The Effect of Conformists' Behavior on Cooperation in the Spatial Public Goods Game

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Abstract. In this paper, we investigate the effects of rational and irrational conformity behavior on the evolution of cooperation in public goods game. In general, conformist should also probably consider the difference of payoff between himself and his neighbors. Therefore, we divide the players into two categories: traditional payoff-driven players and secondly, rational conformists. Rational conformists will only update their strategy according to the conformity-driven rule when they get a higher payoff than their neighbors, whereas irrational conformists' updating rule is the opposite. Remarkably, we find that both rational and irrational conformists enhance cooperation in the spatial public goods game. However, the differences in intensity of this positive effect between rational and irrational conformists are tremendous, and the latter promotes a higher level of cooperation to reach a much higher level and extensive positive effect.

Keywords: Public goods game · Conformity behavior · Social dilemmas · Cooperation

1 Introduction

Cooperation and defection are two key strategies usually existing at the heart of every social dilemma [1–4]. In the areas of environmental resources or social benefits, defectors usually reap benefits on the expense of cooperators. The "tragedy of the commons" succinctly describes such a situation [5, 6]. In the last two decades, evolutionary game theory [7, 8] has strongly developed into a powerful tool for modelling a myriad of social dilemma phenomena characterized by evolutionary dynamics and complex interaction patterns [9, 10]. And ample researchers have focused on the identification of mechanisms that may lead to high cooperation.

Payoff maximization as a classic mechanism has been extensive studied in the past [11–13]. The key assumption behind these researches have been that each player only

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aspires to maximizing its own payoff. It is not always the case in many real-life situations. An individual tends to be follow the majority in behavior or opinion within the interaction range and the conformity also plays an important role in the society [14]. Perc and Szolnoki designated a fraction of population as conformity-driven players instead of payoff-driven players [15, 16]. The conformity-driven players adopt their strategies simply according to the popularity of strategies among populations in their research. They showed that an appropriate fraction of conformists will introduce an effective surface tension around cooperative clusters and ensures smooth interfaces between different strategy domains. Yang and Tian proposed a conformity-driven reproductive ability in which the probability that an individual adopts a strategy both depends on the payoff difference and the popularity of strategies [17]. They find that the cooperation level can be enhanced by moderately increasing the teaching ability of the neighbor with the majority strategy in the local community. Javarone and Antonioni [18] studied the spatial public goods game in the presence of social influences considering both conformity-driven players and fitness-driven players. They find that conformism drives the system towards ordered states, with a prevalence for cooperative equilibria. Niu and Xu [19] set the rational conformity behavior by introducing the mechanism that player will compare its payoff to his last time step payoff. If its payoff at this time is worse than last time step then it will tend to adopt the most common strategy of its neighbors. Yang and Huang [20] treat strategy-updating rule (payoff-driven or conformity-driven) as an attribute of players and allow for the evolution of the attribute and find that frequent alternations of the strategy-updating rule with unbiased rule enhances cooperation.

Motivated by the previous work, we consider two different behaviors of conformists, in which the individual i adopts a randomly chosen neighbor *j's* strategy with the probability driven by conformity only after comparing their payoff at first. Not the same as researches in [17] set all the players in the population has only one rule. Here, we consider the payoff-driven rule, rational and irrational conformity-driven rules. It is also worth noting that, the rational and irrational behaviors defined in this work is by comparing the payoff of neighbors instead of their own payoff [19].

2 Model

We study evolutionary PGGs in a population of N players distributed uniformly at random on a square lattice with periodic boundary conditions. Each individual on site x is designated either as a cooperator $(s_x = C)$ or defector $(s_x = D)$ with equal probability. They play the game with their $k = 4$ neighbors and each of them belongs to $G = 5$ different communities. It means that an individual is the focal individual of a Moore neighborhood and a member of the Moore neighborhood of its four nearest neighbors.

In a pairwise interaction, the cooperator contributes 1 to the public good while defectors contribute nothing as the standard parametrization. The sum of all contributions is multiplied by the synergetic factor $R > 1$, and the resulting amount is shared among the $k + 1$ interacting individuals equally regardless of their strategies. Denoting the number of cooperators and defectors among the k interaction partners by N_c and N_d respectively, each cooperator or defector gets payoff in one group as follows

$$P_c = R(N_c + 1)/(k + 1) - 1, \quad (1)$$

$$P_d = R(N_c + 1)/(k + 1). \quad (2)$$

Obviously, total payoff π_i of each player i is the sum of payoff got in five different communities it belongs to.

