PLOS ONE

The study on the role of dedicators on promoting cooperation in public goods game

Zhenghong Wu[1]☺*, Huan Huang[1]☺*, Qinghu Liao[2]

1 College of Economics and Management, Civil Aviation University of China, Tianjin, China, 2 School of Public Management, Tianjin University of Commerce, Tianjin, China

☺ These authors contributed equally to this work.
* wuzh@cauc.edu.cn (ZW); guaguabanyao@163.com (HH)

Abstract

In daily life, some people are always seen dedicating available resources to support collective activities. In this paper, we call these people who care group goals more than individual goals dedicators. Inspired by this phenomenon, we studied the role of dedicators on the evolution of cooperation in public goods game (PGG) based on a Chinese Folk Spring Festival Gala. Three types of agents were introduced into our PGG model including cooperators, defectors and dedicators. Dedicators tried to donate when the Gala was short of funds. Cooperators and defectors imitated the strategy of the highest-payoff neighbor based on the rational mechanism. And their imitating probability was modified on account of the emotional mechanism for positive effect of the dedicator's donating behavior and negative effect of continuous poor performance. Through numerical simulations, we found that the existence of dedicators can indeed promote cooperation in PGG. It should be noted that dedicators' willingness to donate was more important than their donation quantity in facilitating cooperation. And the stronger the emotional effect intensity of dedicators' donating behavior was, the better. So, the selfless dedication of participants should be praised to promote cooperation by improving their emotional effect intensity. Last but not least, a reasonable activity budget was needed to sustain the highest level of cooperation.

Introduction

Evolutionary game theory is about unraveling the mysteries of cooperation in biological and social systems [1]. A focus of this theory is the situation known as social dilemmas, where short-term self-interest conflicts with long-term group interest [2]. Recently, it is theoretically proved that there is a common dilemma structure mainly observed in binary game by introducing the concept of universal dilemma strength [3–7]. Different from this special case, however, most real-world dilemmas violate the binary format and extend to the closely related public goods game.

Most interactions in human social networks are simulated in multiplayer games. There are significant social dilemmas of multiplayer game in China, which need to be solved urgently. The Folk Spring Festival Galas have sprung up in some villages in Zhejiang province of China

in the last few years. These folk activities are always conducted by village heads. In addition to the funding from local governments and companies, rest of the funds are raised by villagers' voluntary contribution. Everyone can participate in this gala, regardless of donating or not. This activity enriches the cultural life of local villagers, but it is facing a pressing dilemma. Due to the shortage of funds, many villages have stopped hosting the gala. So, how to sustain this folk cultural activity is an issue that need to be solved by the organizer urgently. Different from others, Yunlin Gala is one of the few exceptions, which has been held for ten years in Yunlin village. Although facing the same problem of fund shortage, it is held successfully every year. Inspired by the fact, we try to investigate the reasons for success of this case to find a solution to solve the thorny problem of other villages. After some comparisons, we find that besides the village head there exist dedicators such as college students, art lovers and so on show selfless devotion to conduct Yunlin Gala. Unlike cooperators they concern group goals more than personal goals, so we call them dedicators. Therefore, we have some deep thinking: Are these dedicators the key to promote cooperation in Yunlin Gala? If yes, how can they make it? And are they the more the better? To get the answer of those meaningful questions, we start our work.

In view of natural selection everyone is a competitor to others. It is hard to stop making trouble to each other, let alone cooperate. However, cooperation is widespread around us in real life. Therefore, many scholars devote themselves to explaining this ubiquitous but inconceivable phenomenon in animal and human societies [8–11]. As an outstanding representative of evolutionary games, PGG provides a basic framework to research the origin and stability of cooperation [12]. In a standard PGG, each cooperator contributes c to the common pool, but defectors not. Then total contributions are equally divided among all agents after multiplied by a synergy factor r. It is apparently that defection is the optimal strategy, cooperation becomes a social dilemma. The Folk Spring Festival Gala is similar to the framework of PGG, thus we study the role of dedicators on cooperation on the basis of this model.

To explore the emergence and maintenance of cooperation, several mechanisms have been proposed by PGG, such as heterogeneity [13–16], indirect reciprocity [17–24], social diversity [25–28], punishment [29–39], reward [38–50], reputation [51–57], voluntary contribution [58–62], population structure [63–67] and so on. Recently, some scholars put forward that emotions also have a significant effect on the origin and stability of cooperation [68–72]. Every mechanism is identified through a spatial structure, which stems from the pioneering work of Nowak and May [12]. Because compared to the regular lattice, agents have different number of neighbors in a spatial structure which is much more accordance with the real world.

A few researchers have put forward that some factors can influence the evolution of cooperation in Chinese traditional public cultural activity based on PGG, such as publishing the donation list [73–75], donating time [76], leadership by example [77] and people who donate more money [78]. The above researches mainly assume that agents only focused on personal goals. Different from them, in this paper we study the role of dedicators who pay more attention to the group goals in addition to personal goals. Compared with others, the biggest feature of Yunlin Gala is the existence of those dedicators. Every winter vacation the local college students will come back to help the village head organize and advertise the gala. Art lovers are responsible for programming performances. And when the funds do not reach the budget, they are likely to give money to support the gala. Players are driven by "rationality" to make better decisions and maximize their personal payoff [79]. But human beings are not only rational, but also emotional. Emotions have been demonstrated can affect decision-making [68–71]. So we assume that some agents would be moved by dedicators' donating behavior to be cooperators. However, it should be noted that dedicators' continuous willingness to donate is not strong. And the amount of money a dedicator can donate is limited. What's more, successive poor performances will discourage donating among people. Summarily, we focus on

exploring the role of dedicators on the emergence and maintenance of cooperation in the above condition based on PGG.

The rest of this paper is structured as follows. In Section 2, our PGG model is described. In Section 3, we present the numerical simulation results and analysis. In Section 4, conclusions are proposed according to the experimental results.

Model and methods

Multiplayers' interaction is not as simple as the relationship between two, is interdependent and entangled. Unlike the 2×2 game, secondary and direct neighbors in the multiplayer simulation can affect the payoff of the focus agency [80]. To explain the influence of dedicators, three types of agents are classified in a spatial structure, covering cooperators, defectors and dedicators. Cooperators and defectors only choose to donate money or not. Normally, different from cooperators and defectors, dedicators make non-monetary contributions to the Gala, but when lack of funds, they may donate money as much as they can.

Our PGG model is performed on a scale-free network. A randomly selected agent i has an own number of neighbors (k_i) and attends $k_i + 1$ PGG groups. At the initial time step, the fraction of cooperators and defectors is equal. The fraction of dedicators (f_1) is dynamic to satisfy experiment demand. The payoff obtained by each agent can be calculated as follows:

$$P_i = \sum_{j \in \Omega_i} P_i^j = \sum_{j \in \Omega_i} (r \frac{n_j}{k_j + 1} - c_i) \tag{1}$$

where P_i denotes the payoff of agent i. Ω_i stands for the set of groups where i attends. j is one group of Ω_i. $r (> 1)$ is the game parameter indicating dilemma weakness [80], called synergy factor, reflecting the synergetic effects of cooperation. n_j represents contributions of group j. k_j is the number of neighbors of agent i in group j. c_i is contributions of agent i. If agent i is a cooperator, $c_i = 1$; if agent i is a defector, $c_i = 0$; otherwise, $c_i = c_d$ ($c_d \geq 0$, c_d will be explained detailly in the following paragraph).

It is assumed that the Folk Spring Festival Galas can be held as required if total group contributions (Ti) will reach budget (Tr), otherwise, the quality of the activity will decline. In real social life, if an activity fails continuously, people will have less confidence in its success and may not choose to support it. It means the dedicator is more willing to donate discontinuously instead of continuously. So, we assume that when $Ti < Tr$ happens for the first time, dedicator's probability of donating f_o will be equal to 1(see the upper formula of Eq (2)). When $Ti < Tr$ has ever happened, f_o will be an increasing function of break time steps (t_1) (see the lower formula of Eq (2)). We define dedicator's probability of donating as follows:

$$f_o = \begin{cases} 1 & , \quad Ti < Tr \ \ happens \ \ first \ \ time \\ 1 - exp(-0.1 - \theta_1 t_1) & , \quad Ti < Tr \ \ has \ \ ever \ \ happened \end{cases} \tag{2}$$

where f_o is the dedicator's probability of donating as $Ti < Tr$, $0 < f_o \leq 1$. t_1 is break time steps, indicating the continuous time steps in which contributions reach budget after the last occurrence of $Ti < Tr$. If donating behavior happened among dedicators in last step ($t_1 = 0$), f_o will decrease to a lower limiting value (Fig 1a). However, due to the prosocial preference of human beings, f_o is always greater than zero. We adopt an exponential probabilistic model to describe the relation between f_o and t_1. θ_1 is the recovering coefficient, which reflects the recovery speed of the dedicator's willingness to donate. The greater θ_1 is, the more rapidly f_o enlarges.

