)	$Rg_1 + Rg_2 + Rg_3 - B_1 - S - k(a - a_0) - B_2$	$Rg_1 + Rg_2 - B_1 - S - k(a - a_0)$
		$Rs_1 + Rs_2 + Rs_3 - Cs_1 - Cs_2 + B_1 + k(a - a_0)$	$Rs_1 + Rs_2 - Cs_1 - Cs_2 + B_1 + k(a - a_0) - P_1$
		$Rd_1 + Rd_2 - Cd_1 - Cd_2 + B_2$	$Rd_1 - Cd_1$
	not participate in green PPP projects(1-y)	$Rg_1 + Rg_3 - Cg - B_1 - S - B_2$	$Rg_1 - Cg - B_1 - S - B_2$
		$Rs_1 - Cs_1$	$Rs_1 - Cs_1$
		$Rd_1 + Rd_2 - Cd_1 - Cd_2 + B_2 - L_1$	$Rd_1 - Cd_1$

Payment matrix under non-incentive policy (1-x)

		financing institutions	
		provide green loans(z)	not provide green loans (1-z)
social capital	participate in green PPP projects(y)	$Rg_1 + Rg_2 + Rg_3$	$Rg_1 + Rg_2$
		$Rs_1 + Rs_2 + Rs_3 - Cs_1 - Cs_2$	$Rs_1 + Rs_2 - Cs_1 - Cs_2 - P_1$
		$Rd_1 + Rd_2 - Cd_1 - Cd_2$	$Rd_1 - Cd_1$
	not participate in green PPP projects (1-y)	$Rg_1 + Rg_3 - Cg$	$Rg_1 - Cg$
		$Rs_1 - Cs_1$	$Rs_1 - Cs_1$
		$Rd_1 + Rd_2 - Cd_1 - Cd_2 - L_1$	$Rd_1 - Cd_1$

3.3. Evolutionary Dynamics

3.3.1. Strategic Stability Analysis of Government

Suppose that the expected return when the government chooses "incentive policy" is E_{11} , and the expected return when it chooses "non-incentive policy" is E_{12} . The average expected return for the government is E_1 .

$$E_{11} = yz[Rg_1 + Rg_2 + Rg_3 - B_1 - S - k(a - a_0) - B_2] + y(1 - z)[Rg_1 + Rg_2 - B_1 - S - k(a - a_0)] + z(1 - y)(Rg_1 + Rg_3 - Cg - B_1 - S - B_2) + (1 - y)(1 - z)(Rg_1 - Cg - B_1 - S - B_2) \quad (1)$$

$$E_{12} = yz(Rg_1 + Rg_2 + Rg_3) + y(1 - z)(Rg_1 + Rg_2) + z(1 - y)(Rg_1 + Rg_3 - Cg) + (1 - y)(1 - z)(Rg_1 - Cg) \quad (2)$$

$$E_1 = xE_{11} + (1 - x)E_{12} \quad (3)$$

Therefore, the government's replication dynamic equation is:

$$F(x) = dx/dt = x(x - 1)(B_1 + B_2 + S - yB_2 + yzB_2 + ky(a - a_0)) \quad (4)$$

$$d(F(x))/dx = (2x - 1)(B_1 + B_2 + S - yB_2 + yzB_2 + ky(a - a_0)) \quad (5)$$

$$G(z) = B_1 + B_2 + S + ky(a - a_0) - yB_2 + yzB_2 \quad (6)$$

If $G(z) = 0$, we can get, when $z = \frac{y(B_2 - k(a - a_0)) - B_1 - B_2 - S}{yB_2} = z^*$, $d(F(x))/dx \equiv 0$.

Corollary 1: The probability of the government adopting non-incentive policy decreases with the increase of the probability of social capital participating in green PPP projects and the probability of financial institutions providing green loans.

Proof: Since $G'(z) > 0$, $G(z)$ is an increasing function with respect to z . When $z > z^*$ and $y > \frac{B_1+B_2+S}{B_2-k(a-a_0)}$, $d(F(x))/dx|_{x=0} < 0$ and $d(F(x))/dx|_{x=1} > 0$, so $x = 0$ is the government's evolutionary stability strategy. Otherwise, $x = 1$ is the government's evolutionary stability strategy.

