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Donation of richer individual can support cooperation in spatial voluntary prisoner's dilemma game

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ABSTRACT

The compassionate behavior is present throughout the human society, and rich people always could not help having sympathy for poor individual. Inspired by this fact, we consider a donation model to describe the emergency and maintenance of cooperation with voluntary participate in spatial prisoner's dilemma game and we study this model on a square lattice. In detail, when the focal player has the least income in the group which includes his nearest four neighbors and himself, one of his neighbors who has the highest income will donate some proportion of his extra money to him. On the other hand, if focal individual is not the poorest, he will donate some incomes to his poorest neighbor. Through numeric simulation, we conclude that our donation model can promote the evolution of cooperation monotonously. Especially, the larger proportion payoff rich people can contribute, the higher level of cooperation we can get.

1. Introduction

In our real world there exist many cooperative phenomena ranging from animals to human being. For example, in bee colony, the worker gives up its reproductive ability to help the queen reproduction, and people always cooperate with each other to collect foods. However, it is difficult to understand the widespread cooperative behavior among selfish people [1–4]. According to the Darwinian evolution theory, creatures are selfish and always tend to maximize their payoff, so the altruistic behavior will be eliminated and selfish behavior will be the fittest. Because of this interesting phenomenon, the evolution of cooperation in nature has attracted many experts to do a meaningful research [5–8].

During the last decades, the evolution game theory [9] has been proved a powerful way to solve this puzzling dilemma phenomenon from different directions which include theory and experiments [10–14]. The prisoner's dilemma game (PDG), which model has attracted a lot of interests to study the evolution of cooperation. In the original model, two players simultaneous make a choice from a strategy space which includes two strategies, cooperation (C) and defection (D) in a one-shot game. They will both receive the reward of cooperation R if both cooperate. Mutual defection will lead to the punish P for them. If one of them choose cooperate while the other defects, the former individual will receive a sucker's payoff S, defector can obtain a temptation T. The ranking of these parameter strictly observe $T > R > P > S$, and $2R > T + S$. Obviously, no matter what choice the opponent makes, defection is the best action when selfish individual only care the short-term benefit. However, mutual cooperation can help people get the highest payoff for long-term benefit. Thus, these players will fall into the so-called social dilemma.

With the development of evolutionary game theory, the predecessors have proposed many interesting methods to resolve the social dilemma. Nowak [15] attributed all these to five mechanisms: kin selection [16], direct reciprocity [17], indirect reciprocity [18], group selection [19] and spatial reciprocity [20]. Within these mechanisms, spatial reciprocity has attracted much attention and obtained fruitful results [21–26]. In line with this frame work, many different factors have been considered in structured population for exploring its impact on the evolution of cooperation. For example, environment [27,28], vertex weight [29], redistribution model [30], interdependent network [31–35], to name a few. Besides, the model with three strategies has appealed many people to research, especially voluntary participation [36,37]. In its basic model, players can act as a third role loner (L), the individual which would rely on small fix income rather than participate in the PDG, and the system will fall into cycle dominance of three strategies, thus avoiding fully defection state [38].

In our real world, there exists a kind of vampire bat, they will provide extra blood to the individuals who have no food [39]. Certainly, the same phenomenon exists in human society, some will

