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# Evolutionary Game between the Crowdfunding Initiators and Crowdfunding Investors

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**Abstract.** Crowdfunding is one of the ways to provide newly available funds for enterprises. This paper establishes an evolutionary game model for crowdfunding Initiators and investors to analyze evolutionary stability strategies. the factors that influence the strategic behavior of crowdfunding Initiators and investors, in theory, are found via the evolutionary equilibrium point of the model, and the influencing factors that affect the survival or extinction of crowdfunding activities are obtained.

**Keywords:** crowdfunding, evolutionary game, crowdfunding investors, crowdfunding initiators

## 1. Introduction

Enterprises are always looking for newly available funds. Crowdfunding will be one of the ways to provide newly available funds for them. Schwienbacher & Larralde [1] defined crowdfunding for the first time. They attributed crowdfunding to raise funds directly from the public through the Internet without the help of professional financiers (banks, financial institutions, venture capital institutions, etc.). Wheat Wang & Byrnes [2] directly define it as a brand-new investment and financing method, which can find investment funds for a project on the crowdfunding platform. Molick [3] 's point of view is that enterprises or individual groups can realize rapid financing through non-financial institutions and Internet channels, and quickly concentrate financing funds into a certain project to achieve the ultimate investment goal. It can be considered that crowdfunding is that a certain person, group, or enterprise initiates a project through the Internet crowdfunding platform to enable the public investment completely, and the public investors get benefits after the project completion.

Molick [3] and Sheng et.al [4] hold that the success of crowdfunding is determined by the quality of crowdfunding projects, and the quality of high-quality crowdfunding projects will be identified by investors. Information asymmetry, recommendation of crowdfunding platform, project risk, Initiator's efforts, social factors, and information transmission channels all affect the quality of crowdfunding projects. High-quality projects are more attractive to investors in crowdfunding; Otherwise, no one cares. Investors would rather not participate in low-quality crowdfunding projects because perhaps their funds will get higher returns.

In an evolutionary game, the research object is no longer an individual modeled as absolute rationality, but an individual in a bounded rational group to try and make mistakes, to achieve the equilibrium of the game, which is similar to the principle of biological evolution. Evolutionary game theory has also been used in crowdfunding research many times. Zhang. et.al [5] obtains the influencing factors of investors and agencies' strategic behavior through the evolutionary game and points out that the steady-state of the model is sensitive to the saddle point threshold determined by the initial state of the game. Yu.et.al [6] constructed an evolutionary game model between growers and crowdfunders to solve the troubles caused by price fluctuations to growers, processing enterprises, and consumers, which indicated that the relative price between sowing date and harvest date and social/logistics costs affected crowdfunding. Yu.et.al [7] constructed an evolutionary game model based on the relationship between agricultural products suppliers and urban residents in the financial system. Via analyzing ESS in the model, the results can be optimized by reducing the cost of GAPSC and enhancing the operational capability of GAPSC. Cheng. et.al [8] studies the social capital contributed by individuals in crowdfunding through the evolutionary game. Making full use of

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social capital will attract more people to participate in crowdfunding projects, effectively solving the dilemma of insufficient public participation in public utilities and the high construction cost of public goods.

Focusing initiators and investors both of who are vital participants in crowdfunding activities, this study explores interaction mechanism between crowdfunding initiators and crowdfunding investors. The strategy executed by crowdfunding initiators impacts the quality of crowdfunding project, while the strategy executed by crowdfunding investors determines whether the crowdfunding project can receive sufficient funds for promoting relative activities. In order to further examine the interaction mechanism between crowdfunding initiators and crowdfunding investors, increase the probability of successful crowdfunding activities, promote the development of the crowdfunding industry and provide new funds for enterprises, this paper analyzes crowdfunding initiators and crowdfunding investors. For analysis, builds a model based on game theory. Managerially, most of players hardly make strategical decisions with absolute rationality. Thus, this paper attempts to construct an evolutionary game between crowdfunding initiators and crowdfunding investors under the assumption of bounded rationality, and then analyze the dynamic changes of the two parties under realistic conditions. and stability to find out the evolutionary stability strategy and optimize it.

## 2. Construction of Evolutionary Game Model

### 2.1. Model Construction & Parameter Description

To construct an evolutionary game model and analyze its evolutionary stability strategy (ESS), the following parameter descriptions and assumptions are given.

Investors have two strategies {Participation( $A_1$ ), Nonparticipation( $A_2$ )} means participating in crowdfunding and not participating in crowdfunding. The probabilities of individuals choosing these two strategies are q and 1-q ($0 \le q \le 1$), respectively. The initiator has two strategies { High-quality($B_1$), Low-quality($B_2$)}, which provide high-quality crowdfunding projects and low-quality crowdfunding projects, respectively. The probabilities of individuals adopting these two strategies are r and 1-r ($0 \le r \le 1$), respectively.