Then we construct the phase diagram of government's strategy evolution. Assuming that the probability that the government adopts non-incentive policy is V_{A1} , and the probability that the government adopts incentive policy is V_{A2} , we can calculate:

$$V_{A1} = \int_0^1 \int_{\frac{B_1+B_2+S}{B_2-k(a-a_0)}}^1 z^* dx dy = \frac{B_1+B_2+S}{B_2} \ln \frac{B_1+B_2+S}{B_2-k(a-a_0)} \quad (7)$$

$$V_{A2} = 1 - V_{A1} = 1 - \frac{B_1+B_2+S}{B_2} \ln \frac{B_1+B_2+S}{B_2-k(a-a_0)} \quad (8)$$

Corollary 2: The probability of the government adopting incentive policy is positively related to the goals set by the project and negatively related to the government's regulatory costs, the amount of subsidies provided to social capital and financial institutions, and the actual effectiveness of the green PPP project. And the relationship with the government's reward and punishment intensity is influenced by a variety of factors.

Proof: taking first order partial derivatives for each parameter of V_{A2} separately, we can get: $\frac{\partial V_{A2}}{\partial a_0} > 0$, $\frac{\partial V_{A2}}{\partial a} < 0$, $\frac{\partial V_{A2}}{\partial B_2} < 0$, $\frac{\partial V_{A2}}{\partial S} < 0$, $\frac{\partial V_{A2}}{\partial B_1} < 0$, $\frac{\partial V_{A2}}{\partial k} > 0$ ($a < a_0$ or $k(a - a_0) > B_2$). Therefore, when $a < a_0$ or $k(a - a_0) > B_2$, as k increases, V_{A2} increases. In addition, with the increase of a_0 and the decrease of B_1 , B_2 , S and a , the probability of government adopting incentive policy will increase.

3.3.2. Strategic Stability Analysis of Social Capital

Suppose that the expected return of social capital choosing "participate in green PPP projects" is E_{21} , and the expected return of choosing "not participate in green PPP projects" is E_{22} . The average expected return of social capital is E_2 .

$$E_{21} = xz[Rs_1 + Rs_2 + Rs_3 - Cs_1 - Cs_2 + B_1 + k(a - a_0)] + x(1 - z)[Rs_1 + Rs_2 - Cs_1 - Cs_2 + B_1 + k(a - a_0) - P_1] + z(1 - x)(Rs_1 + Rs_2 + Rs_3 - Cs_1 - Cs_2) + (1 - x)(1 - z)(Rs_1 + Rs_2 - Cs_1 - Cs_2 - P_1) \quad (9)$$

$$E_{22} = xz(Rs_1 - Cs_1) + x(1 - z)(Rs_1 - Cs_1) + z(1 - x)(Rs_1 - Cs_1) + (1 - x)(1 - z)(Rs_1 - Cs_1) = Rs_1 - Cs_1 \quad (10)$$

$$E_2 = yE_{21} + (1 - y)E_{22} \quad (11)$$

Therefore, the replication dynamic equation of social capital is:

$$F(y) = dy/dt = -y(y - 1)(Rs_2 - P_1 - Cs_2 + xB_1 + zP_1 + zRs_3 + kx(a - a_0)) \quad (12)$$

$$d(F(y))/dy = (1 - 2y)(Rs_2 - P_1 - Cs_2 + xB_1 + zP_1 + zRs_3 + kx(a - a_0)) \quad (13)$$

$$H(z) = Rs_2 - P_1 - Cs_2 + xB_1 + zP_1 + zRs_3 + kx(a - a_0) \quad (14)$$

If $H(z) = 0$, we can get, when $z = \frac{Cs_2+P_1-Rs_2-xB_1-kx(a-a_0)}{Rs_3+P_1} = z^{**}$, $d(F(y))/dy \equiv 0$.

Corollary 3: The probability of social capital participating in green PPP projects increases with the probability of government adopting incentive policy and the probability of financial institutions providing green loans.

Proof: Since $H'(z) > 0$, $H(z)$ is an increasing function with respect to z . When $z > z^{**}$ and $x > \frac{Cs_2+P_1-Rs_2}{B_1+k(a-a_0)}$, $d(F(y))/dy|_{y=1} < 0$ and $d(F(y))/dy|_{y=0} > 0$, so $y = 1$ is the evolutionarily stable strategy of social capital. When $z < z^{**}$ and $x < \frac{Cs_2+P_1-Rs_2}{B_1+k(a-a_0)}$, $d(F(y))/dy|_{y=0} < 0$ and $d(F(y))/dy|_{y=1} > 0$, so $y = 0$ is the evolutionarily stable strategy of social capital.