For rational consideration of survival, there exists a donation threshold λ for each dedicator, which indicates the maximum amount of money a dedicator can afford to give. Therefore,
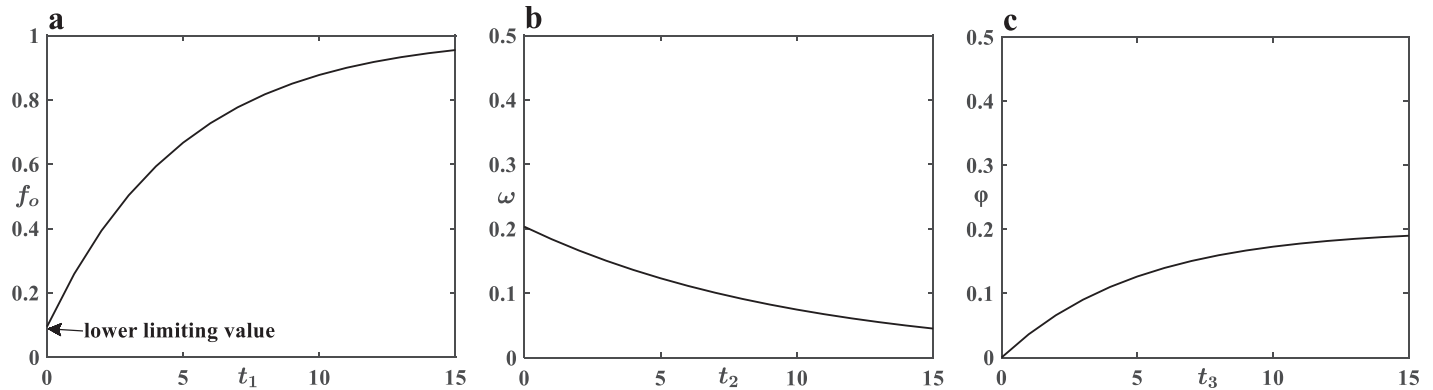
Fig 1. Descriptions of relationships between some parameters. Here $\theta_1 = 0.2$, $\delta = 0.5$, $\theta_2 = 0.2$, $\theta_3 = 0.2$. (a) The dedicator's probability of donating (f_o) for different break time steps (t_1) when $Ti < Tr$ has ever happened. (b) The extra cooperation probability (ω) for different time steps (t_2) after dedicators' donating behavior. (c) The extra defection probability (ϕ) for different successive times of poor performances (t_3).

dedicator's monetary contributions c_d is calculated as follows:

$$c_d = \begin{cases} \min\left(\frac{Tr-Ti}{f_1 N}, \lambda\right) & , \quad t_1 = 0 \\ \\ 0 & , \quad t_1 \neq 0 \end{cases} \quad (3)$$

where $Tr - Ti$ represents the shortfall between the funds needed for the Gala and donations of cooperators in this generation. The shortfall of money will be shared equally by the dedicators. N is the total number of people. f_1 denotes the proportion of dedicators. λ represents the donation threshold of each dedicator. When dedicators needn't donate continuously ($t_1 = 0$), they will donate as much as they can. Otherwise, they will not. To show the model briefly, we assume that any dedicator has the same value of λ and c_d.
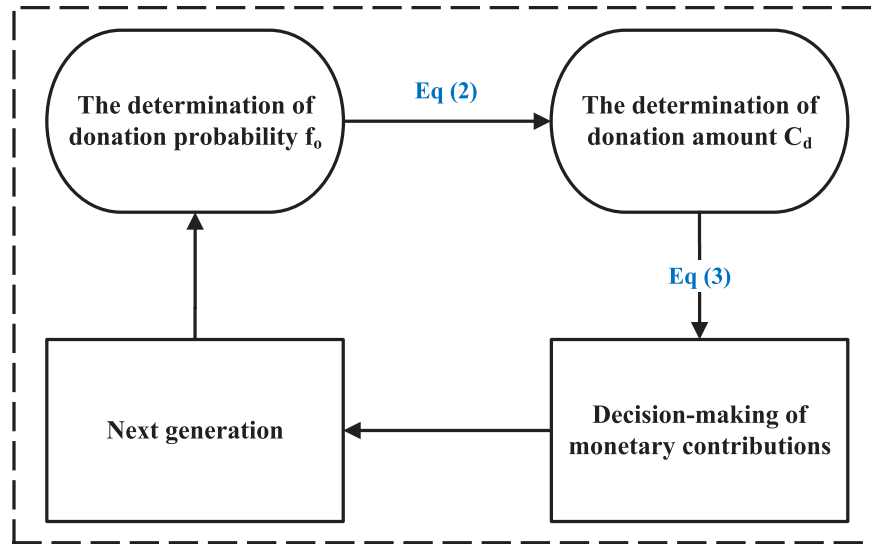
Contributions of dedicators include monetary and non-monetary contributions. The decision process for a dedicator's monetary contributions is shown in Fig 2. When the contributions are less than budget, dedicator's monetary donation decisions are influenced by both collective and individual goals based on Eqs (2) and (3). The decision of a dedicator's monetary contributions is divided into two parts: the determination of whether to donate (with the probability f_o) and the question of how much to donate. The last step of this generation is the first step of the next generation.

Normally, cooperators and defectors are rational payoff-driven agents who always change strategies to maximize their payoff. They make the initial decision by imitating the strategy of the neighbor who has highest payoff (excluding dedicators) with the following probability:

$$W'(s_i \leftarrow s_j) = \frac{1}{1 + exp[(P_i - P_j)/\phi]} \quad (4)$$

where ϕ represents the amplitude of environment noise [61, 81]. s_i and s_j denote the strategies of agent i and neighbor j, respectively. $P_i - P_j$ is the difference of payoff between agent i and neighbor j.

However, human-beings can't be completely rational. Sometimes, due to emotion mechanism, decisions of cooperators and defectors will be influenced by donating behavior of dedicators inevitably. Thus, an extra cooperation probability ω is added to cooperators and defectors. On the basis of common sense, we assume that the extra cooperation probability ω is a decreasing function of time steps. An exponential probabilistic model is chosen to describe the variation trend of ω (Fig 1b). So, the extra cooperation probability is expressed by the

Fig 2. The circulatory process of decision-making of dedicators. Dedicators' contributions include monetary and non-monetary contributions. Decision-making of monetary contributions requires determining in advance the possibility and amount of donations.

Table 1. The definitions and descriptions of parameters.

Parameter	Definition and description
P	The payoff of the agent
Ω	The set of PGG groups where the agent attends
r	The synergy factor
c	The contributions of the agent
Ti	The contributions donated by all of cooperators
Tr	The budget of the gala
λ	The donation threshold of dedicators
N	The population
f_1	The fraction of dedicators
f_2	The fraction of cooperators
f_3	The fraction of defectors
f_o	The dedicators' probability of donating when $Ti < Tr$
θ_1	The recovering coefficient, the recovery speed of dedicators' willingness to donate
θ_2	The positive sustained coefficient, which affects the reduction velocity of emotional effect of dedicators' donating behavior
θ_3	The negative sustained coefficient, the sustained impact of the poor performance
ϕ	The amplitude of environment noise
ω	The general extra cooperation probability
δ	The emotion coefficient, the emotional effect intensity of dedicators' donating behavior
φ	The general extra defection probability
t_1	Break time steps, which means cooperators' contributions reach budget in the continuous time steps after latest condition of $Ti < Tr$
t_2	The time steps after dedicators' donating behavior
t_3	The successive times of poor performances

following function:

$$\omega = \frac{\delta}{3\exp[\theta_2(0.5t_2 - 1)]} \tag{5}$$

where ω denotes the extra cooperation probability, $0 < \omega \leq 0.2$. t_2 denotes the successive time steps after dedicators' donating behavior. It should be noted that we only consider the single impact of the time-closest donating behavior instead of the accumulated impact of all donating behavior. δ is emotion coefficient, which represents the emotional effect intensity of dedicators' donating behavior. θ_2 is a positive sustained coefficient, which affects the reduction velocity of emotional effect of dedicators' donating behavior. The greater θ_2 is, the more slowly ω declines.

When total contributions are still less than the budget after dedicators donating money, the quality of Spring Festival Gala will decline. Audiences can tolerate the poor performance one time, but cannot endure continuously. So, successive poor performances will add an extra defection probability φ to cooperators and defectors. Therefore, we choose an exponential probabilistic model to describe the variation trend of φ (Fig 1c). In addition, this model can show our assumption that the extra defection probability will grow more and more slowly with the increase of t_3. So, we define the extra defection probability as follows:

$$\varphi = [1 - \exp(-\theta_3 t_3)]/5 \tag{6}$$

where φ is the extra defection probability, $0 < \varphi \leq 0.2$. t_3 denotes the successive times of poor performances. θ_3 is the negative sustained coefficient, positively correlated with φ, which reflects the sustained impact of the poor performance. All parameters in this paper are defined and explained in Table 1.

