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Promotion of cooperation induced by heterogeneity of both investment and payoff allocation in spatial public goods game

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HIGHLIGHTS

- Provide a new PGG model with both heterogeneous investment and payoff allocation.
- Address three different feedback mechanisms to explore the intrinsic motivation of cooperative behavior.
- Construct a method to measure the investment comparative advantages.
- The mixed mechanism promotes evolution of cooperation and formation of win–win situation.
- The extent of cooperation is promoted under the structures of the BA scale free networks.

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ABSTRACT

Heterogeneity has attracted mounting attention across multiple disciplines and is confirmed to be a greater promoter of cooperation. It is often the case that the heterogeneity always exists in investment and payoff allocation concurrently instead of separately. In addition, the factors that affect heterogeneous investment and payoff allocation are various. Inspired by this, this paper extends the previous models by incorporating heterogeneous investment and payoff allocation into the typical PGG model to further investigate the incentive mechanisms of cooperative behavior. In order to better understand the model, three different feedback mechanisms, namely the wealth-preference mechanism, the social-self-preference mechanism, and the mixed-preference mechanism, are addressed. The former two mechanisms correspond to the case of single factor and the latter corresponds to the case of double factors. The numerical simulations indicate that feedback mechanism by bridging the connections between the investment and the payoff allocation can reduce the free-rider problem. Furthermore, it is found that the cooperative frequency and average payoff perform better in the case of the mixed-preference mechanism where players will not only take previous payoff feedback as well as current investment but also their social status into their game decision-making process. In addition, full cooperation and profitability over all players can be promoted by means of increasing r or reducing α. At last, compared with another two classic networks, the extent of cooperation is promoted under the structures of the BA scale free networks.

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1. Introduction

Cooperation is omnipresent in natural, economic and social systems [1]. Yet understanding the question why selfish players to participate in costly cooperative activities remains a challenge and needs much work to do. So far, more and more scholars across multiple disciplines resort to the evolutionary game theory to investigate the cooperative behavior. For instance, the Prisoners Dilemma Game (PDG) [2] and the Snowdrift Game (SG) [3] are the simplest game models, which provide a suitable theoretical framework to analyze the cooperative or uncooperative behavior in the pair-wise interactions. In particular, the Public Goods Game (PGG) provides a reasonable explanation for group interactions among multiple players, such as environmental protection problem, public resources problem and team cooperation problem [4]. In the typical PGG model, all players must choose whether to invest simultaneously, and then all investments are multiplied by an enhancement factor r ($r > 1$) and equally redistributed among all players irrespective of their investments. According to a theoretical prediction, the best strategy for all players is to become defectors (or called free-riders) in a well-mixed situation because of costly cooperation [5], which is inconsistent with the observation that the cooperative behaviors are ubiquitous in realistic society.

Aiming at revealing the reason why cooperation can sustain in the context with selfish individuals, quite a few mechanisms have been proposed. Some scholars believe that the cooperation level can be improved by the mechanisms of volunteering [6], reputation [7], conditional strategies [8], rewards and punishment [9–11]. Nevertheless, these mechanisms do not work well in all conditions. For example, the effects of rewards and punishment are enervated by the consequent problems such as the fairness of the reward criteria, the second-order free-riders [12] or the counter-punishment caused by the penalty cost [13]. Along with the seminal research introduced by Nowak and May, it is found that the various spatial topologies formed by the local interactions among the structured population can also induce the emergence of cooperation [14,15], such as regular lattices, small-world networks, BA scale free networks [16,17], which can be called the network reciprocity [18]. Besides, the introduction of heterogeneity triggers the development of spatial evolutionary theory, and it has confirmed to be a greater promoter of cooperation. So far, the researches of heterogeneity mainly focus on the following aspects. (1) Personality. Some researchers concentrated on the inhomogeneities in the personality, such as production capability, social status or activity [19–21]. (2) Strategy updating rules. Individual learning process from neighbors is no longer follow a random selection, but on neighbor's payoff, social influence, memory or fitness [22–25]. (3) Enhancement factor. Instead of identical enhancement factor, Li et al. and Chen et al. constructed a dynamical enhancement factor by considering cooperative level [26,27]. (4) Investment. The heterogeneous investment assigned to each PGG group should be based on the player's degree [28,29], previous payoff [30,31], cooperative qualities [32–34], or even a random variable [35], instead of uniform. (5) Payoff allocation. Peng et al. and Zhang et al. regarded the individuals' degree as the main criteria of payoff allocation [36,37].

These previous works provide a further perspective on understanding the emergence and persistence of cooperation, and have made it clear that heterogeneity plays a pivotal role on the emergence of cooperation. In particular, these researches can shed a light on understanding the collective dilemmas existing in the realistic systems by employing public goods games. However, most previous works on the typical PGG model focused on the heterogeneity of the investment or the payoff allocation, respectively, which failed to adequately construct a PGG model to establish connections between the investment and payoff allocation. This is out of accord with the actual economic behavior to a certain degree. In fact, it is often the case that the heterogeneity always exists in investment and payoff allocation concurrently. For example, when confronting with several alternative projects, a rational investor will tend to differentiate projects and pursue the most profitable project and then invest more to it in the next time. In return, without considering extraneous risks, the payoff will be augmented to a large extent with the increment of investment. As can be seen, the investment and the payoff allocation are the supplementary processes that promote mutually [30,31]. In addition, the factors that affect heterogeneous investment and payoff allocation are various.

Inspired by this, we in this work extend the previous models by incorporating heterogeneous investment and payoff allocation into the typical PGG model to further investigate the incentive mechanisms of cooperative behavior. In order to gain further insights into this model, we address three different feedback mechanisms, namely the wealth-preference mechanism, the social-self-preference mechanism, and the mixed-preference mechanism. In the wealth-preference mechanism, players regard the current investment as an important prerequisite for the payoff allocation and meanwhile consider the previous payoff feedback as a major reference for their future investment. In the social-self-preference mechanism, player's heterogeneous investment and payoff allocation are only based on their degree that may be presented social status. In this case, players are more likely to contribute more to groups centered on themselves in which they can be seemed as the hub players. In the mixed-preference mechanism, players will not only take previous payoff feedback as well as current investment but also their social status into their game decision-making process. The key contribution of this work is to construct a new PGG model by incorporating heterogeneous investment and payoff allocation concurrently and investigate the cooperative behaviors under three mechanisms. In this way, we can gain a thorough understanding about the role of heterogeneity in the spatial PGG.

The remainder of this paper is organized as follows. The model with heterogeneity of both investment and payoff allocation is constructed in Section 2. Then the corresponding simulation results are given in Section 3. At last, the conclusions are provided in Section 4.