We consider two types of strategy-updating rules. One is the traditional payoff-driven rule and the other is the conformity-driven rule. The payoff-driven player i adopt to the strategy of their randomly chosen neighbor j with the probability determined by Fermi function [21]

$$W_{s_i \leftarrow s_j} = 1/\{1 + \exp[(\pi_i - \pi_j)/K]\}, \quad (3)$$

Where $\pi_i(\pi_j)$ is the payoff of player $i(j)$ and K quantifies the intensity of the noise related to the strategy adaption. In the conformity-driven rule, we consider two different behaviors of conformists. One is the rational conformist. The player i will compare its payoff with the randomly chosen neighbor j. Nothing will happen and player i will stick to its original strategy if $\pi_i \geq \pi_j$. On the contrary, player i will adopt the strategy of player j according to the probability of conformity-driven rule. The second behavior is the opposite of rational conformist and we set it as irrational conformist. The irrational conformist will adopt the most common strategy among its neighbors only when its payoff is better than its neighbor. It is worth pointing out that irrational conformist doesn't mean that the player is a stupid individual and it is just one kind of behavior. In real-life situations, irrational conformist may get more payoff than rational individuals at sometimes. The conformity-driven probability is described as [15]

$$W_{N_{s_i} - k_h} = 1/\{1 + \exp[(N_{s_i} - k_h)/K]\}, \quad (4)$$

where N_{s_i} is the number of players holding the strategy s_i in the neighbors of player i and k_h is one half of the degree of player i.

We simulate the model in accordance with the standard Monte Carlo simulation procedure. In this work, we set $N = 4 \times 10^4$, $K = 0.5$. Initially, the cooperators and defectors are randomly distributed among the population with equal probability. Payoff-driven rule and conformity-driven rule are assigned to players with probabilities of β and $1 - \beta$ respectively. We note that each full Monte Carlo step (MCS) consists of N elementary steps described below, which are repeated consecutively, thus making sure each player has the opportunity to change its strategy once on average.

(1) Select one player x randomly, and select one of its neighbors y randomly;
(2) Each player $x(y)$ plays the PGG with all its five different communities and then calculate the total payoff π_x and π_y;
(3) Player x performs the strategy revision phase according to its attribute, *i.e.* payoff-driven or conformity-driven (rational or irrational behavior).
(4) Repeat from (2) until N Monte Carlo steps elapsed.

3 Results

First, we study the impact of the number of rational conformists among the population on cooperation in the public goods game with different synergetic factor (R). In Fig. 1, we plot the evolution of the fraction of cooperators (ρ) as a function of MCS time for several different values of β and R. One can see that, for small values of R $(i.e.,\ R = 2, 3, 4)$, the introduction of rational conformist has a little positive impact on the cooperation during the evolution process and the intensity of the effect increases with R increases. Especially, the system gets rid of all-Ds state with high fraction of rational conformist $(i.e.,\ \beta = 0.8 \text{ and } 1)$ when R increase to 4. It is worth noting that,