Considering emotional factors, the imitation probability, quantified by PW-Fermi rule, can be modified [82]. Cooperators and defectors update strategies with the modified probability:

$$W(s_i \leftarrow s_j) = \begin{cases} \frac{1}{1+\exp[(P_i - P_j)/\phi]} + \omega - \varphi \;, & c_j = 1 \\ \\ \frac{1}{1+\exp[(P_i - P_j)/\phi]} - \omega + \varphi \;, & c_j = 0 \end{cases} \tag{7}$$

where $c_j = 1$ means the strategy of neighbor j is cooperation in last round, and $c_j = 0$ means defection. If the selected neighbor j is a cooperator, the transition probability $W(s_i \leftarrow s_j)$ updates based on the upper formula. Conversely, $W(s_i \leftarrow s_j)$ changes according to the lower formula.

The decision-making process of cooperators and defectors is displayed in Fig 3. As rational men, cooperators and defectors employ the same set of decision-making process. First of all, driven by personal payoff, the agent make the initial decision by imitating his/her neighbor's strategy with the probability of $W'(s_i \leftarrow s_j)$. After that the agent will be affected by dedicators' donating behavior and successive poor performances and update the strategy with the probability of $W(s_i \leftarrow s_j)$ to make the final decision.

Simulation and analysis

To investigate the role of dedicators on the evolution of cooperation in the Folk Spring Festival Gala, a large number of simulations are performed in PGG model. The results are obtained by average over 30 independent runs for 10000 time steps. Each equilibrium datum is obtained by averaging the last 5000 generations of 30 independent runs. Initially, the population $N = 1000$, average number of neighborhood $k = 4$, budget $Tr = 500$, synergy factor $r = 1.2$, noise figure $\varphi = 0.1$, dedicators' donation threshold $\lambda = 0.5$. The fraction of dedicators, cooperators and
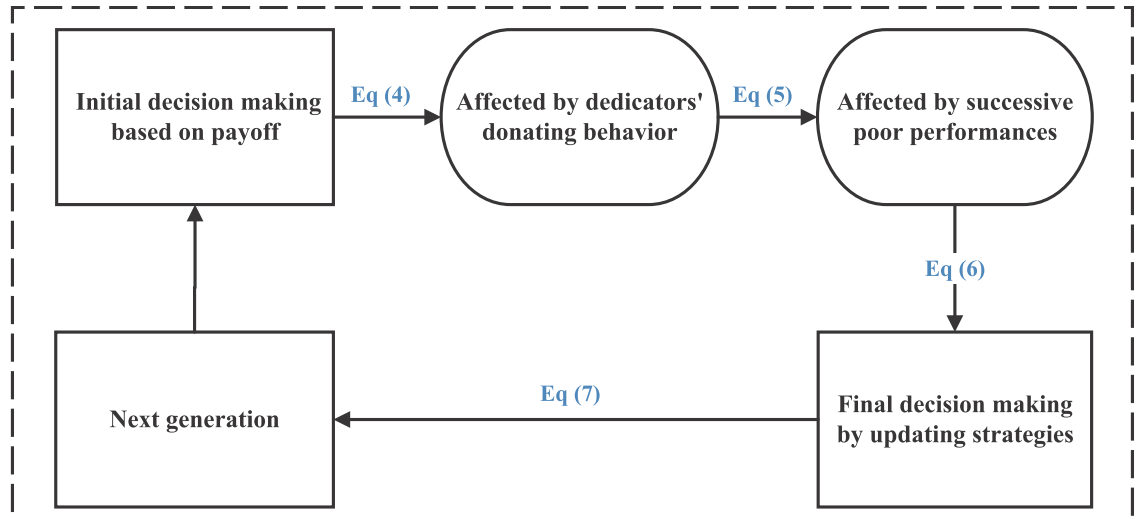
Fig 3. The circulatory process of decision-making of cooperators and defectors. Cooperators and defectors make decisions at the same time. Decisions of cooperators and defectors are driven by personal payoff and affected by dedicators' donating behavior based on emotional effect and successive poor performances.

defectors is $f_1 = 0.1, f_2 = 0.45, f_3 = 0.45$, respectively. The rest parameters are $\theta_1 = 0.2, \delta = 0.5, \theta_2 = 0.2, \theta_3 = 0.2$. While one of the parameters changes, others keep stationary. In this paper, ρ refers to cooperation frequency which means the ratio of cooperators to the sum of cooperators and defectors. Ts represents the total contributions.

Firstly, the role of budget (Tr) is discussed in Fig 4. We can find from the figure that there is a threshold (about 500 here) of Tr, which includes two meanings: (i) When Tr is not greater than the threshold, the equilibrium results of total contributions Ts can meet the required level (Tr) and the Gala will succeed. When Tr is greater than the threshold, the equilibrium results of Ts can't reach Tr and the activities can not be held with high quality. (ii) When Tr is less than the threshold, the equilibrium results of Ts and ρ get larger as the threshold enlarges. Otherwise, Ts and ρ go down as Tr increases. As we can see, a too high budget will lead to a collapse of the whole cooperation system. Therefore, a reasonable activity budget needs to be decided by organizers to sustain the maximum level of cooperation.

Then, the impact of the fraction of dedicators (f_1) on cooperation will be investigated. In real life, there are only a few dedicators. Therefore, the initial value of f_1 is set to 0.1, and the research range of f_1 is from 0 to 0.22. It can be drawn that the existence of dedicators can help
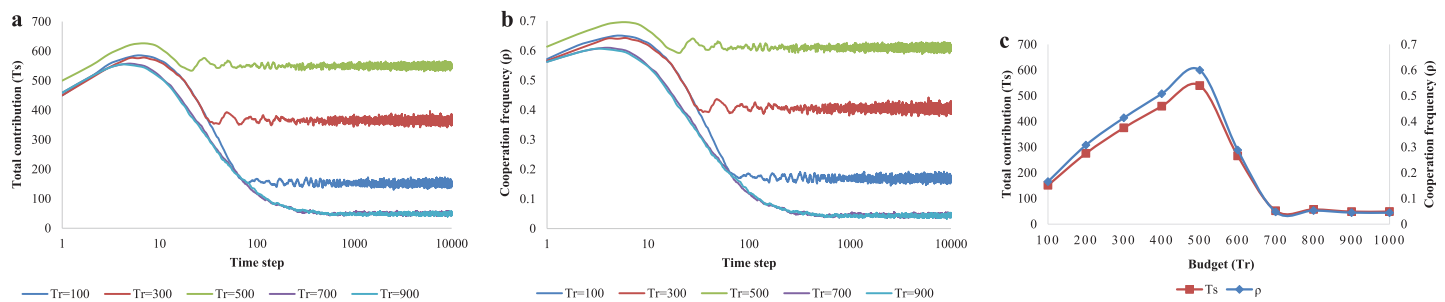
Fig 4. The evolution results of total contributions Ts and cooperation frequency ρ for different values of budget Tr. (a) The evolution process of total contributions for different budgets ($Tr = 100, 300, 500, 700, 900$). (b) The evolution results of cooperation frequency for different budgets ($Tr = 100, 300, 500, 700, 900$). (c) The equilibrium results of total contributions and cooperation frequency for different budgets from 100 to 1000 with an interval of 100.
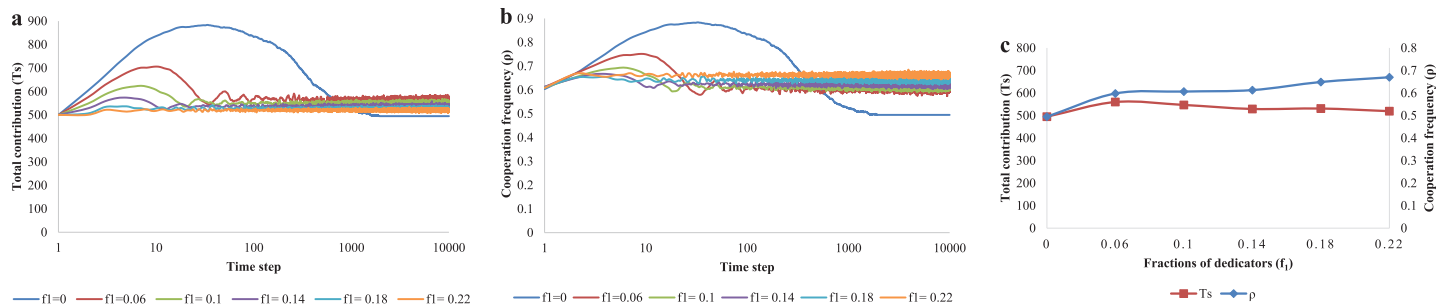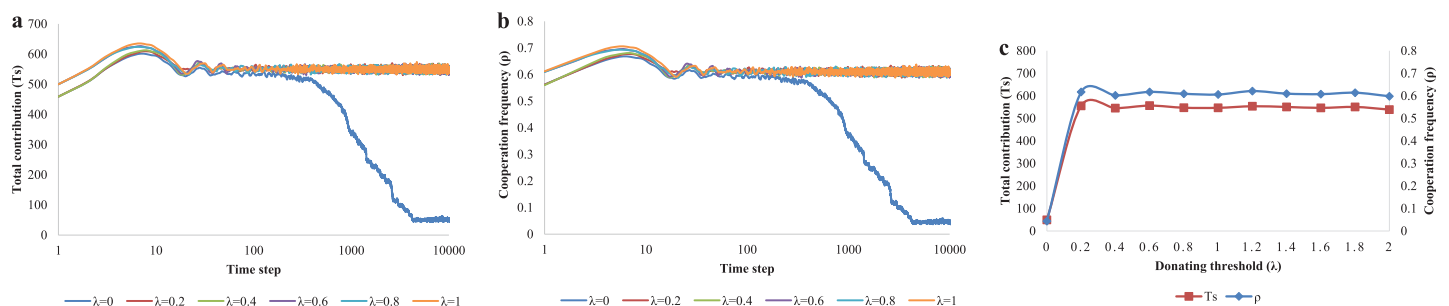
Fig 5. The evolution results of total contributions *Ts* and cooperation frequency *ρ* for different fractions of dedicators *f₁*. (a) The evolution process of total contributions for different fractions of dedicators (f_1 = 0, 0.06, 0.1, 0.14, 0.18, 0.22). (b) The evolution results of cooperation frequency for different fractions of dedicators (f_1 = 0, 0.06, 0.1, 0.14, 0.18, 0.22). (c) The equilibrium results of total contributions and cooperation frequency for different fractions of dedicators (f_1 = 0, 0.06, 0.1, 0.14, 0.18, 0.22).

