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Sustainable cooperation based on reputation and habituation in the public goods game

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ABSTRACT

Reputation can promote cooperation in public goods game and player's cooperative behavior is not pure economical rationality, but habituation would influence their behaviors as well. One's habituation can be formed by repeated behaviors in daily life and be affected by habitual preference. We aim to investigate the sustainable cooperation based on reputation and habit formation. To better investigate the impacts of reputation and habitual preference on the evolution and sustainability of cooperation. We introduce three types of agents into our spatial public goods game. Through numerical simulations, we find that the larger habitual preference make cooperation easier to emerge and maintain. Additionally, we find that a moderate number of agents who want to obtain more reputation (ICs) are best for the sustainability of cooperation. Finally, we observe that the variation of donations of ICs can influence greatly on the equilibrium of public goods game. When ICs reduce their donations, a proper contribution will be better to maintain the cooperative behaviors.

1. Introduction

The problem of maintaining public goods that everybody could free to use emerges in many social dilemmas (Hardin, 1968, 1998; Berkes et al., 1989; Ostrom et al., 1999; Orbell and Dawes, 1996). Therefore, for researchers, it becomes a long lasting pursuit to promote cooperation. Evolutionary game theory has become one of the most prevalent methods to study cooperation in all kinds of social dilemma situations (Nowak, 2006). In the system of evolutionary game theory, Public goods game (PGG) is regarded as a classical model for studying the evolution of cooperation (Binmore, 1994). In a typical PGG, individuals who choose cooperative strategy must contribute c to the common pool, while defectors do not. The total contribution is multiplied by a factor r, and then distributed equally among all group members. Here we can find that defection is always the best strategy. Cooperation has become a social dilemma (Wang et al., 2009; Axelrod and Hamilton, 1981; Wedekind and Milinski, 2000; Rand and Nowak, 2013).

Customarily, the agents who participate in a PGG are identified as rational and self-interested. However, in recent time many studies have indicated that no matter for what purpose, many people are willing to make sacrifices for public goods (Hauser et al., 2014). To explain the emergence and maintenance of cooperative behaviors, many mechanisms promoting cooperation have been proposed (Wu et al., 2014; Chatterjee et al., 2012; Milinski et al., 2002; Roca and Helbing, 2011; Lu, 2015; Forsyth and Hauert, 2011; Ohtsuki et al., 2015). Hauert et al. proposed a voluntary participation mechanism in the PGG and found that cooperation could be promoted by loner (Hauert and Szabó, 2003; Hauert et al., 2002). Santos et al. indicated that social diversity can promote and maintain cooperative behaviors, and explained the emergence of cooperation based on reputation and punishment (Santos et al., 2008). Cheng-yi Xia et al. introduced that people with different strategy transfer probability can promote cooperation (Zhu et al., 2014).

What's more, many theorists have shown that cooperation can also be promoted by indirect reciprocity (Nowak and Sigmund, 2005, 1998; Lotem et al., 1999). People build up good reputation or a positive image score by helping others (Nowak and Sigmund, 1998, 2005; Alexander, 1987). The empirical study of Milinski showed that when human volunteers alternated with indirect reciprocity games and this alternation produced a high level of cooperation in the PGG (Semmann et al., 2004). And Semmann et al. (2005) showed that reputation is a driving force for cooperation in PGG and sustain public resource. People are more likely to make more contributions and these extra donations can enhance their reputations (Vugt and Hardy, 2010). Actually, it is very similar with the

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realistic situations. There are always some individuals will donate to the public pool for reputation, such as entrepreneurs. They want to build up good reputation by charitable donations. Then they can obtain an amount of benefits by their good reputation which we call them long-term interests (Wedekind and Braithwaite, 2010). In reality, people live in different social networks. Their behaviors will be observed in many networks. So when different networks intertwine, it would influence the cooperation level because of the change of overall payoffs (Deng et al., 2016). If we are generous to others, and some people, we called observers, are observing our behaviors. The observers will think that we are also generous to them. On the contrary, if we are nasty to others. The observers would want avoid dealing with us in the future. Reputation play an important role in the social networks, and would create opportunities unavailable to non-cooperators (Van Vugt et al., 2007). So people not only consider the payoffs in PGG, but also take the payoffs of their behaviors in other networks into account when people make decisions. That's the reason why we call these payoffs long-term interests and why some people are willing to contribute more. For example, many entrepreneurs will do charity to establish a good reputation in society. These behaviors could improve their brand awareness so that they would gain more payoffs, just as advertisement. However, the donators will not always contribute more donations to public goods in the real world so that they will reduce the amount of their donations at some point. Furthermore, their reputations will change with the amount of the donations.