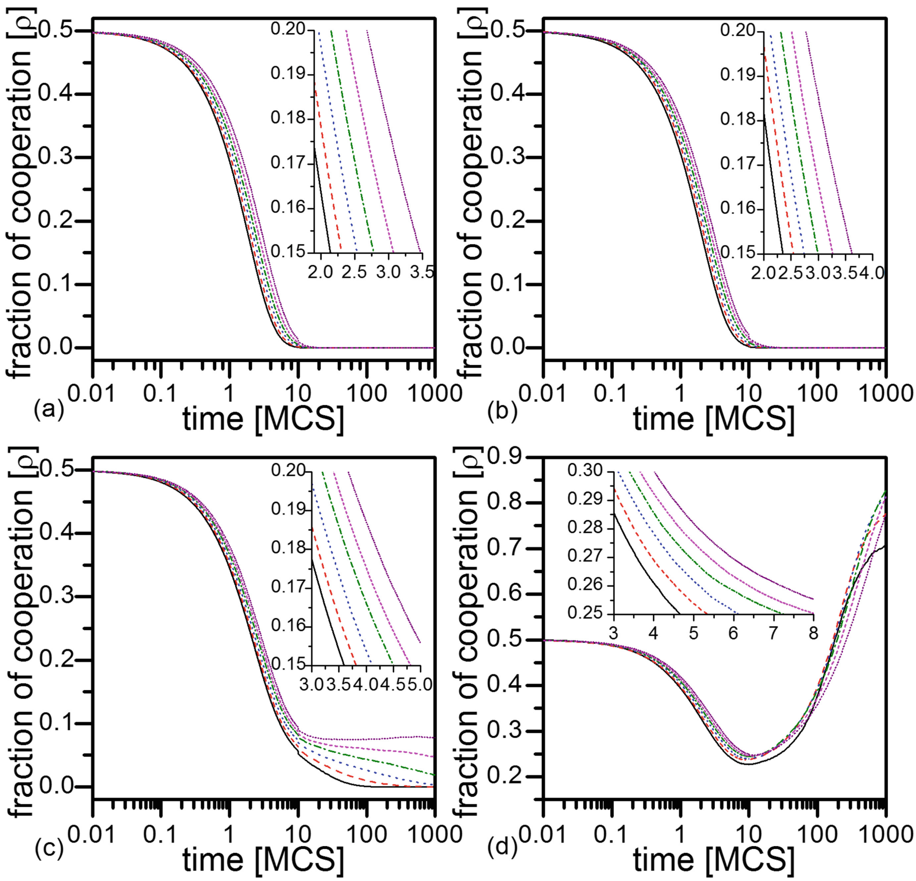

Fig. 1. The evolution of the cooperative frequency (ρ) with Monte Carlo time guided by the behavior of different fraction of rational conformists (β) among the population. (a)–(d) depict different synergetic effects of cooperation $\mathrm{R} = 2, 3, 4, 5$ respectively. $\beta = 0$ (black solid line), $\beta = 0.2$ (red dashed line), $\beta = 0.4$ (blue dotted line), $\beta = 0.6$ (olive dash-dotted line), $\beta = 0.8$ (magenta short-dashed) and $\beta = 1$ (purple short-dotted line) are all considered with different combinations of $\mathrm{k_h} = 2, \mathrm{N} = 4 \times 10^4, \mathrm{K} = 0.5$. To improve accuracy, the final results are averaged over 20 independent realizations, including the generation of random initial strategy distributions and rational conformist distributions, for each set of parameter values. (Color figure online)

this promotion loses its robustness and the system tends to be a high fraction of cooperation after experiencing a valley value (*i.e.*, $MCS = 10$, ρ is smaller than 20%) with the main effect of R as it increases to 5.

Then we depict the fraction of cooperators with the effect of irrational conformist within 1000 MCS in Fig. 2 in order to further explore what kind of conformist can boost the cooperation best. One can see that, the introduction of irrational conformist has a significant role in promoting cooperation when R is not so big $(i.e.,\ \mathrm{R} = 2, 3, 4)$. Figure 2(a), (b) show that ρ increases to 1 as β increase to 1 and the strength of positive effect is proportional to the fraction of irrational conformist among the population. We can also see that, for relatively small values of R $(i.e.,\ R = 2 \text{ and } 3)$, the positive effect