total contributions exceed the budget and stabilize cooperation at high level. In Fig 5a and 5b, we can see that as f_1 increases, the corresponding curves reach cooperation equilibrium more quickly and stably. Except for the dark blue curve, the other curves remain at higher level. It means dedicators can strongly stabilize and promote cooperation. Similar to Fig 5a and 5b, it can be seen that the red and blue curves are at lowest level when f_1 = 0 in Fig 5c. Moreover, we find an interesting phenomenon. Under the condition of $f_1 > 0.06$, the blue curve and the red curve diverge in Fig 5c. Through analyzing, we can speculate that: (i) f_1 is directly proportional to $ρ$ because more defectors will become cooperators with the increase of dedicators. (ii) f_1 is inversely proportional to *Ts* as dedicators don't need to donate after cooperators' contributions reach the budget even though there are more dedicators.

Next, we will look at the effect of the donation threshold of dedicators (λ). We find that dedicators' donating behavior can promote cooperation, but dedicators' willingness to donate is more important than the amount of money they donate. As we can see in Fig 6a and 6b, when λ = 0, the blue curve drops down to the bottom as time goes by, which means *Ts* and $ρ$ are getting closer to 0. While λ > 0, corresponding curves keep on high level, which means *Ts* and $ρ$ have relatively large value. Similar results can be found in Fig 6c. It is clear that when λ is 0, both curves are close to the bottom. When λ changes from 0.2 to 2, the red and blue curves maintain high level steadily, and *Ts* reach the required level. Based on the above results, we can sum up that once dedicators donate, they will promote cooperation and variation of donation

Fig 6. The evolution results of total contributions *Ts* and cooperation frequency *ρ* for different values of the donation threshold λ. (a) The evolution process of total contributions for different values of donation threshold (λ = 0,0.2,0.4,0.6,0.8,1). (b)The evolution results of cooperation frequency for different values of donation threshold (λ = 0,0.2,0.4,0.6,0.8,1). (c) The equilibrium results of total contributions and cooperation frequency for different values of donation threshold λ varying from 0 to 2 with an interval of 0.2.
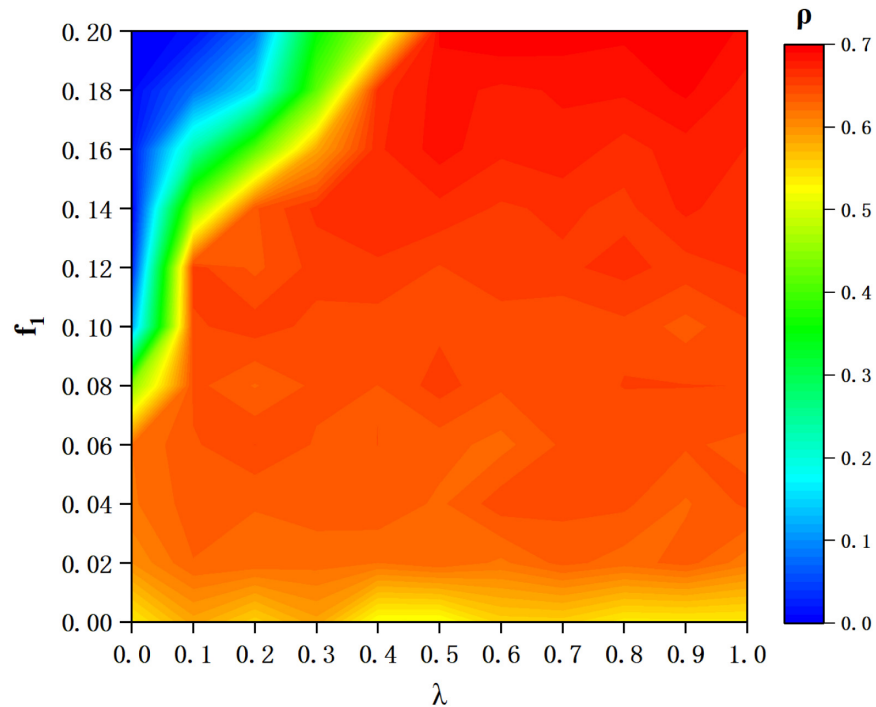
Fig 7. Heat-maps of cooperation frequency ρ at equilibrium along 2D plain based on proportion of dedicators f_1 and the donation threshold of a dedicato λ. All kinds of colors represent various cooperation frequency under the joint action of different value of f_1 and λ. The X-axis is λ (from 0 to 1) and the Y-axis is f_1 (from 0 to 0.2).

quantity has little effect to influence. Therefore, we conclude that dedicators' willingness to donate is more important than the quantity to facilitate cooperation.

As we know, f_1 and λ are the significant factors for dedicator's monetary contributions C_d. The upper left corner of the Heat-maps in Fig 7 where minimum of ρ appears is blue and green, which means that the cooperation rate is less than 50 percent. So, the combination of a large f_1 and a small λ is not good for cooperation. The rest of the graph is mostly red and small areas of yellow, indicating that the combination of f_1 and λ in these cases is favorable for cooperation. And in the red area, with the increase of f_1, the color is gradually deepened and the level of cooperation is slowly improved.