Then we construct the strategy evolution phase map of social capital. Assuming that the probability that social capital participates in green PPP projects is V_{B1} , and the probability that social capital does not participate in green PPP projects is V_{B2} , we can calculate:

$$V_{B2} = \int_0^1 \int_0^{\frac{Cs_2+P_1-Rs_2}{B_1+k(a-a_0)}} z^{**} dx dy = \frac{(Cs_2+P_1-Rs_2)^2}{2(Rs_3+P_1)} \quad (15)$$

$$V_{B1} = 1 - V_{B2} = 1 - \frac{(Cs_2+P_1-Rs_2)^2}{2(Rs_3+P_1)} \quad (16)$$

Corollary 4: The probability of social capital participating in green PPP projects is positively correlated with the additional benefits of social capital participating in green PPP projects and the benefits brought to social capital by green loans provided by financial institutions, while it is negatively correlated with the additional costs of social capital participating in green PPP projects and the losses caused by financial institutions not providing loans.

Proof: taking first order partial derivatives for each parameter of V_{B1} separately, we can get: $\frac{\partial V_{B1}}{\partial Rs_2} > 0$, $\frac{\partial V_{B1}}{\partial Rs_3} > 0$, $\frac{\partial V_{B1}}{\partial Cs_2} < 0$, $\frac{\partial V_{B1}}{\partial P_1} < 0$. Therefore, the increase of Rs_2 and Rs_3 and the decrease of Cs_2 and P_1 can increase the probability of social capital participating in green PPP projects.

3.3.3. Strategic Stability Analysis of Financial Institutions

Suppose that the expected return of financial institutions choosing "provide green loans" is E_{31} , and the expected return of choosing "not provide green loans" is E_{32} . The average expected return of financial institutions is E_3 .

$$E_{31} = xy(Rd_1 + Rd_2 - Cd_1 - Cd_2 + B_2) + x(1-y)(Rd_1 + Rd_2 - Cd_1 - Cd_2 + B_2 - L_1) + (1-x)y(Rd_1 + Rd_2 - Cd_1 - Cd_2) + (1-x)(1-y)(Rd_1 + Rd_2 - Cd_1 - Cd_2 - L_1) \quad (17)$$

$$E_{32} = xy(Rd_1 - Cd_1) + x(1-y)(Rd_1 - Cd_1) + (1-x)y(Rd_1 - Cd_1) + (1-x)(1-y)(Rd_1 - Cd_1) \quad (18)$$

$$E_3 = zE_{31} + (1-z)E_{32} \quad (19)$$

Therefore, the replication dynamic equation for financial institutions is:

$$F(z) = dz/dt = -z(z-1)(Rd_2 - L_1 - Cd_2 + xB_2 + yL_1) \quad (20)$$

$$d(F(z))/dz = (1-2z)(Rd_2 - L_1 - Cd_2 + xB_2 + yL_1) \quad (21)$$

$$I(x) = Rd_2 - L_1 - Cd_2 + xB_2 + yL_1 \quad (22)$$

If $I(x) = 0$, we can get, when $x = \frac{Cd_2+L_1-Rd_2-yL_1}{B_2} = x^*$, $d(F(z))/dz \equiv 0$.

Corollary 5: The probability of financial institutions providing green loans increases with the probability of government adopting incentive policy and the probability of social capital participating in green PPP projects.

Proof: Since $I'(x) > 0$, $I(x)$ is an increasing function with respect to x . When $x > x^*$ and $y > \frac{Cd_2+L_1-Rd_2}{L_1}$, $d(F(z))/dz|_{z=1} < 0$ and $d(F(z))/dz|_{z=0} > 0$, so $z = 1$ is the evolutionary stability strategy of financial institutions. When $x < x^*$ and $y < \frac{Cd_2+L_1-Rd_2}{L_1}$, $d(F(z))/dz|_{z=0} < 0$ and $d(F(z))/dz|_{z=1} > 0$, so $z = 0$ is the evolutionary stability strategy of financial institutions.

Then we construct the strategy evolution phase diagram of financial institutions. Assuming that the probability of financial institutions providing green loans is V_{C1} , and the probability of not providing green loans is V_{C2} , we can calculate:

$$V_{C2} = \int_0^1 \int_0^{\frac{Cd_2+L_1-Rd_2}{L_1}} x^* dydz = \frac{(Cd_2+L_1-Rd_2)^2}{2B_2L_1} \quad (23)$$

$$V_{C1} = 1 - V_{C2} = 1 - \frac{(Cd_2+L_1-Rd_2)^2}{2B_2L_1} \quad (24)$$

Corollary 6: The probability of financial institutions providing green loans is positively correlated with the additional benefits of financial institutions providing green loans and the amount of subsidies provided by the government, but negatively correlated with the additional cost of financial institutions providing green loans and the loss caused by social capital not participating in green PPP projects.