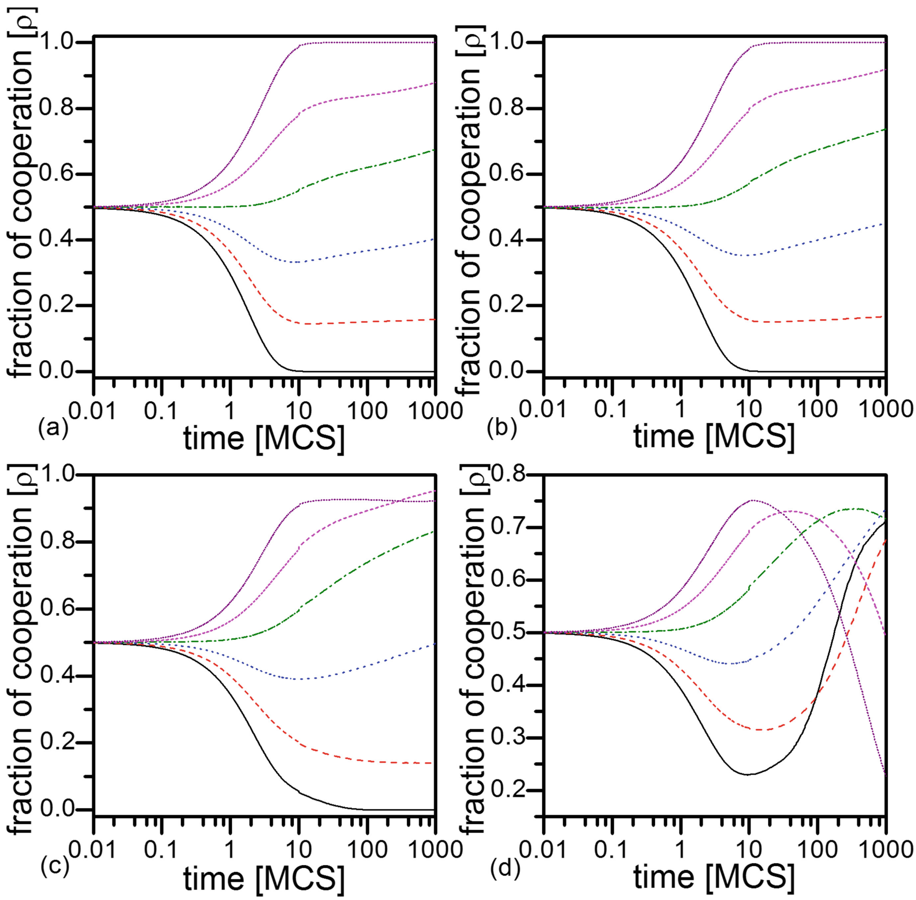

Fig. 2. The evolution of the cooperator frequency (ρ) with MCS considering the effect of different fraction of irrational conformists (β) among the population. (a)–(d) depict different synergetic effects of cooperation $R = 2, 3, 4, 5$ respectively. $\beta = 0$ (black solid line), $\beta = 0.2$ (red dashed line), $\beta = 0.4$ (blue dotted line), $\beta = 0.6$ (olive dash-dotted line), $\beta = 0.8$ (magenta short-dashed) and $\beta = 1$ (purple short-dotted line) are all considered with different combinations of $k_h = 2$, $N = 4 \times 10^4$, $K = 0.5$. Final results are averaged over 20 independent realizations, including the generation of random initial strategy distributions and rational conformist distributions, for each set of parameter values. (Colour figure online)

of β is robust as the main key of enhancement of cooperation no matter how R changes. However, for larger values of R (*i.e.*, $R = 4$ and 5), the positive role of β received the suppression of R. The highest fraction of cooperation $\rho = 0.95$ and 0.75 when $R = 4$ and 5 respectively. Especially, the effect of irrational conformist on cooperation is quite unstable and usually has a negative effect during the most period of evolution when $R = 5$. For example, the fraction of cooperation is $\rho = 0.23$ and 0.49 at the end of 1000 MCS when $\beta = 1$ and 0.8 respectively.

We depict the density of cooperator on varying the density of conformist (β) and the synergy factor (R) in Fig. 3 in order to complete a clear understanding about the effect of the fraction of irrational conformist on cooperative evolution. In general, it is obvious that the irrational conformist has a positive effect on the cooperation when R is small (*i.e.*, $R \leq 4.40$). When we fix the value of R, cooperators become more and more as β increases. For example, $\beta = 0$, $\rho = 0$; $\beta = 0.4$, $\rho = 47.9\%$; $\beta = 0.8$, $\rho = 94.5\%$, and $\beta = 1$, $\rho = 1$ when we fix $R = 2.80$. That is to say, the existence of irrational conformist in the population enables the cooperators to survive, and a large value of β could significantly promote cooperative behavior. When R is greater than 4.40, the positive impact is disturbed. Especially, $\beta = 1$ will no longer ensure all-Cs and disordered phase occurs when R is around 5.

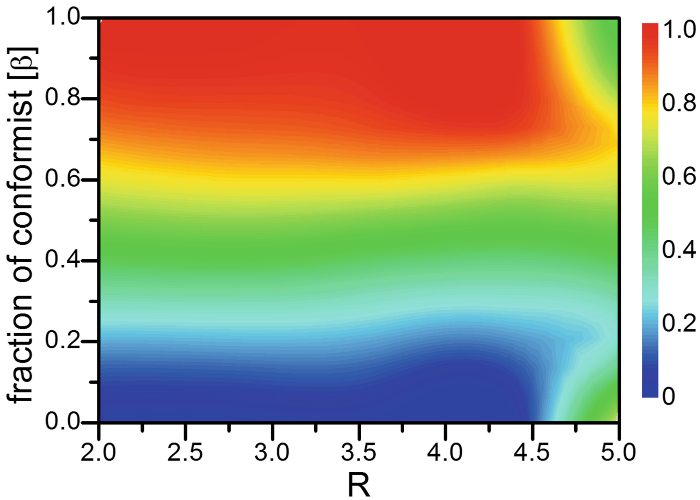

Fig. 3. Cooperation diagram on varying R and β in a population with $N = 4 \times 10^4$, $k_h = 2$, $K = 0.5$, R is in the range $\in [2.0, 5.0]$, β is in the range $\in [0.0, 1.0]$. Results are averaged over the last 3000 steps of 13000 MCS and have been computed using 21×5 parameter values.