Next, recovering coefficient θ_1, positive sustained coefficient θ_2 and negative sustained coefficient θ_3 are discussed in this part. It can be observed that curves in Fig 8a–8c, are almost
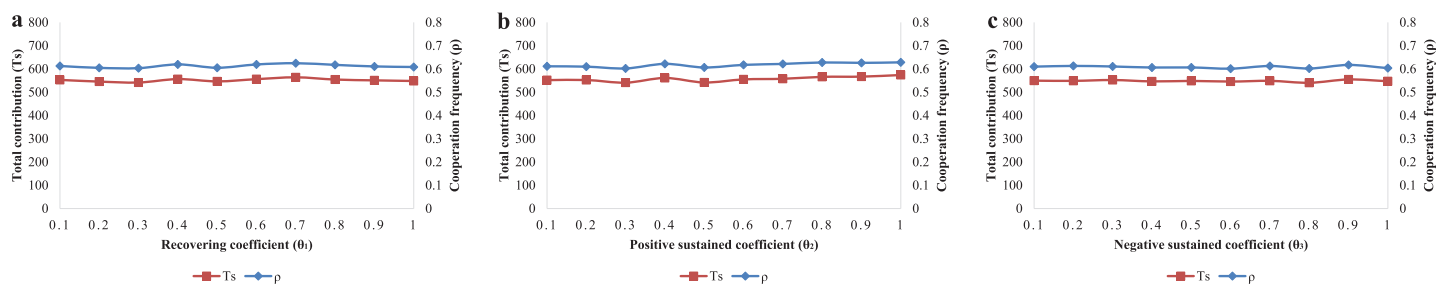
Fig 8. The equilibrium results of total contributions Ts and cooperation frequency ρ for different values of θ_1, θ_2 and θ_3. (a)The equilibrium results of total contributions and cooperation frequency for different values of recovering coefficient θ_1 varying from 0.1 to 1 with an interval of 0.1. (b) The equilibrium results of total contributions and cooperation frequency for different values of positive sustained coefficient θ_2 varying from 0.1 to 1 with an interval of 0.1. (c)The equilibrium results of total contributions and cooperation frequency for different values of negative sustained coefficient θ_3 varying from 0.1 to 1 with an interval of 0.1.
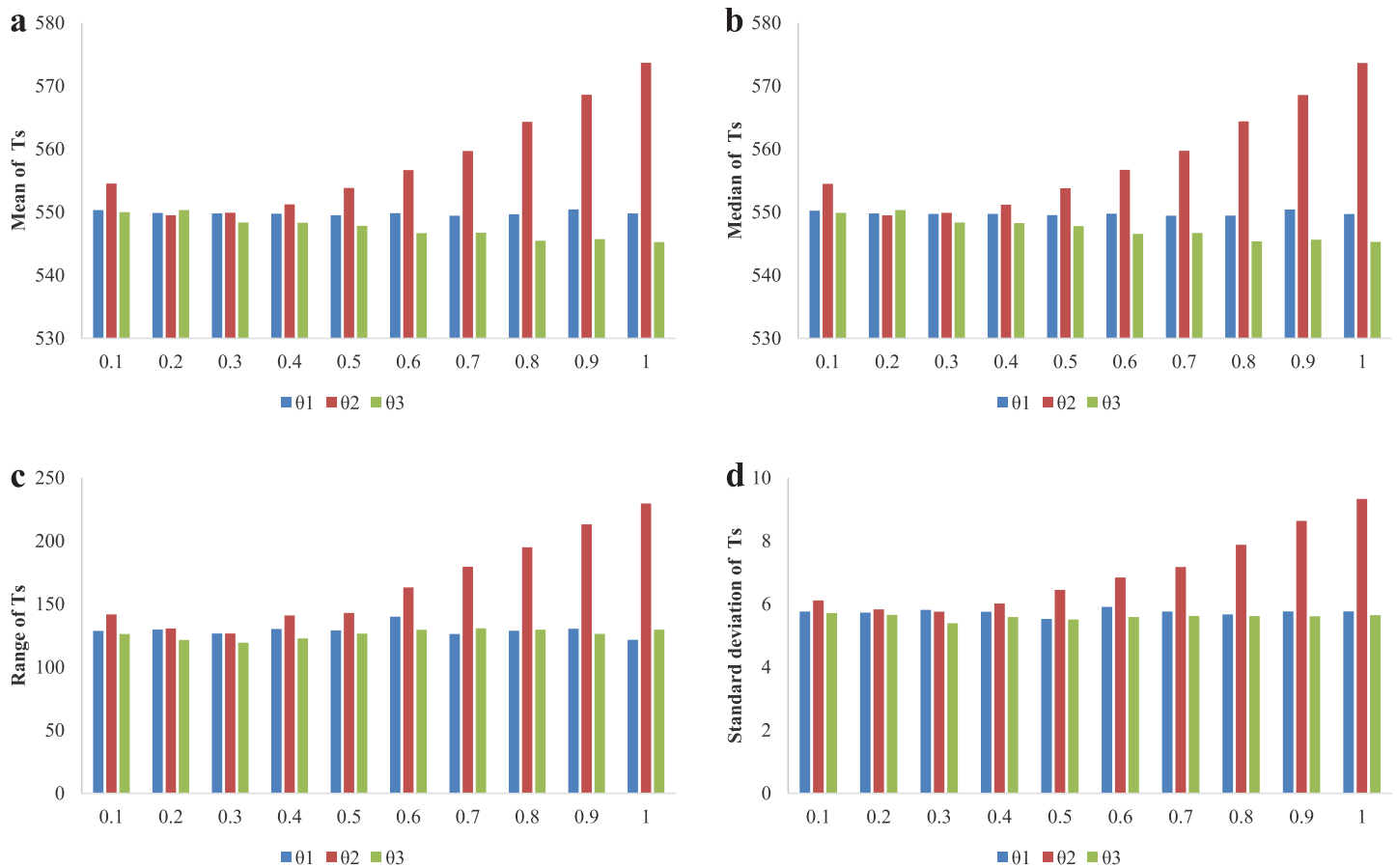
Fig 9. Results to show the mean, median, range and standard deviation of total contributions based on θ_1, θ_2 and θ_3. (a)-(d) The result of mean, median, range and standard deviation of *Ts* for θ_1, θ_2 and θ_3 varying from 0.1 to 1 with an interval of 0.1, respectively.

https://doi.org/10.1371/journal.pone.0257475.g009

horizontal. No matter how the values of θ_1, θ_2 and θ_3 change, the blue and red curves always keep on stable high level. It means that the recovery speed of dedicators' donation willingness, reduction velocity of emotional effect and the continuous influence of bad performance have little difference in impact on the evolution of cooperation. This finding is somewhat unexpected. It shows the model is so strong robustness that it can resist the impact of these three parameters.

To analyze the robustness more detailly, we depict Fig 9. Compare to Fig 8, it can be seen that the mean and median values of *Ts* obtained based on θ_1, θ_2 and θ_3 from Fig 9a and 9b are similar to the equilibrium results in Fig 8, all of which are around 550. Besides, Fig 9a–9d, we can see that the height of the blue and green columns are both almost unchangeable. Obviously, the height of the red columns shows an overall upward trend. As a whole, this model is more robustness against θ_1 and θ_3 than θ_2. What is more, it can be found that when the value of θ_2 is less than 0.5, the result has a little stronger stability.

In addition to the parameters above, the attention is transferred to the emotion coefficient δ, which represents the emotional effect intensity of donating behavior of dedicators. We find that the greater δ is, the better cooperation level can get and there is a threshold (about 0.3 here) for δ. In Fig 10a and 10b, when $\delta = 0.1$, the dark blue curve moves rapidly to a value close to 0. Once δ reaches or exceeds 0.3, the other curves eventually remain high level. We can clearly see in Fig 10c, as δ rises 0.1 to 1, the red and blue curves are always increasing. When δ
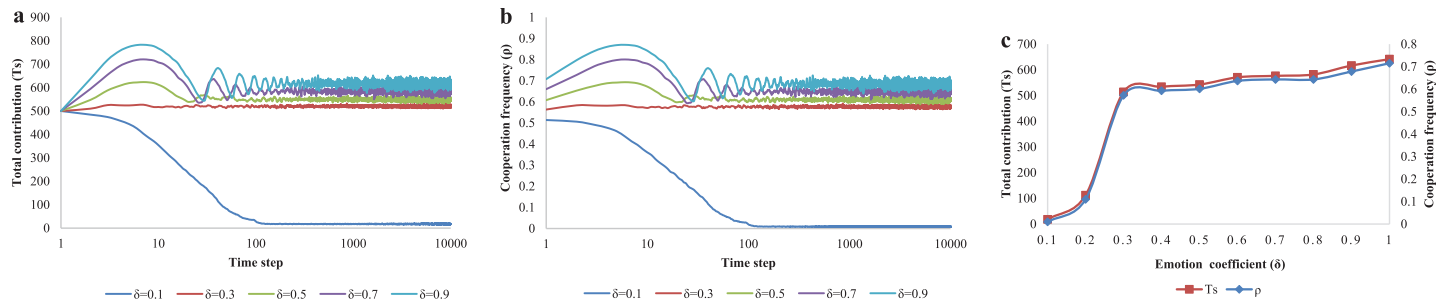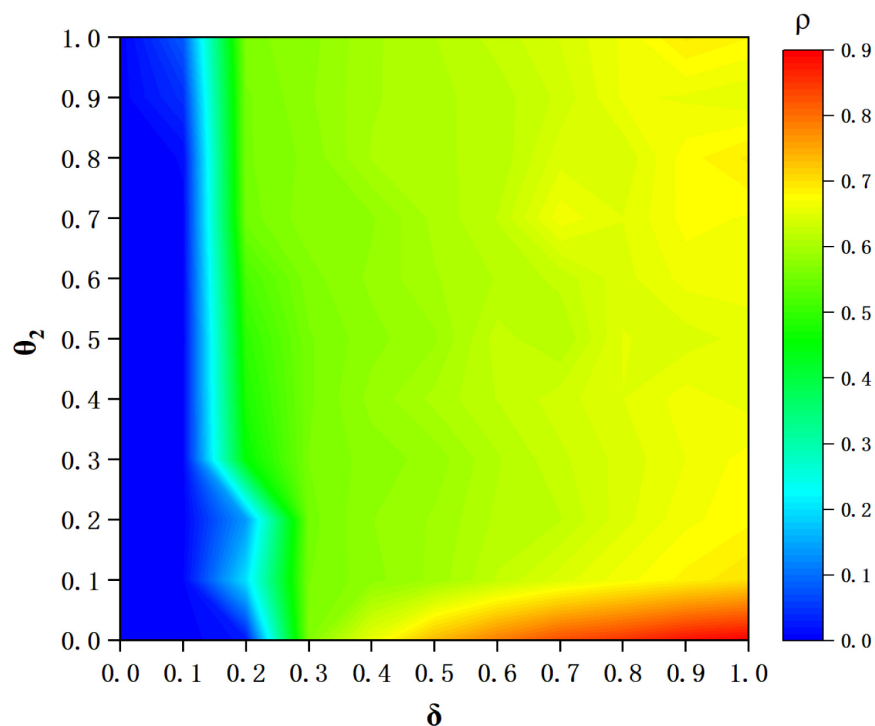
Fig 10. The evolution results of total contributions *Ts* and cooperation frequency *ρ* for different values of emotion coefficient *δ*. (a) The evolution process of total contributions for different values of emotion coefficient ($\delta = 0.1, 0.3, 0.5, 0.7, 0.9$). (b)The evolution results of cooperation frequency for different values of emotion coefficient ($\delta = 0.1, 0.3, 0.5, 0.7, 0.9$). (c)The equilibrium results of total contributions and cooperation frequency for different values of emotion coefficient *δ* varying from 0.1 to 1 with an interval of 0.1.