Proof: taking first order partial derivatives for each parameter of V_{C1} separately, we can get: $\frac{\partial V_{C1}}{\partial Rd_2} > 0$, $\frac{\partial V_{C1}}{\partial B_2} > 0$, $\frac{\partial V_{C1}}{\partial Cd_2} < 0$, $\frac{\partial V_{C1}}{\partial L_1} < 0$. Therefore, the increase of Rd_2 and B_2 and the decrease of Cd_2 and L_1 can increase the probability of financial institutions providing green loans.

3.3.4. Equilibrium Point Analysis and Stability Discussion

If $F(x) = 0$, $F(y) = 0$, $F(z) = 0$, 8 pure strategy equilibrium points can be obtained: $E_1(0, 0, 0)$, $E_2(1, 0, 0)$, $E_3(0, 1, 0)$, $E_4(0, 0, 1)$, $E_5(1, 1, 0)$, $E_6(1, 0, 1)$, $E_7(0, 1, 1)$, $E_8(1, 1, 1)$. According to the method proposed by Friedman [24], the evolutionary stability strategy of a differential equation system can be obtained from the local stability analysis of the Jacobian matrix of the system. The equilibrium point satisfying that all the eigenvalues of the Jacobian matrix are non-positive is the evolution-stable point of the system.

Table 3. Stability of equilibrium points

Equilibrium point	Characteristic value $\beta_1, \beta_2, \beta_3$	Stability	Condition
$E_1(0, 0, 0)$	$-(B_1 + B_2 + S), Rs_2 - P_1 - Cs_2, Rd_2 - L_1 - Cd_2$	ESS	(1)
$E_2(1, 0, 0)$	$B_1 + B_2 + S, Rs_2 - P_1 - Cs_2 + B_1 + k(a - a_0), Rd_2 - L_1 - Cd_2 + B_2$	unstable	
$E_3(0, 1, 0)$	$-(B_1 + S + k(a - a_0)), -(Rs_2 - P_1 - Cs_2), Rd_2 - Cd_2$	ESS	(2)
$E_4(0, 0, 1)$	$-(B_1 + B_2 + S), Rs_2 - Cs_2 + Rs_3, -(Rd_2 - L_1 - Cd_2)$	ESS	(3)
$E_5(1, 1, 0)$	$B_1 + S + k(a - a_0), P_1 + Cs_2 - B_1 - Rs_2 - k(a - a_0), B_2 + Rd_2 - Cd_2$	ESS	(4)
$E_6(1, 0, 1)$	$B_1 + B_2 + S, Rs_2 + Rs_3 - Cs_2 + B_1 + k(a - a_0), -(Rd_2 - L_1 - Cd_2 + B_2)$	unstable	
$E_7(0, 1, 1)$	$-(B_1 + B_2 + S + k(a - a_0)), -(Rs_2 - Cs_2 + Rs_3), -(Rd_2 - Cd_2)$	ESS	(5)
$E_8(1, 1, 1)$	$B_1 + B_2 + S + k(a - a_0), Cs_2 - Rs_3 - Rs_2 - B_1 - k(a - a_0), -(B_2 + Rd_2 - Cd_2)$	ESS	(6)

Condition: (1) $Rs_2 - P_1 - Cs_2 < 0$, $Rd_2 - L_1 - Cd_2 < 0$; (2) $B_1 + S + k(a - a_0) > 0$, $Rs_2 - P_1 - Cs_2 > 0$, $Rd_2 - Cd_2 < 0$; (3) $Rs_2 - Cs_2 + Rs_3 < 0$, $Rd_2 - L_1 - Cd_2 > 0$; (4) $B_1 + S + k(a - a_0) < 0$, $P_1 + Cs_2 - B_1 - Rs_2 - k(a - a_0) < 0$, $B_2 + Rd_2 - Cd_2 < 0$; (5) $B_1 + B_2 + S + k(a - a_0) > 0$, $Rs_2 - Cs_2 + Rs_3 > 0$, $Rd_2 - Cd_2 > 0$; (6) $B_1 + B_2 + S + k(a - a_0) < 0$, $Cs_2 - Rs_3 - Rs_2 - B_1 - k(a - a_0) < 0$, $B_2 + Rd_2 - Cd_2 > 0$.