Therefore, depending on this situation, we here aim to investigate the sustainability of cooperation. The existing researches mainly introduced that the mechanism of reputation can promote cooperative behavior. As mentioned above, some people like entrepreneurs are willing to contribute more due to acquire reputation from others. These minds make them cooperate in PGG and their behaviors can exert an influence on their neighbors so that cooperation can be remarkably promoted. Nevertheless, in real world, the marginal utility of their donations will be decreasing. And neighbors will slowly accustom to their behaviors because of diminishing sensitivity (Wathieu, 2004), which means the increased amount of their reputation would reduce gradually. Hence, they will reduce their donations in the future. How will the cooperative behavior change by that time? We suppose that three types of agents are distributed randomly on a square lattice (Roca et al., 2009; Nowak and May, 1992; Szolnoki et al., 2009a; Li et al., 1847; Wang and Chen, 2015), including investor (IC), cooperator (C), defector (D). Investors are the persons who want to gain the long-term interests by obtaining reputation. They are always cooperative, but they can independently change their donations by themselves. They will contribute more at the beginning of the spatial PGG and reduce the contribution in the future. Their reputations will increase when they give extra donations. On the contrary, it will decrease when they reduce their donations. The value of their reputations will be influenced by a parameter h, which we call it habitual preference. It denotes that the degree of the influence of ICs by their additional contributions or the amount which they reduce. Notably, the purpose that investors contribute more is to obtain long-term interests so that we can regard their reputations as their benefits in PGG. Based on above hypotheses, we primarily focus on researching the importance of investors, and observing the impacts of habitual preference, the number of ICs and the variation of donations on evolution of cooperation in spatial PGG.

This paper is organized as follow. We introduce our model in Section 2. The numerical simulation results have been shown in Section 3. Conclusion is provided in Section 4.

2. The PGG model with three types of agents

We simulate our model with three types of agents (ICs, Cs and Ds) on a $L \times L$ regular lattice with periodic boundary conditions. We assume that N agents are randomly distributed on the square lattice. Every agent i has k neighbors. Initially, the fraction of ICs are dynamic in order to satisfy experiment demand. Other agents are regarded as Cs and Ds with equal probability. Meanwhile, each agent will make decision simultaneously.

Every agent attends $G = k + 1$ PGG groups (Szabó and Fath, 2007) and calculates a payoff according to the following equation:

$$P_i = \sum_{j \in \Omega_i} P_i^j + \frac{R_i}{50} = \sum_{j \in \Omega_i} \left(r \frac{c_\alpha n_\alpha^j + c_\beta n_\beta^j}{k_j + 1} - c_i \right) + \frac{R_i}{50} \tag{1}$$

where $r(1 < r < N)$ stands for a synergy factor (Szolnoki and Perc, 2010); Ω_i denotes the set of PGG groups in which agent $i(IC, C, D)$ participates. j is one of the set of PGG groups. n_α^j and n_β^j mean the number of ICs and Cs in PGG group j respectively. $c_\alpha (c_\alpha = u)$ stands for the number which agent IC will donate. $c_\beta (c_\beta = 1)$ denotes the donation of C. k_j is the number of neighbors of central agent in PGG group j. R_i is the reputation of agent i. We assume that only ICs have reputation. So R_C and R_D is set to be 0. R_{IC} is calculated by Eqs. (3) and (4). $\frac{R_i}{50}$ is the long-term benefit which agent i obtain by reputation. Only ICs have these benefits. There are two reasons for $\frac{R_i}{50}$. Firstly, from the perspective of reality, the investors can obtain payoffs by their reputation. However, as mention above, the payoffs are a kind of long-term interests. It means reputation cannot become the payoffs immediately. So here 50 can been seen as the time cost of reputation. Secondly, in terms of mathematics, R_i is calculated by Eqs. (3) and (4). The value of R_i is too big so that its influence on the evolutionary process losses authenticity. 50 is a proper value for evolution by experiment. It makes the model more accurate.

Additionally, ICs, who want to pursue reputation, always cooperate and contribute u to the group and their reputation can be increased with the time. Their strategies are difficult to be changed by others. However, Cs and Ds are easier to be influenced by ICs. So agent Cs and Ds will update his strategy with the following probability by selecting his neighbor j randomly (Szabó and Fath, 2007):

$$W\left(c_i \longleftarrow c_j\right) = \frac{1}{1 + \exp\left(\frac{P_i - P_j}{K}\right)} \tag{2}$$

where K denotes the impact of ambient noise, and we set $K = 0.1$ here based on previous studies (Szabó and Hauert, 2002). According to this formula we can know the agent with higher payoff will be chose with high probability.

On the beginning, we assume that ICs contribute $u = 2$ to the group and their reputation will increase with time, but the increments of the reputation decrease with time. In the real-world systems, the individuals who like ICs cannot obtain the reputation from others all the time, so that their reputation always have an extreme value. And the increments of the reputation are influenced by a parameter h, which we call it habitual preference. So we can calculate the reputation of the ICs as follow:

$$R_{IC}(t) = R_{IC}(t-1) + (1 - ht)(u - 1) \tag{3}$$

When their reputation reaches the maximum, the reputation will not be updated with the time. Firstly, the system will reach equilibrium. When $t \le 1000$, we will not change the value of u in order to observe the stability of the system. Then we reduce the value of u when $t > 1000$. And the reputation of ICs will change as follow:

$$R_{IC}(t) = R_{IC}(t-1) - [1 - h(t - 1000)](2 - u) \tag{4}$$