is less than 0.3, the red and blue curves rise rapidly, but *Ts* and *ρ* are low. While *δ* rises from 0.3 to 1, the red and blue curves remain high level and increase slowly.

For further research, we plot the heat maps cooperation frequency *ρ* at equilibrium of θ_2 and *δ*. θ_2 and *δ* are the important parameters of extra cooperation probability *ω*. In Fig 11, we find that the closer to the right of the image, the brighter it is. This also means that the larger *δ*, the higher *ρ*. The maximum value of *ρ* appears in the lower right corner of the image, and a state close to all-C is obtained when $\theta_2 < 0.1$ and $\delta > 0.4$. When $\delta < 0.1$, a state close to all-D appears.

Fig 11. Heat-maps of cooperation frequency *ρ* at equilibrium along 2D plain based on positive sustained coefficient θ_2 and emotion coefficient *δ*. All kinds of colors represent various cooperation frequency under the joint action of different θ_2 and *δ*. The X-axis is *δ* (from 0 to 1) and the Y-axis is θ_2 (from 0 to 1).
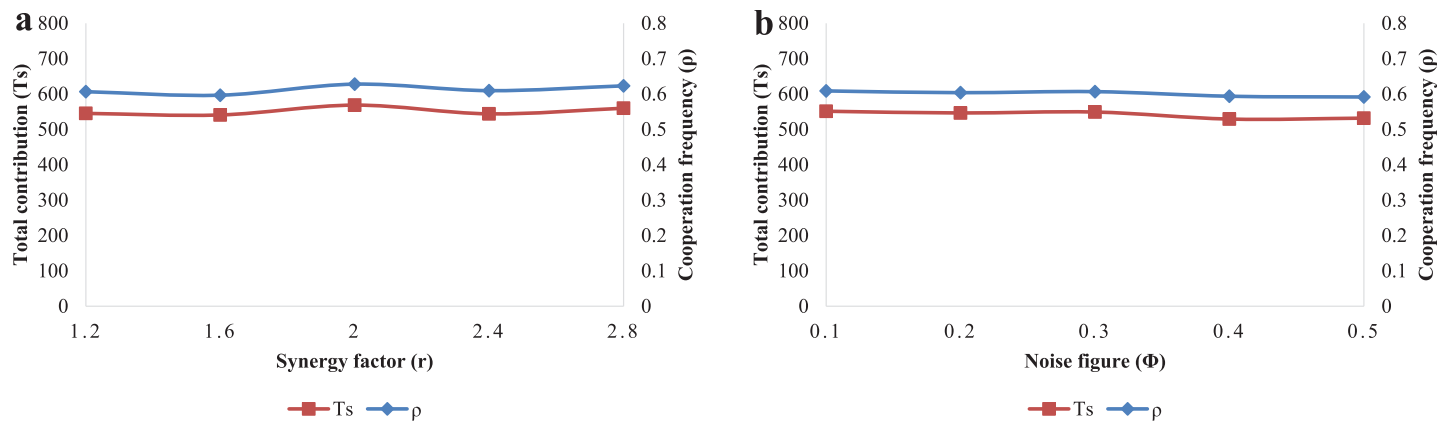
Fig 12. The equilibrium results of total contributions *Ts* and cooperation frequency *ρ*. (a) The equilibrium results of total contributions and cooperation frequency for different synergy factors (*r* = 1.2, 1.6, 2, 2.4, 2.8). (b) The equilibrium results of total contributions and cooperation frequency for different noise figure (*φ* = 0.1, 0.2, 0.3, 0.4, 0.5).

Finally, the robustness analysis of synergy factor r and noise figure ϕ will be discussed in the following content. As shown in Fig 12a, two curves run smoothly while the value of r changes from 1.2 to 2.8. Generally speaking, the cooperation level will not increase remarkably, as the value of synergy factor rises in a moderate interval. Then the effect of noise figure ϕ is described. In Fig 12b, *Ts* and ρ do not show significant fluctuation with different values of ϕ. It means the equilibrium results are robust against the parameter of ϕ in our PGG model.

Conclusion

The government of China is focusing on providing satisfactory public cultural services. A series of measures has been taken to attract the public to participate in public cultural construction to easing the shortage of local government. As a successful spontaneous activity, Yunlin Gala provides a good case to research the origin and stability of cooperation in public cultural activities. The difference of population structure is an important distinction between activities in real social life. Differing from the common cooperator and defector, the dedicator is a typical example, who focuses on the group goal more than personal one. Based on the mechanisms of emotions, the role of dedicators on the evolution of cooperation is investigated in this paper. Through massive simulations, the specific conclusions are shown in the following: Firstly, by our researching, we find that the presence of dedicators can promote the cooperation in PGG. Then, a moderate budget of the activity is significant. A too high budget will lead to a collapse of the whole cooperation system. Next, dedicators' willingness to donate is more important than their donation quantity in facilitating cooperation. Moreover, the stronger the emotional effect intensity of dedicators' donating behavior is, the better. So, the unselfish donations of dedicators should be appreciated publicly to improve the emotional effect intensity. This is according with the reality, because the People Who Moved Yunlin Award which is set up to speak highly of donating dedicators has been existed for several years. We think it plays a positive role on promoting cooperation in the public culture activities.

Our study can make some contributions to policy makers and managers. For one thing, public cultural activities should be conducted by those people who pay more attention to group goals. For another, activity budget should be within the scope of the local financial capacity. What's more, the selfless dedication of participants should be praised to promote cooperation by improving the emotional effect intensity.

In summary, we have investigated the influence of dedicators on evolution of cooperation in PGG. We find that dedicators can help avoid the tragedy of the commons by stabilizing and promoting cooperation. We hope that this study could shed a light into the understanding of the origin and stability of cooperation.

Author Contributions

Conceptualization: Zhenghong Wu, Huan Huang, Qinghu Liao.

Data curation: Zhenghong Wu, Huan Huang, Qinghu Liao.

Formal analysis: Zhenghong Wu, Huan Huang, Qinghu Liao.

Methodology: Zhenghong Wu.

Software: Zhenghong Wu.

Validation: Qinghu Liao.

Writing – original draft: Zhenghong Wu, Huan Huang.

Writing – review & editing: Zhenghong Wu.