Through calculation, the eigenvalues of the Jacobian matrix can be obtained as follows: $\beta_1 = (2x - 1)(B_1 + B_2 + S - yB_2 + yzB_2 + ky(a - a_0))$, $\beta_2 = (1 - 2y)(Rs_2 - P_1 - Cs_2 + xB_1 + zP_1 + zRs_3 + xk(a - a_0))$, $\beta_3 = (1 - 2z)(Rd_2 - L_1 - Cd_2 + xB_2 + yL_1)$. According to Lyapunov criterion, the equilibrium point is Evolutionarily Stable Strategy (ESS) when all the eigenvalues of

the equilibrium point are negative. When the eigenvalues of the equilibrium point are not all negative, the equilibrium point is an unstable point. Therefore, the stability of each equilibrium point is obtained through analysis, as shown in Table 3.

The six situations under different conditions are analyzed as follows:

Situation 1: When the sum of the additional cost of participating in green PPP projects and the loss caused by financial institutions not providing loans is greater than the additional gain, social capital chooses "not participate in green PPP projects". When the sum of the additional cost of providing green loans and the loss caused by non-participation of social capital is greater than the additional income, financial institutions choose to "not provide green loans". In this case, the evolutionary stability strategy of the system is $(0, 0, 0)$.

Situation 2: When the sum of supervision cost and the amount of subsidies given to social capital is greater than the reward and punishment cost, the government chooses "non-incentive policy". When the additional benefits of participating in green PPP projects are greater than the additional costs and losses caused by financial institutions not providing loans, social capital chooses to "participate in green PPP projects". When the additional benefits from providing green loans are less than the increased costs, financial institutions choose to "not provide green loans". In this case, the evolutionary stability strategy of the system is $(0, 1, 0)$.

Situation 3: When the sum of the additional benefits obtained by participating in green PPP projects and the benefits brought by green loans is less than the additional cost, social capital chooses "not participate in green PPP projects". When the additional benefits of providing green loans are greater than the additional costs and losses caused by non-participation of social capital, financial institutions choose to "provide green loans". In this case, the evolutionary stability strategy of the system is $(0, 0, 1)$.

Situation 4: When the sum of supervision cost and subsidy cost is less than the reward and punishment cost, the government chooses "incentive policy". When the sum of the additional benefits and government subsidies of participating in green PPP projects is greater than the sum of the additional costs, government penalties for failing to meet the targets, and losses caused by financial institutions not providing loans, social capital chooses to "participate in green PPP projects". When the sum of the additional income and government subsidies of providing green loans is less than the additional cost, financial institutions choose "not provide green loans". In this case, the evolutionarily stable strategy of the system is $(1, 1, 0)$.

Situation 5: When the sum of supervision cost and subsidy cost is greater than the reward and punishment cost, the government chooses "non-incentive policy". When the sum of the additional benefits of participating in green PPP projects and the benefits brought by green loans is greater than the additional costs, social capital chooses to "participate in green PPP projects". When the additional benefits of providing green loans are greater than the additional costs, financial institutions choose to "provide green loans". In this case, the evolutionarily stable strategy of the system is $(0, 1, 1)$.

Situation 6: When the sum of supervision cost and subsidy cost is less than the cost of reward and punishment, the government chooses "incentive policy". When the sum of the additional benefits of participating in green PPP projects, the benefits brought by green loans and government subsidies is greater than the additional costs and government penalties for not meeting the targets, social capital chooses to "participate in green PPP projects". When the sum of the additional benefits and government subsidies is greater than the additional cost, financial institutions choose to "provide green loans". In this case, the evolutionary stability strategy of the system is $(1, 1, 1)$.

4. Numerical Simulation

For the above six stability strategy combinations, numerical simulation analysis is carried out using MATLAB2021b software to verify the effectiveness of evolutionary stability and analyze the influence of key parameters on the strategy selection of all parties.

4.1. Evolutionarily Stable Strategy

We set up six arrays, each of which satisfies six conditions in Table 3: $B_1 = 20, S = 10, k = 100, a = 0.6, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 90, Rd_2 = 30, Cd_2 = 45, L_1 = 5, P_1 = 5$; $B_1 = 20, S = 10, k = 100, a = 1, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 50, Rd_2 = 30, Cd_2 = 45, L_1 = 5, P_1 = 5$; $B_1 = 20, S = 10, k = 100, a = 0.6, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 90, Rd_2 = 30, Cd_2 = 20, L_1 = 5, P_1 = 5$; $B_1 = 20, S = 5, k = 100, a = 0.6, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 50, Rd_2 = 30, Cd_2 = 45, L_1 = 5, P_1 = 5$; $B_1 = 20, S = 10, k = 100, a = 1, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 50, Rd_2 = 30, Cd_2 = 20, L_1 = 5, P_1 = 5$; $B_1 = 20, S = 10, k = 100, a = 0.5, a_0 = 1, B_2 = 10, Rs_2 = 80, Rs_3 = 6, Cs_2 = 50, Rd_2 = 30, Cd_2 = 20, L_1 = 5, P_1 = 5$. By evolutionary simulation of the six arrays, we can obtain six system evolution diagrams, as shown in Fig. 1. It can be seen that the simulation results are consistent with the previous model analysis.