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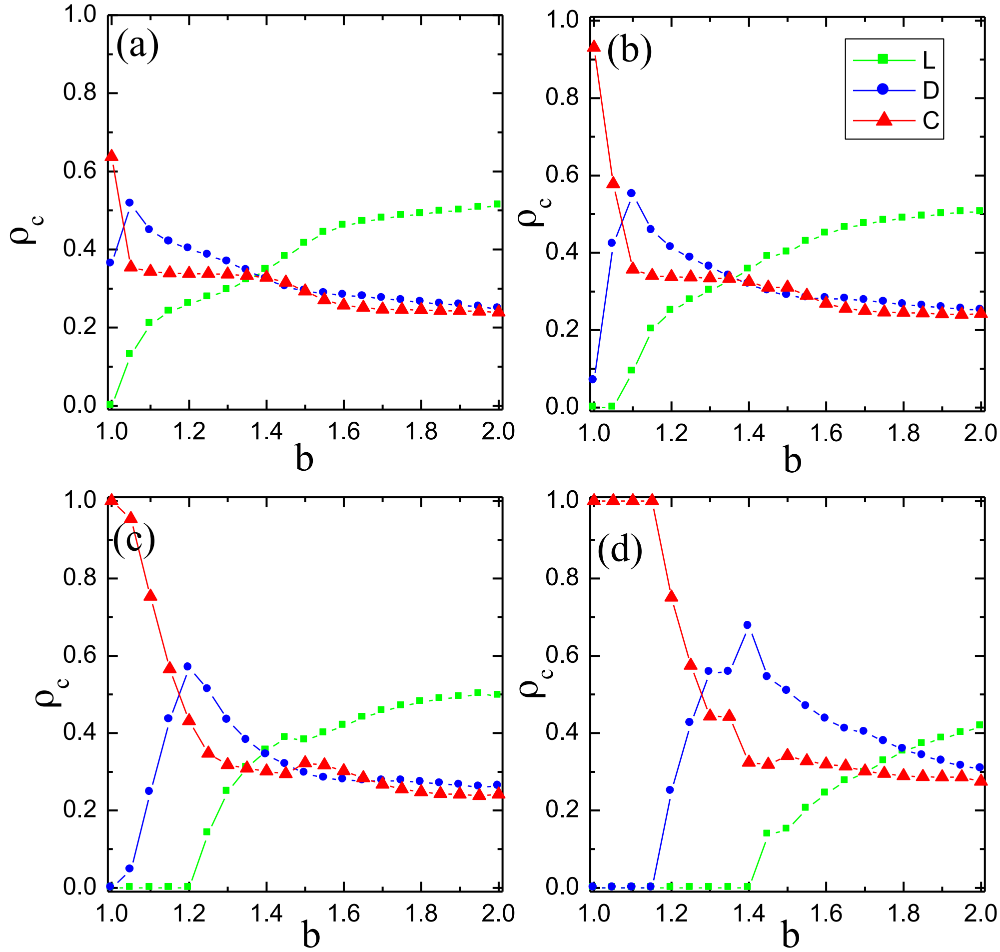

Fig. 1. The fraction of three strategies C (red), D (blue), and L (green) in dependence on the temptation to defect b for different values of u. From panel (a) to (d), the donation parameter obtains 0 (traditional version), 0.1, 0.3, 0.5, respectively. Clearly, donation model can promote the evolution of cooperation. Depicted results are obtained for $\sigma = 0.3$ and $K = 0.1$. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

bad to others, while some individuals may compassionate, they will donate some of their incomes to help the poorest people. Thus an interesting question appears: if we combine the donation model with voluntary participation to explore the evolution of cooperation, can this setup promote cooperation? Based on the Monte Carlo simulation, we find that cooperation can be greatly enhanced. Especially, when the temptation is small, cooperators can dominant the network. In the following, we will first describe the evolution game model in Section 2, and then show the numerical simulation results in Section 3. Finally, we summarize our conclusions and give a discussion in Section 4.

2. Model

We consider a voluntary prisoner's dilemma game with players located on L*L square lattice with period boundary, in which each node is occupied by a player. Each player is appointed to be either cooperator (C), defector (D) or loner (L) with equal probability, which can be described as:

$$S_x = \begin{pmatrix}1\\0\\0\end{pmatrix} \text{ or } S_x = \begin{pmatrix}0\\1\\0\end{pmatrix} \text{ or } S_x = \begin{pmatrix}0\\0\\1\end{pmatrix}. \tag{1}$$

Here, we consider the weak prisoner's dilemma game with the participant of loner, thus payoff matrix is defined as follows:

$$M = \begin{pmatrix}1 & 0 & \sigma\\ b & 0 & \sigma\\ \sigma & \sigma & \sigma\end{pmatrix} \tag{2}$$

where the parameter $b(1 < b < 2)$ denotes the temptation to defect and ensures the proper payoff ranking. The parameter σ represents the payoff loner can obtain in one-shot game, which means no matter what strategy the opponent choose, loner can get a small but fix benefit σ, his opponents can obtain the payoff σ. According to the work in ref [38], we define $\sigma = 0.3$.

When considering the evolutionary process, player i plays the game with its nearest four neighbors and obtains the income P_i:

$$P_i = \sum_{j\in N_i} S_i^T M S_j, \tag{3}$$

where N_i represents the neighbors of individual i, and its neighbors' payoff can be obtained in the same way. The income redistribution is introduced into the model in the following way: on the one hand, if focal player i's income is the smallest in group i (it includes focal player i and its nearest neighbors), the richest neighbor j will donate its income to individual i according to their income difference, and their fitness will be redefined:

$$\begin{aligned} F_i &= P_i + u^*\left(P_j - P_i\right)\\ F_j &= P_j - u^*\left(P_j - P_i\right). \end{aligned} \tag{4}$$