To intuitively understand why the conformist that can affect cooperation when R is not so large (*i.e.*, $R = 2, 3$ and 4), we plot spatial strategy distributions as time evolves for traditional payoff-driven rule, rational conformity-driven rule and irrational conformity-driven rule from the top to the bottom respectively when $R = 2$. From Fig. 4(a1)–(a5), one can see that for the traditional payoff-driven rule, the defector cluster continually expands while the cooperator cluster rapidly shrinks. Similar pattern we can see in Fig. 4(b1)–(b5) but the speed of demise will be slightly slowed with the introduction of rational conformist (*i.e.*, MCS = 15 and 30 for the all-Ds state for traditional payoff-driven rule and rational conformity-driven rule respectively). However, the scenario is quite different in Fig. 4(c1)–(c5). Plenty of small cooperator clusters have been preserved and scattered throughout the whole population, which is very important for inhibiting the formation of defector cluster. In the end, the entire system tends to be an all-Cs state.

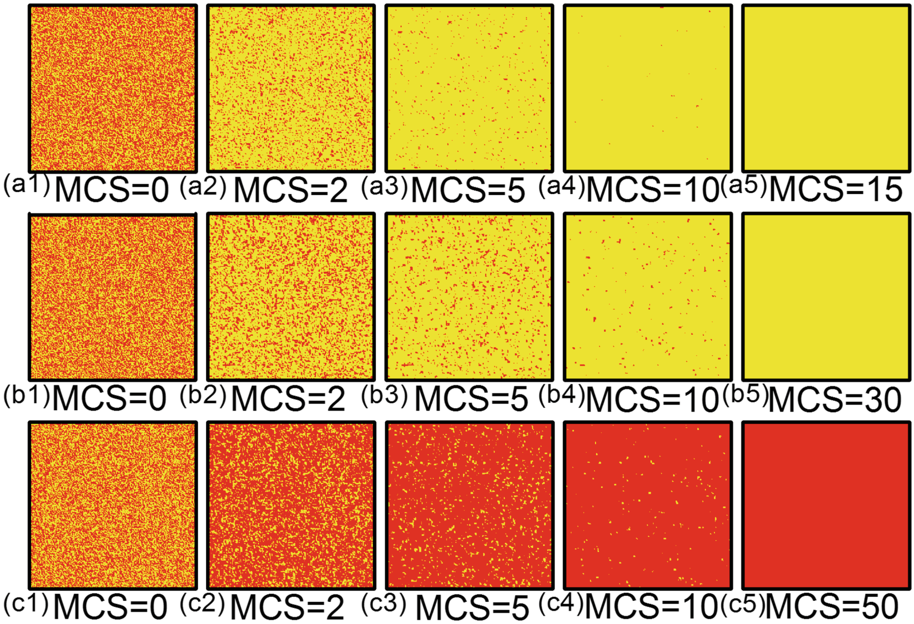

Fig. 4. Characteristic snapshots of cooperation (red) and defection (yellow) strategies with the effect of traditional payoff-driven rule, rational conformity-driven rule and irrational conformity-driven rule from the top to the bottom. The low synergetic effect of cooperation $R = 2$, as well as all results are obtained for $k_h = 2$, N $= 4 \times 10^4$, K $= 0.5$. (Colour figure online)

4 Conclusions

In evolutionary game theory, players usually update their strategies according to different strategy-updating rules. The traditional payoff-driven rule as one of the most popular rules has been widely studied in the last decades. Recently, more and more researchers pay attention to the conformity-driven rule. In the previous work [10], proper fraction of players following conformity-driven strategy-updating rule may improve network reciprocity and enhance cooperation. In this work, to further explore the impact of the conformist on cooperation, we have considered two kinds of behavior of conformists. In particular, the rational conformists are those that to imitate the strategy of the majority only when they got less payoff than their randomly chosen neighbor, while the irrational conformists are those that tend to imitate the strategy of the majority when their payoff are higher than their randomly chosen neighbor's. Here, we highlight the prominent role of irrational conformist in the spatial public goods game: it seems that rational and irrational conformist both enhance the cooperation among spatial public goods game. Whereas the latter promotes the population to reach a high level of cooperation and the positive effect is robust among a wide range of R.

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