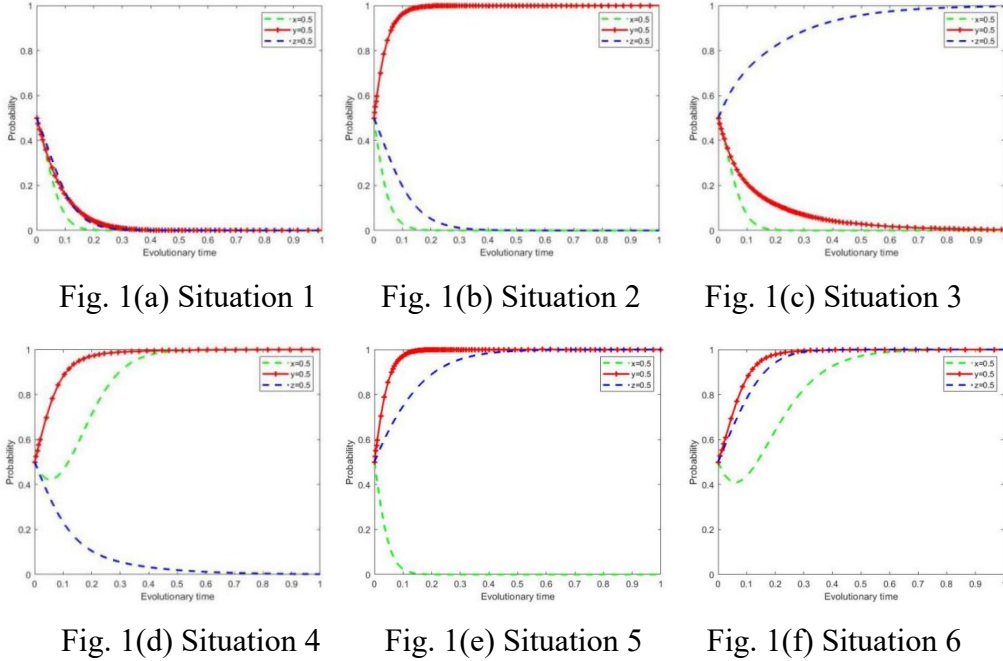


Fig 1. Time evolution diagram of tripartite game players under different situations

4.2. Influence of Initial Strategy on System Evolution Path

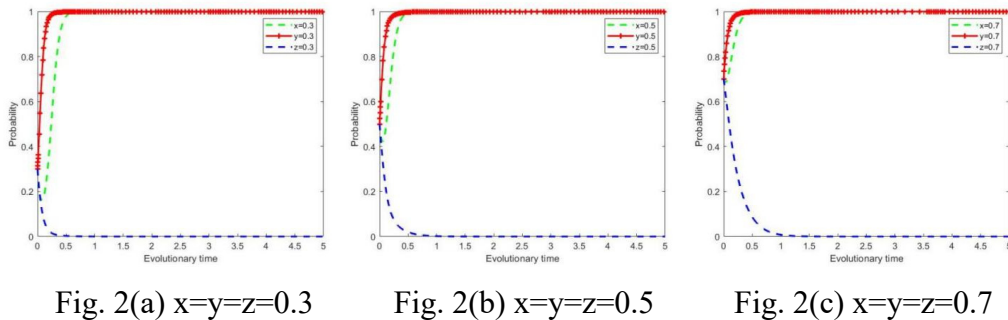


Fig 2. Time evolution diagram of different initial strategies

Based on array 4, this paper discusses the effects of different initial strategies on system evolution. In each figure, the horizontal axis represents the evolution time t , which ranges from 0 to 5, and the vertical axis represents the strategy selection probability of each game player, which ranges from 0 to 1. Three cases where the initial strategies of all parties are simultaneously 0.3, 0.5 and 0.7 are simulated respectively, and the evolution process is shown in Fig. 2.

4.3. Influences of Key Parameters on System Evolution Path

Based on array 4, this paper will separately analyze the impact of key parameters on the system evolution, including government subsidy amount, reward and punishment intensity, additional income of social capital participating in green PPP projects, and additional income of financial institutions providing green loans.