References

1. Arefin M.R., Kabir K.M.A., Jusup M., Ito H., Tanimoto J. Social efficiency deficit deciphers social dilemmas. Scientific Reports. 2020; 10:16092. https://doi.org/10.1038/s41598-020-72971-y PMID: 32999303

2. Tanimoto J. Evolutionary Games with Sociophysics: Analysis of Traffic Flow and Epidemics. Springer.;2018.

3. Tanimoto J. Sociophysics Approach to Epidemics. Springer Nature. 2021; 23.

4. Tanimoto J., Sagara H. Relationship between dilemma occurrence and the existence of a weakly dominant strategy in a two-player symmetric game. BioSystems. 2007; 90:105–114. https://doi.org/10.1016/j.biosystems.2006.07.005 PMID: 17188808

5. Wang Z., Kokubo S., Jusup M., Tanimoto J. Universal scaling for the dilemma strength in evolutionary games. Physics of life reviews. 2015; 14:1–30. https://doi.org/10.1016/j.plrev.2015.04.033 PMID: 25979121

6. Wang Z., Kokubo S., Jusup M., Tanimoto J. Dilemma strength as a framework for advancing evolutionary game theory: "Universal scaling for the dilemma strength in evolutionary games". Physics of life reviews. 2015; 14:56–58. https://doi.org/10.1016/j.plrev.2015.07.012 PMID: 26298212

7. Habib A., Kabir K. A., Tanimoto J. "Do humans play according to the game theory when facing the social dilemma situation?" A survey study. Evergreen. 2020; 7(1). https://doi.org/10.5109/2740936

8. Fehr E., Gachter S. Cooperation and punishment in public goods experiments. American Economic Review. 1999; 90:980–994. https://doi.org/10.1257/aer.90.4.980

9. Vásárhelyi Z., Scheuring I. Invasion of cooperators in lattice populations: Linear and non-linear public good games. BioSystems. 2013; 113:81–90. https://doi.org/10.1016/j.biosystems.2013.05.003 PMID: 23727301

10. Nowak M. A. Five rules for the evolution of cooperation. science. 2006; 314:1560–1563. https://doi.org/10.1126/science.1133755 PMID: 17158317

11. Trivers R. L. The evolution of reciprocal altruism. The Quarterly review of biology. 1971; 46:35–57. https://doi.org/10.1086/406755

12. Nowak M. A., May R. M. Evolutionary games and spatial chaos Nature. 1992; 359:826–829.

13. Chaudhuri A., Paichayontvijit T. Smith A., Belief heterogeneity and contributions decay among conditional cooperators in public goods games. Journal of Economic Psychology. 2017; 58:15–30. https://doi.org/10.1016/j.joep.2016.11.004

14. Cao X.B., Du W.-B., Rong Z.H. The evolutionary public goods game on scale-free networks with heterogeneous investment Physica A: Statistical Mechanics and its Applications. 2010; 389:1273–1280. https://doi.org/10.1016/j.physa.2009.11.044

15. Fischbacher U., Gächter S., Fehr E. Are people conditionally cooperative? Evidence from a public goods experiment. Economics letters. 2001; 71:397–404. https://doi.org/10.1016/S0165-1765(01)00394-9

16. Zhang L., Xie Y., Huang C., Li H., Dai Q. Heterogeneous investments induced by historical payoffs promote cooperation in spatial public goods games. Chaos, Solitons & Fractals. 2020; 133:109675. https://doi.org/10.1016/j.chaos.2020.109675

17. Panchanathan K., Boyd R. Indirect reciprocity can stabilize cooperation without the second-order free rider problem. Nature. 2004; 432:499–502. https://doi.org/10.1038/nature02978 PMID: 15565153

18. Ghang W., Nowak M. A. Indirect reciprocity with optional interactions. Journal of theoretical biology. 2015; 365:1–11. https://doi.org/10.1016/j.jtbi.2014.09.036 PMID: 25305556

19. Ohtsuki H., Iwasa Y., Nowak M. A. Indirect reciprocity provides a narrow margin of efficiency for costly punishment. Nature. 2009; 457:79. https://doi.org/10.1038/nature07601 PMID: 19122640

20. Berger U. Learning to cooperate via indirect reciprocity. Games and Economic Behavior. 2011; 72:30–37. https://doi.org/10.1016/j.geb.2010.08.009

21. Sylwester K., Roberts G. Reputation-based partner choice is an effective alternative to indirect reciprocity in solving social dilemmas. Evolution and Human Behavior. 2013; 34:201–206. https://doi.org/10.1016/j.evolhumbehav.2012.11.009

22. Marsh C. Indirect reciprocity and reputation management: Interdisciplinary findings from evolutionary biology and economics. Public Relations Review. 2018; 44:463–470. https://doi.org/10.1016/j.pubrev.2018.04.002

23. Gong B., Yang C. Cooperation through indirect reciprocity: The impact of higher-order history. Games and Economic Behavior. 2019; 118:316–341. https://doi.org/10.1016/j.geb.2019.09.001

24. Romano A., Balliet D., Wu J. Unbounded indirect reciprocity: Is reputation-based cooperation bounded by group membership?. Journal of Experimental Social Psychology. 2017; 71:59–67. https://doi.org/10.1016/j.jesp.2017.02.008

25. Santos F. C., Santos M. D., Pacheco J. M. Social diversity promotes the emergence of cooperation in public goods games. Nature. 2008; 454:213–216. https://doi.org/10.1038/nature06940 PMID: 18615084

26. Wang L., Chen T., You X., Wang Y. The effect of wealth-based antiexpectation behaviors on public cooperation. Physica A Statistical Mechanics & Its Applications. 2018; 493:84–93. https://doi.org/10.1016/j.physa.2017.10.034 PMID: 11541307

27. Liu P., Liu J. Contribution diversity and incremental learning promote cooperation in public goods games. Physica A-statistical Mechanics and Its Applications. 2017; 486:827–838. https://doi.org/10.1016/j.physa.2017.05.057

28. Santos F. C., Pinheiro F. L., Lenaerts T., Pacheco J. M. The role of diversity in the evolution of cooperation. Journal of Theoretical Biology. 2012; 299:88–96. https://doi.org/10.1016/j.jtbi.2011.09.003 PMID: 21930134

29. Zhang B., An X., Dong Y. Conditional cooperator enhances institutional punishment in public goods game. Applied Mathematics and Computation. 2021; 390:125600. https://doi.org/10.1016/j.amc.2020.125600

30. Flores L.S., Fernandes H.C.M., Amaral M. A., Vainstein M. H. Symbiotic behaviour in the public goods game with altruistic punishment. Journal of Theoretical Biology. 2021; 524:110737. https://doi.org/10.1016/j.jtbi.2021.110737 PMID: 33930439

31. Fehr E., Gächter S. Altruistic punishment in humans. Nature. 2002; 415:137–140. https://doi.org/10.1038/415137a PMID: 11805825

32. Rockenbach B., Milinski M. The efficient interaction of indirect reciprocity and costly punishment. Nature. 2006; 444:718–723. https://doi.org/10.1038/nature05229 PMID: 17151660

33. Denant-Boemont L., Masclet D., Noussair C. N. Punishment, counterpunishment and sanction enforcement in a social dilemma experiment. Economic theory. 2007; 33:145–167. https://doi.org/10.1007/s00199-007-0212-0

34. Clutton-Brock T. H., Parker G. A. Punishment in animal societies. Nature. 1995; 373:209–214. https://doi.org/10.1038/373209a0 PMID: 7816134

35. Fowler J. H. Altruistic punishment and the origin of cooperation. Proceedings of the National Academy of Sciences of the United States of America. 2005; 102:7047–7049. https://doi.org/10.1073/pnas.0500938102 PMID: 15857950

36. Deng Z., Huang Y., Gu Z., Ligao. Multigames with social punishment and the evolution of cooperation. Physica A-statistical Mechanics and Its Applications. 2018; 505:164–170. https://doi.org/10.1016/j.physa.2018.03.054

37. Santos M. D., Wedekind C., Reputation based on punishment rather than generosity allows for evolution of cooperation in sizable groups. Evolution and Human Behavior. 2015; 36:59–64. https://doi.org/10.1016/j.evolhumbehav.2014.09.001

38. Jiao Y., Chen T., Chen Q. Probabilistic punishment and reward under rule of trust-based decision-making in continuous public goods game. Journal of Theoretical Biology. 2020; 486:110103. https://doi.org/10.1016/j.jtbi.2019.110103 PMID: 31809719

39. Wang S., Liu L., Chen X. Tax-based pure punishment and reward in the public goods game. Physics Letters A. 2021; 386:126965. https://doi.org/10.1016/j.physleta.2020.126965

40. Szolnoki A., Perc M. Reward and cooperation in the spatial public goods game. EPL (Europhysics Letters). 2010; 92:38003. https://doi.org/10.1209/0295-5075/92/38003

41. Sigmund K., Hauert C., Nowak M. A. Reward and punishment Proceedings of the National Academy of Sciences. 2001; 98:10757–10762. https://doi.org/10.1073/pnas.161155698 PMID: 11553811

42. Liu L., Chen X. The Evolution of Cooperation and Reward in a Corrupt Environment FAC-PapersOnLine. 2020; 53:16938–16945. https://doi.org/10.1016/j.ifacol.2020.12.1239

43. dos Santos M. The evolution of anti-social rewarding and its countermeasures in public goods games. Proceedings of the Royal Society of London B: Biological Sciences. 2015; 282:20141994. https://doi.org/10.1098/rspb.2014.1994 PMID: 25429015

44. Hauert C. Replicator dynamics of reward & reputation in public goods games. Journal of Theoretical Biology. 2010; 267:22–28. https://doi.org/10.1016/j.jtbi.2010.08.009 PMID: 20708018

45. Sasaki T., Uchida S. Rewards and the evolution of cooperation in public good games. Biology letters. 2014; 10:20130903. https://doi.org/10.1098/rsbl.2013.0903 PMID: 24478200