Table 1: Parameter Description

| | |
|---|---|
| $G_H$ | Investors get the return of high-quality projects |
| P | Investors spend funds to participate in crowdfunding |
| $C_H$ | The cost of Initiator providing high-quality projects |
| R | Crowdfunding funds obtained by Initiators |
| $\delta$ | Risk-free return coefficient |
| $G_L$ | Investors get returns from low-quality projects |
| $C_L$ | Cost of Initiator providing low-quality projects |
| I | The punishment that the regulatory authorities will impose on the initiators of crowdfunding projects when the initiators provide low-quality projects and the financing is successful. |

Table 2: Income Matrix of Initiator & Investors of Crowdfunding

| Initiator / Investor | High-quality($\mathbf{B_1}$) | Low-quality($\mathbf{B_2}$) |
|---|---|---|
| Participation($\mathbf{A_1}$) | $G_H - P, R - C_H$ | $G_L$-P, R-$C_L - I$ |
| Non-participation($\mathbf{A_2}$) | $\delta P, -C_H$ | $\delta P$, -$C_L$ |

Constraints:

The above income matrix has the following constraints:

(1)$G_H > G_L$. The return of high-quality projects to crowdfunding investors is higher than that of low-quality products.

(2)$C_H > C_L$. The cost of providing high-quality projects by crowdfunding project initiators is higher than that of low-quality projects.

(3) $G_H - P > \delta P > G_L$-P. In reality, the benefits brought by high-quality projects provided by crowdfunding initiators to investors need to be higher than the risk-free benefits of crowdfunding amount

itself, such as the interest of the national debt, so that investors have the motivation to participate in crowdfunding projects, otherwise crowdfunding activities are not possible. Crowdfunding investors in low-quality projects will only get lower income than the risk-free income of crowdfunding, otherwise crowdfunding investors have no motivation not to participate in crowdfunding projects. If the risk-free income of crowdfunding amount is lower than the income when crowdfunding investors get low-quality projects, it means that every time crowdfunding project initiators initiate crowdfunding, crowdfunding investors will participate in crowdfunding projects regardless of whether they provide high or low project quality, which is illogical.

(4)$C_H - C_L < I$. Under the premise of crowdfunding funders participating in crowdfunding projects, the income obtained by crowdfunding project initiators providing low-quality projects is lower than that of producing high-quality products or services. Moral punishment is greater than the difference between high-quality cost and low-quality cost, otherwise, it will lose the meaning of moral punishment.

(5)$R>C_H$. Because$C_H - C_L < I$, if $R\text{-}C_L - I$ is positive, the crowdfunding funds that crowdfunding project initiators will obtain are greater than the cost of providing high-quality products or services; If $R\text{-}C_L - I$ is negative, the initiators of crowdfunding projects need a positive income, otherwise, it is not in line with reality and is illogical.

(6)$R \neq P$. This paper discusses the game between crowdfunding project initiators and crowdfunding investors about the quality of crowdfunding projects, so crowdfunding platforms will not be discussed for the time being. P and R are not equal to the expenses incurred by crowdfunding platforms in crowdfunding activities.

## 2.2. Replicator Dynamics Equation and ESS Analysis

### 2.2.1. Replicator Dynamics Equation of Crowdfunding Investors

Based on the above income matrix, $U_1$is recorded as the expected income of investors participating in crowdfunding, $U_2$ as the expected income of investors not contributing and not participating in crowdfunding, and $\overline{U}$ as the average expected income of crowdfunding investors, then

$$U_1 = r(G_H - P) + (1-r)(G_L - P) = rG_H - P + G_L - rG_L \quad (1)$$

$$U_2 = r\delta P + (1-r)\delta P = \delta P \quad (2)$$

$$\overline{U} = qU_1 + (1-q)U_2 = qrG_H - qP + qG_L + \delta P - q\delta P \quad (3)$$

The replicator dynamics equation of investors participating in crowdfunding is

$$F(q) = \frac{dq}{dt} = q(U_1 - \overline{U}) = q(1-q)(U_1 - U_2) = (q - q^2)(rG_H - P + G_L - rG_L - \delta P) \quad (4)$$

$$F'(q) = (\frac{dq}{dt})' = (1\text{-}2q)(U_1 - U_2) = (1\text{-}2q)(rG_H - P + G_L - rG_L - \delta P) \quad (5)$$

Let's $F(q) = 0$, then q=0 or 1, or $r=r^* = \frac{P - G_L + \delta P}{G_H - G_L}$.

When $r=r^*$, $F(q) = 0$, that is, it is a stable state for all q levels.

When $r \neq r^*$, q=0 and q=1 are two equilibrium points of the game process. The local stability criterion [10] F(q) = 0 $F'(q)<0$ of differential equation will judge whether its evolution equilibrium point is stable or not.