4.3.1. Analysis of Government Subsidies to Social Capital and Financial Institutions

Keep other parameters unchanged and set B_1 as 20, 30 and 40 respectively. The simulation results are shown in Fig. 3. With the increase of B_1 , the rate at which the government converges to the "incentive policy" strategy will slow down, while the rate at which social capital converges to the "participation in green PPP projects" strategy and the rate at which financial institutions converge to the "not providing green loans" strategy will speed up. It can be seen that the change of subsidy amount has an impact on the strategic choice of the three parties. When the subsidy amount is large enough, the cost of the government incentive exceeds its benefits, and the government will choose the "non-incentive policy".

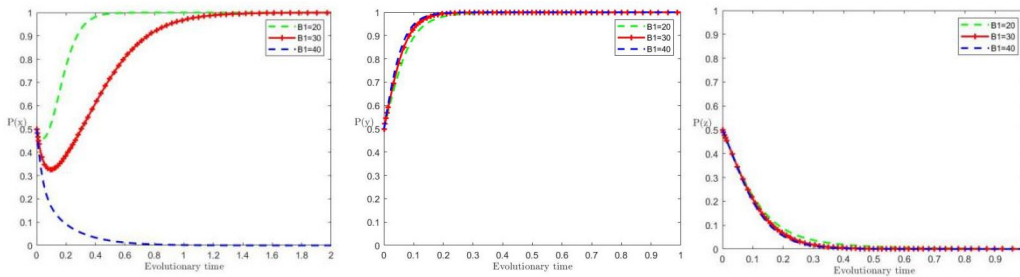


Fig. 3(a) government

Fig. 3(b) social capital

Fig. 3(c) financial institution

Fig 3. The effect of subsidy amount B_1 on the evolution strategy of each entity

Keep other parameters unchanged and set B_2 as 5, 9 and 14 respectively. The simulation results are shown in Fig. 4. With the increase of B_2 , the rate at which the government converges to the "incentive policy" strategy will slow down, and the probability of financial institutions converging to "not providing green loans" will decrease. When subsidy amount B_2 is increased enough to fully cover the net losses of financial institutions, they will choose to provide green loans.

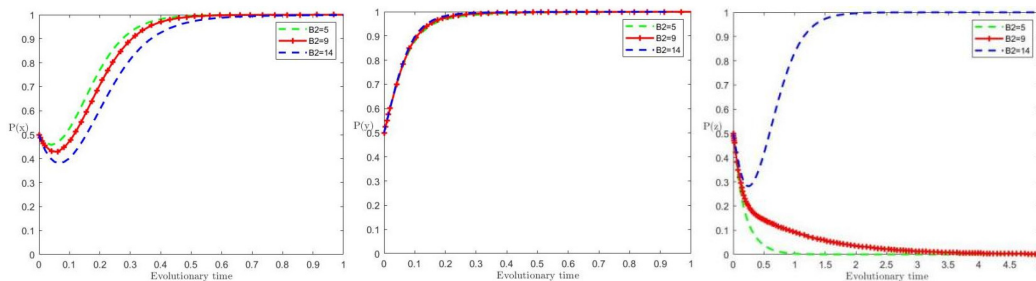


Fig. 4(a) government

Fig. 4(b) social capital

Fig. 4(c) financial institution

Fig 4. The effect of subsidy amount B_2 on the evolution strategy of each entity

4.3.2. Analysis of the Government's Reward and Punishment Intensity

Keep other parameters unchanged and set k as 100, 105 and 110 respectively. The simulation results are shown in Fig. 5. We can see that the change of reward and punishment intensity k mainly affects

the strategic choice of the government and social capital. Since $a < a_0$ at this time, the actual effect of the project is less than the goal of the project. So the government will punish the social capital, and the penalty amount is $k(a < a_0)$. Therefore, when the reward and punishment intensity k increases, the government's willingness to adopt incentive policies increases, while the willingness of social capital to participate in green PPP projects decreases. When the penalty exceeds the net benefit of its participation in the project, social capital will choose not to participate.

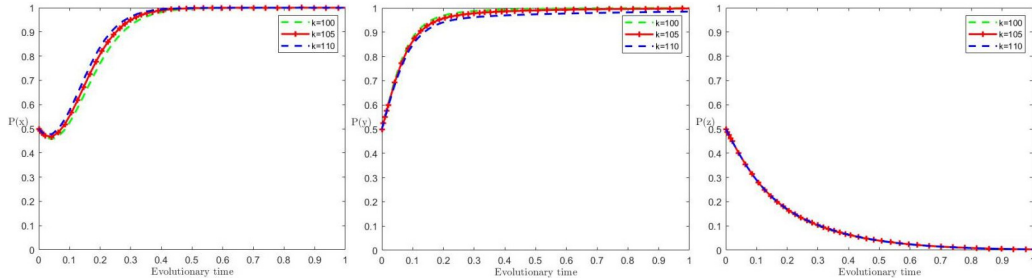


Fig. 5(a) government

Fig. 5(b) social capital

Fig. 5(c) financial institution

Fig 5. The effect of reward and punishment intensity k on the evolution strategy of each entity

