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Heterogeneity of inferring reputation probability in cooperative behaviors for the spatial prisoners' dilemma game

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HIGHLIGHTS

- This paper investigates the heterogeneity of inferring reputation, which is not adequately revealed before.
- The effect of inferring reputation probability is decomposed into two parts, the mean effect and the heterogeneity effect.
- The mean merely enhances cooperation as it is smaller, and undermines cooperation when it is larger.
- The heterogeneity does not influence cooperation on the whole range of mean, but reduces cooperation with a smaller mean and propels cooperation with a larger mean.

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ABSTRACT

As an important mechanism designed to counteract temptation and promote cooperation, reputation is widely investigated in the spatial Prisoners' dilemma game. Existing research assumes that each agent imitates the neighbor that has the highest reputation with an inferring reputation probability p_i, which is heterogeneous and enhances cooperation to some extent. So far the effect of heterogeneity has not been adequately revealed. Therefore, we will inspect the heterogeneity effect on a square lattice where agents play the prisoners' dilemma game. It is assumed that the inferring reputation probability is normally distributed, and its mean p and standard deviation sd represent its mean effect and heterogeneity effect on cooperation. Simulation results demonstrate that the mean or overall effect on cooperation fits a nonlinear relationship. It promotes cooperation substantially as the mean is smaller ($p < 0.5$), it stabilizes cooperation at a stable state as the mean is in the middle range, and it undermines cooperation while p is larger ($p > 0.8$). The heterogeneity effect varies with p as well: In the whole range of p, sd neither promotes nor reduces cooperation. However, heterogeneity reduces cooperation when p is smaller ($p < 0.5$), but turns to increasing cooperation when it grows larger ($p \geqslant 0.5$).

1. Introduction

As cooperation is vital for the human society, promoting it becomes a permanent pursuit for scientists [1–9]. Related solutions and models have been proposed to promote cooperation [1–62]. As the temptation seduces individuals to defect and therefore reduces cooperation [1,10], the core idea is to develop mechanisms overcoming the temptation that leads to

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defection and free riding [6,11–13]. The Prisoner's dilemma game, the snowdrift game, and the public good game, are usually applied to investigate how temptation influences cooperation and to suggest possible countervailing solutions [14–25].

Related solutions have been developed to counteract temptation and promote cooperation, such as selective investment [9], kin selection [26], spatial reciprocity [27–31], group selection [32–34], altruism punishment [35,36,43], tolerance [44], spatially structured populations [27,37,38,45,63–66], networks or graphs [67–73], social value [46], social diversity [47,48], volunteerism [49–51], etc. It has been proved that all of these solutions are able to promote cooperation to some extent. Most of these models are executed under the paradigm of evolutionary games [74–76]: agents interact with each other within limited numbers of iterations or times; they adopt actions based on the rule of teaching or learning [74,75]; agents are not nuclear powers and they belong to different sub-groups [75] or have specific individual networks [76]; the outcome indicator or dependent variable is still the cooperation rate. Among these solutions and methods, reputation is proposed as an effective solution to overcome temptation and enhance cooperation [5,6,13,39–42,51].

Due to the cost and errors in information dissemination [5], the highest reputation for each agent is identified with a probability p_i, which is deemed the inferring reputation probability. It has been found that p_i promotes cooperation more than the more traditional way [5]. In the real world, heterogeneity is inevitable and each player might have a different p_i. The issue of heterogeneity has aroused much attention. Scientists believe that heterogeneity is able to raise cooperation under specific conditions [77–83]: optimal and heterogeneous incentives or payoffs can promote cooperation [77]; heterogeneous aspirations [78], diversity of reproduction [81] or social diversity [80,81], and diversity of teaching and learning [82] promote cooperation as well. However, it is possible that heterogeneity impedes cooperation as well in that strong heterogeneity does not substantially promote cooperation for each agent [83].

Therefore, the effect of heterogeneity is diverse and there ought to be an optimal degree. Heterogeneity is critical factor in reputation studies [5,11,40], and in spatial prisoners' dilemma games how different levels of heterogeneity of reputation influence cooperation would be significant as well. This study focuses on heterogeneity of inferring reputation in order to investigate how the heterogeneity influences cooperation. The prisoner's dilemma game is widely applied [5,78]. Following the paradigm of spatial prisoners' dilemma games [4,5,52–54], our model is built on a square lattice [3,45,53,55–57] and each one has eight neighbors (Moore neighbor) and imitates the neighbor with highest reputation [5,6,12,45] or imitates randomly. Then, we collect data to evaluate effects of the inferring reputation probability and its heterogeneity on cooperation.

2. Model

Similar to previous research, agents play prisoners' dilemma games [4,5,52–54,78] and interact with each other in a square lattice [5,38,45,53,55–57]. Model settings are presented in six aspects as follows.

2.1. The payoff matrix

We apply the reduced payoff matrix of the prisoners' dilemma game [4–6]. Agents play the prisoners' dilemma game with eight neighbors, and each one has two strategy options that are cooperation and defection, which are denoted as C and D respectively. The payoff matrix is shown in Fig. 1, which has only one parameter b that satisfies $b \in (1, 2]$, which coincides with existing studies [5,6]. If one cooperates with a neighbor who cooperates he receives 1, if he or she defects with a neighbor who cooperates then the payoff is b, and the payoff would be 0 otherwise. As $b > 1$, the preferred strategy would be defecting with a cooperative partner.

2.2. Calculation of reputation

Eq. (1) is applied to generate reputation for each agent. Initially, each agent is given a reputation of 1. Afterwards, reputation is solely determined by the increment of reputation, $\Delta_i Z$, or the action by each one at each time t [5,6]. If action is C, then $\Delta_i Z = 1$ and $\Delta_i Z = 0$ if action is D. The terms of $Z_i(t)$ and $Z_i(t-1)$ represent individual's reputation at time t and $t-1$.

$$Z_i(t) = Z_i(t-1) + \Delta_i Z. \quad (1)$$

2.3. Action of focal agent

For each focal agent, neighbor* denotes each agent's neighbor with highest reputation. It is assumed that each focal agent successfully finds his or her neighbor* with the probability p_i that is called inferring reputation probability [5]. Hence, as is indicated in Fig. 2, each focal agent or individual targets his or her own neighbor* successfully with the probability p_i, and imitates what the neighbor* does with the transition probability P_{ij}. In other cases, agent imitates one neighbor randomly.

2.4. Strategy updating

In Fig. 2, the focal agent adopts the action of neighbor* with the transition probability P_{ij}, and imitates a random neighbor for other cases. The formation of P_{ij} is shown in Eq. (2), where s_i and s_j represent the focal agent's current action and