①When $r < r^*$, $F(q) = 0$, $F'(0)<0, F'(1)>0$. Therefore, q=0 is the evolutionary stable equilibrium point. Investors choose not to contribute and "not participate" in crowdfunding.

②When $r > r^*$, $F(q)= 0$, $F'(0)>0$, $F'(1)<0$. Therefore, q=1 is the evolutionary stable equilibrium point. Investors choose to contribute to "participate" crowdfunding.

### 2.2.2. Replicator dynamics equation of initiators

According to the income matrix in Table 2 take $\pi_1$ as the expected income of crowdfunding project Initiators for providing high-quality projects, $\pi_2$as the expected income of crowdfunding project Initiators for providing low-quality projects, and $\overline{\pi}$ as the average expected income of crowdfunding project Initiators, then get

$$\pi_1 = q(R - C_H) + (1 - q)(-C_H) = qR - C_H \tag{6}$$

$$\pi_2 = q(-C_L + R - I) + (1 - q)(-C_L) = qR - qI - C_L \tag{7}$$

$$\overline{\pi} = r\pi_1 + (1 - r)\pi_2 = r(C_L - C_H + qI) - q(R - I) - C_L \tag{8}$$

The replicator dynamics equation of high-quality projects provided by crowdfunding project Initiators is:

$$G(r) = \frac{dr}{dt} = r(\pi_1 - \overline{\pi}) = r(1 - r)(\pi_1 - \pi_2) = (r - r^2)(qI - C_H + C_L) \tag{9}$$

$$G'(r) = (\frac{dr}{dt})' = (1\text{-}2r)(\pi_1 - \pi_2) = (1\text{-}2r)(qI - C_H + C_L) \tag{10}$$

Let`s $G(r) = 0$, then r = 0orr = 1, or q =$q^* = \frac{C_H - C_L}{I}$.

When q=$q^*$, $G(r) = 0$, that is, it is a stable state for all r levels.

When $q \neq q^*$, r=0 and r=1 are two equilibrium points of the game process, the stability of the differential equation is judged by the local stability criterion. For example, if $G(r) = 0$, $G'(r) < 0$, the equilibrium point is stable.

①Whenq $< q^*$, $G(r) = 0, G'(0) < 0$, $G'(1) > 0$. Therefore, r=0 is the evolutionary stable equilibrium point. Initiators will provide low-quality projects.

②When q>q*, G(r)=0，G' (0)>0，G'(1)<0. Therefore, r=1 is the evolutionary stable equilibrium point. Initiators will provide high-quality projects.

2.2.3. Stability Analysis of Evolutionary Strategy of Crowdfunding Investors and Initiators

Simultaneous replicator dynamics equations (4) and (9) constitute equations Five equilibrium points (0, 0), (0, 1), (1, 1), $(q^* r^*)$ can be obtained in the plane [(q, r) 0 $\leq q, r \leq 1$] The stability of each equilibrium point can be judged according to the stability judgment method of the Jacobian matrix[11]. The Jacobian matrix of the system is:

$$J = \begin{bmatrix} \frac{dF(q)}{dq} & \frac{dF(q)}{dr} \\ \frac{dG(r)}{dq} & \frac{dG(r)}{dr} \end{bmatrix} = \begin{bmatrix} (1 - 2q)(rG_H - P + G_L - rG_L - \delta P) & (q - q^2)(G_H - G_L) \\ (r - r^2)I & (1 - 2r)(qI - C_H + C_L) \end{bmatrix}$$

The determinant and trace of the Jacobian matrix are calculated, and the determinant is Det J and trace is Tr J. If the equilibrium point of the evolutionary game satisfies Det J > 0 and Tr J < 0, the equilibrium point is stable. If Det J > 0 and Tr J=0, the equilibrium point is the center; If Det J > 0 and Tr J > 0, the equilibrium point is unstable; If Det J < 0 and Tr J is uncertain, the equilibrium point is the saddle point.

$$\text{Det J} == (1 - 2q)(rG_H - P + G_L - rG_L - \delta P)(1 - 2r)(qI - C_H + C_L) - (r - r^2)I(q - q^2)(G_H - G_L) \tag{10}$$

$$\text{Tr J} = (1 - 2q)(rG_H - P + G_L - rG_L - \delta P) + (1 - 2r)(qI - C_H + C_L) \tag{11}$$

The results of the local stability analysis are shown in Table 2.