46. Ya Li B. N., Chen S. Reward depending on public funds stimulates cooperation in spatial prisoner's dilemma games. Chaos Solitons & Fractals. 2018; 114:38–45. https://doi.org/10.1016/j.chaos.2018.07.002

47. Fu M., Guo W., Cheng L., Huang S., Chen D. History loyalty-based reward promotes cooperation in the spatial public goods game. Physica A:statistical Mechanics and Its Applications. 2019; 525:1323–1329. https://doi.org/10.1016/j.physa.2019.03.108

48. Wang X., Nie S., Jiang L., Wang B., Chen S. Role of delay-based reward in the spatial cooperation. Physica A:statistical Mechanics and Its Applications. 2017; 465:153–158. https://doi.org/10.1016/j.physa.2016.08.014

49. Wu Y., Zhang Z., Chang S. Reciprocal reward promotes the evolution of cooperation in structured populations. Chaos Solitons & Fractals. 2019; 119:230–236. https://doi.org/10.1016/j.chaos.2019.01.006

50. Hu L., He N., Weng Q., Chen X., Perc M. Rewarding endowments lead to a win-win in the evolution of public cooperation and the accumulation of common resources. Chaos Solitons & Fractals. 2020; 134:109694. https://doi.org/10.1016/j.chaos.2020.109694

51. Milinski M., Semmann D., Krambeck H.J. Reputation helps solve the tragedy of the commons. Nature. 2002; 415:424–426. https://doi.org/10.1038/415424a PMID: 11807552

52. McIntosh C., Sadoulet E., Buck S., Rosada T. Reputation in a public goods game: Taking the design of credit bureaus to the lab. Journal of Economic Behavior & Organization. 2013; 95:270–285. https://doi.org/10.1016/j.jebo.2012.09.013

53. Dai Y., Lu P. When does inferring reputation probability countervail temptation in cooperative behaviors for the prisoners dilemma game?. Chaos Solitons & Fractals. 2015; 78:238–244. https://doi.org/10.1016/j.chaos.2015.07.030

54. Cox C. A., Jones M. T., Pflum K. E., Healy P. J. Revealed reputations in the finitely repeated prisoners dilemma. Economic Theory. 2015; 58:441–484. https://doi.org/10.1007/s00199-015-0863-1

55. Wang X., Chen X., Gao J., Wang L. Reputation-based mutual selection rule promotes cooperation in spatial threshold public goods games. Chaos Solitons & Fractals. 2013; 56:181–187. https://doi.org/10.1016/j.chaos.2013.07.019

56. Yang W., Wang J., Xia C. Evolution of cooperation in the spatial public goods game with the third-order reputation evaluation. Physics Letters A. 2019; 383:125826. https://doi.org/10.1016/j.physleta.2019.07.014

57. Wang L., Chen T., Wu Z. Promoting cooperation by reputation scoring mechanism based on historical donations in public goods game. Applied Mathematics and Computation. 2021; 390:125605. https://doi.org/10.1016/j.amc.2020.125605

58. Semmann D., Krambeck H.J., Milinski M. Volunteering leads to rock-paper-scissors dynamics in a public goods game. Nature. 2003; 425:390. https://doi.org/10.1038/nature01986 PMID: 14508487

59. Rivas M. F., Sutter M. The benefits of voluntary leadership in experimental public goods games. Economics Letters. 2011; 112:176–178. https://doi.org/10.1016/j.econlet.2011.04.007

60. Bochet O., Page T., Putterman L. Communication and punishment in voluntary contribution experiments. Journal of Economic Behavior & Organization. 2006; 60:11–26. https://doi.org/10.1016/j.jebo.2003.06.006

61. Szabó G., Hauert C. Phase transitions and volunteering in spatial public goods games. Physical review letters. 2002; 89:118101. https://doi.org/10.1103/PhysRevLett.89.118101 PMID: 12225171

62. Dragone D., Galeotti F., Orsini R. Non-Monetary Feedback Induces More Cooperation: Students and Workers in a Voluntary Contribution Mechanism. Revue conomique. 2017; 68:793–808. https://doi.org/10.3917/reco.pr3.0095

63. Grujić J., Cuesta J. A., Sanchez A. On the coexistence of cooperators, defectors and conditional cooperators in the multiplayer iterated Prisoner's Dilemma. Journal of theoretical biology. 2012; 300:299–308. https://doi.org/10.1016/j.jtbi.2012.02.003 PMID: 22530239

64. Kirchkamp O., Nagel R. Naive learning and cooperation in network experiments. Games and Economic Behavior. 2007; 58:269–292. https://doi.org/10.1016/j.geb.2006.04.002

65. Traulsen A., Semmann D., Sommerfeld R. D., Krambeck H.-J., Milinski M. Human strategy updating in evolutionary games. Proceedings of the National Academy of Sciences. 2010; 107:2962–2966. https://doi.org/10.1073/pnas.0912515107 PMID: 20142470

66. Grujić J., Fosco C., Araujo L., Cuesta J. A., Sánchez A. Social experiments in the mesoscale: Humans playing a spatial prisoner's dilemma. PloS one. 2010; 5:e13749. https://doi.org/10.1371/journal.pone.0013749 PMID: 21103058

67. Kim D. G. Population Uncertainty in Voluntary Contributions of Public Goods. Journal of Economic Behavior and Organization. 2018; 145:218–231. https://doi.org/10.1016/j.jebo.2017.10.009

68. Wang Y., Chen T., Chen Q., Si G. Emotional decisions in structured populations for the evolution of public cooperation. Physica A: Statistical Mechanics and its Applications. 2017; 468:475–481. https://doi.org/10.1016/j.physa.2016.10.077

69. Bechara A., Damasio H., Damasio A. R. Emotion, decision making and the orbitofrontal cortex. Cerebral cortex. 2000; 10:295–307. https://doi.org/10.1093/cercor/10.3.295 PMID: 10731224

70. Greene J. D., Sommerville R. B., Nystrom L. E., Darley J. M., Cohen J. D. An fMRI investigation of emotional engagement in moral judgment. Science. 2001; 293:2105–2108. https://doi.org/10.1126/science.1062872 PMID: 11557895

71. Kühberger A. The influence of framing on risky decisions: A metaanalysis. Organizational behavior and human decision processes. 1998; 75:23–55. https://doi.org/10.1006/obhd.1998.2781 PMID: 9719656

72. Haselhuhn M. P., Mellers B. A. Emotions and cooperation in economic games. Cognitive Brain Research. 2005; 23:24–33. https://doi.org/10.1016/j.cogbrainres.2005.01.005 PMID: 15795131

73. Chen Q., Chen T., Wang Y. How the expanded crowd-funding mechanism of some southern rural areas in China affects cooperative behaviors in threshold public goods game. Chaos Solitons & Fractals. 2016; 91:649–655. https://doi.org/10.1016/j.chaos.2016.08.015

74. Chen Q., Chen T., Wang Y. Publishing the donation list incompletely promotes the emergence of cooperation in public goods game. Applied Mathematics and Computation. 2017; 310:48–56. https://doi.org/10.1016/j.amc.2017.04.017

75. Chen Q., Chen T., Wang Y. Cleverly handling the donation information can promote cooperation in public goods game. Applied Mathematics and Computation. 2019; 346:363–373. https://doi.org/10.1016/j.amc.2018.10.068

76. Chen T., Wu Z. H., Wang L. Donating money is not the only way to sustain cooperation in public goods game. International Journal of Modern Physics C. 2018; 28:1750149. https://doi.org/10.1142/S0129183117501492

77. Wang Z., Chen T., Wang Y. Leadership by example promotes the emergence of cooperation in public goods game. Chaos Solitons & Fractals. 2017; 101:100–105. https://doi.org/10.1016/j.chaos.2017.05.027

78. Liu Y., Chen T., Wang Y. Sustainable cooperation in Village Opera based on the public goods game. Chaos Solitons & Fractals. 2017; 103:213–219. https://doi.org/10.1016/j.chaos.2017.06.007

79. Kabir K. A., Tanimoto J., Wang Z. Influence of bolstering network reciprocity in the evolutionary spatial Prisoner's Dilemma game: A perspective. European Physical Journal B. 2018; 91:1–10.

80. Tanimoto J. Difference of reciprocity effect in two coevolutionary models of presumed two-player and multiplayer games. Physical Review E. 2013; 87:062136. https://doi.org/10.1103/PhysRevE.87.062136 PMID: 23848656

81. Kabir K. A., Tanimoto J. The role of pairwise nonlinear evolutionary dynamics in the rock-paper-scissors game with noise. Applied Mathematics and Computation. 2021; 394:125767. https://doi.org/10.1016/j.amc.2020.125767

82. Shigaki K., Kokubo S., Tanimoto J., Hagishima A., Ikegaya N. Does copy-resistance enhance cooperation in spatial prisoner's dilemma?. EPL (Europhysics Letters). 2012; 98:40008. https://doi.org/10.1209/0295-5075/98/40008