4.3.3. Analysis of Additional Benefits of Social Capital and Financial Institutions Participating in Green PPP Projects

Keep other parameters unchanged and set Rs_2 as 80, 90 and 100 respectively. The evolution result of social capital is shown in Fig. 6. It can be seen that as additional benefit Rs_2 increases, the net income that social capital can obtain also increases. Therefore, the evolution rate at which social capital converges to the "participation in green PPP projects" strategy significantly speed up.

Keep other parameters unchanged and set Rd_2 as 30, 40, and 50 respectively. The evolution result of financial institution is shown in Fig. 7. It can be seen that as additional benefit Rd_2 increases, the net income received by financial institutions increases, so they are more willing to provide green loans. When the additional benefit Rd_2 increases so that the benefit of providing green loans exceeds the cost, financial institutions will converge to the strategy of "providing green loans".

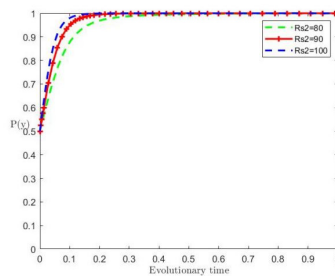


Fig 6. The impact of additional benefit Rs_2 on the strategies for social capital

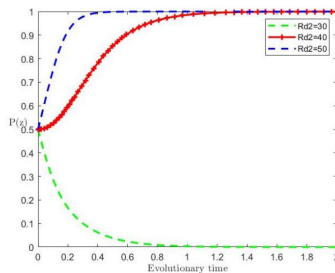


Fig 7. The impact of additional benefit Rd_2 on the strategies for financial institutions

5. Conclusion

Aiming at the financing problem of green PPP projects, this paper constructs a tripartite evolutionary game model of government, social capital and financial institutions, and analyzes the stability of the

system equilibrium strategy combination. Then the sensitivity of the parameters is analyzed by numerical simulation. The main conclusions are as follows:

(1) The additional income of social capital and financial institutions participating in green PPP projects is a key factor in determining their behavioral decisions. When its participation in green PPP projects has higher corporate image, good reputation and other additional benefits, social capital and financial institutions have sufficient motivation to participate. Even if the government does not adopt incentives, social capital and financial institutions will choose to participate in the project. Therefore, in order to increase its additional benefits and improve the enthusiasm of social capital and financial institutions, it should be carried out in the following aspects: first, establish a reasonable return mechanism for green PPP projects, innovate the construction and operation mode of green PPP projects, and expand the revenue channels of projects; The second is to establish a market reputation mechanism, give more cooperation opportunities and support to enterprises with good reputation, and punish and expose enterprises with bad reputation; The third is to enrich the channels for social supervision and reporting, report and expose illegal enterprises, and publicize and commend enterprises with good social and environmental benefits.

(2) The government subsidies have a positive impact on the participation of social capital and financial institutions in green PPP projects, but the amount of subsidies needs to be within a reasonable range. Although increasing government subsidies can improve the enthusiasm of social capital and financial institutions to participate in green PPP projects, excessive subsidies will increase the financial pressure on the government, resulting in government benefits less than the cost. Then the government chooses "non-incentive policy". Therefore, the government should adopt more flexible and diverse incentive methods, establish a dynamic incentive mechanism, and make dynamic adjustments according to the operation of the project and the willingness of the incentive parties to participate actively, so as to reduce the government's financial expenditure.

(3) The government's reward and punishment intensity is an important factor affecting the decision-making of social capital behavior. When the actual effect of the project is greater than the project target, the government will give corresponding rewards to social capital. At this time, the greater the rewards and punishments, the higher the willingness of social capital to participate in green PPP projects. On the contrary, when the actual effect of the project cannot reach the project goal, the government will punish social capital. The greater the reward and punishment, the lower the willingness of social capital to participate. Therefore, the government should improve the project performance evaluation mechanism. On the one hand, the performance evaluation system of green PPP projects should be more comprehensive, considering the impact of the project on the public, society and the environment, and the evaluation index of each content should be clearly defined. On the other hand, a reasonable reward and punishment coefficient should be set, and the reward or punishment should be adjusted according to the results of the performance assessment of green PPP projects.

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