Table 3: Local Stability Analysis of Evolutionary Game

| Equilibrium point | Det J | Symbol | Tr J | Symbol | Conclusion |
|---|---|---|---|---|---|
| q=0<br>r=0 | $(G_L - P - \delta P)(C_L - C_H)$ | + | $(G_L - P - \delta P) + (C_L - C_H)$ | - | ESS |
| q=0<br>r=1 | $(G_H - P - \delta P)(C_H - C_L)$ | + | $(G_H - P - \delta P) + (C_H - C_L)$ | + | Unstable |
| q=1<br>r=0 | $(P + \delta P - G_L)(I - C_H + C_L)$ | + | $(P + \delta P - G_L) + (I - C_H + C_L)$ | + | Unstable |
| q=1<br>r=1 | $(G_H - P - \delta P)(C_L - C_H)$ | + | $(P - G_H + \delta P) + (C_H - C_L)$ | - | ESS |
| q=$q^*$<br>r=$r^*$ | $(1 - q^*)(1 - r^*)$<br>$(P + G_L + \delta P)$<br>$(C_L - C_H)$ | - | 0 | | Saddle point |

The corresponding phase diagram is shown in Fig. 1 evolution path phase diagram.

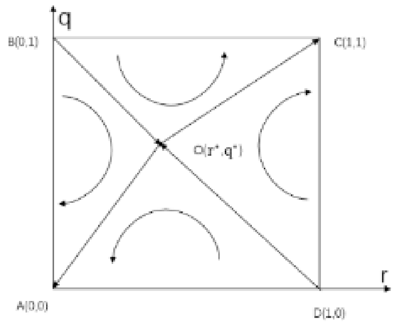


Fig. 1: Phase diagram of evolution path.

According to the phase diagram, we can see that A (0, 0) and C (1, 1) are stable points of evolutionary equilibrium, and the strategies they represent are (non-participation, Low-quality) and (participation, High-quality), respectively. BOD is the critical line at which the system converges to two points. OBCD and OBAD converge to A and C respectively, by which it can be found that the steady-state of the system depends on the relative position of O, that is, the initial state of the system. When crowdfunding is stable because initiators actively provide high-quality projects, high-quality crowdfunding projects will always exist; When crowdfunding is stable because investors do not participate in low-quality projects, crowdfunding dies. Further analysis needs to explore the specific changes of each factor.

# 3. Model analysis

## 3.1. Parameters with positive excitation

Theorem 1: Improving the quality of high-quality crowdfunding projects increases the income of investors and increases the probability that the system is stable at point C; Crowdfunding survives.

Theorem 2: Improving the quality of low-quality projects will increase the attractiveness of crowdfunding projects, and the probability of individual investors choosing participation strategies means that investors are more motivated to participate in crowdfunding, which enables crowdfunding to survive.

Theorem 3: Increasing the cost and moral punishment of low-quality projects directly reduces the income of individual initiators in choosing low-quality strategies. Individual initiators are more motivated to provide high-quality projects, and the probability that the system is stable at point C increases, which enable crowdfunding more likely to survive.

## 3.2. Parameters With Negative Excitation

Theorem 4: The cost of high-quality projects affects the income of initiators in providing high-quality projects. More individual initiators give up the strategy of providing high-quality projects because of the increased cost. Therefore, the probability of individual initiators choosing low quality will increase, so crowdfunding activities will be stable in extinction after evolution.

Theorem 5: Risk-free interest rate represents the safest growth of capital. The increase of risk-free interest rate will increase the probability that risk-averse individuals among investors don't participate in the strategy, that is, the benefits brought by participating in crowdfunding cannot overcome the risk aversion, which leads more people to not participate in crowdfunding. Crowdfunding will die out.

Theorem 6: P represents the funds spent by investors to participate in crowdfunding, which can be regarded as the entry barrier to participate in crowdfunding. The improvement of barriers to entry makes fewer investors participate in crowdfunding, so crowdfunding activities are stable in extinction.

# 4. Conclusion

Based on evolutionary game theory, an evolutionary game model between Initiators and investors of crowdfunding projects with bounded rational conditions is constructed. According to the replicator dynamics equation, the equilibrium point of the model is found. The stability of each equilibrium point of the game model is analyzed by the stability discrimination method of the Jacobian matrix, and the phase diagram of the evolution path is obtained. It is found that “Participation, High-quality" is the global optimal evolutionary stability strategy. By analyzing the influence of various parameters on the saddle point, the influence of saddle point on the probability of convergence of game system to global optimal evolutionary stability strategy is discussed. It is found that $G_H$, $G_L$, $C_L$, and I have a positive incentive effect on the stability of the system to the global optimal evolutionary stability strategy. P,δ,$C_H$have a negative incentive effect on the system to be stable in the global optimal evolutionary stability strategy.

According to the analysis conclusion, suggestions for crowdfunding activities between Initiators and investors of crowdfunding projects are put forward in this thesis: Improving the quality of crowdfunding products or services is helpful to control costs, that is, reducing cost $C_H$, increasing cost $C_L$, reducing crowdfunding purchase price P, strengthening government regulation and supervision by regulatory authorities.

## 5. Acknowledgment

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