PHYSICAL REVIEW E **108**, 024123 (2023)

Dual effects of conformity on the evolution of cooperation in social dilemmas

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(Received 30 January 2023; accepted 18 July 2023; published 14 August 2023)

Human beings are easily impacted by social influences, due to their social nature. As an essential manifestation of social influences, conformity is associated with the frequency witnessed in others' behavior, involving normative conformity and informational conformity according to the reaction of individuals. The former comes from the fear of a normative environment, while the latter means most behaviors are followed due to information asymmetry. Normative conformity significantly enhances network reciprocity, producing optimal cooperation at a moderate proportion, which induces within-cluster behavioral homogeneity and between-cluster behavioral diversity. On the contrary, informational conformity has an inhibitory effect on the evolution of cooperation for a low proportion of the conformity population, which contributes to the formation of defectors' clusters. The symmetry and duality of the two types of conformity on cooperation evolution provide an interesting and unexplored approach for future research, revealing the mechanism of conformity in evolutionary games.

DOI: 10.1103/PhysRevE.108.024123

I. INTRODUCTION

Cooperation is ubiquitous from biological systems to human society. However, based on Darwinian theory, individuals are inherently self-interested and aim to maximize their own benefits. This means that they will select not to cooperate if doing so will result in greater personal gains. As a result, social dilemmas arise when conflicts arise between individual and group interests, and explaining the emergence and maintenance of cooperation is a persistent challenge [1]. The exploration of how cooperation emerges among self-interested individuals has become a fascinating topic of research in the physics community, and evolutionary game theory on structured networks provides a valuable framework to investigate this phenomenon [2,3].

As a commonly used model in previous studies, the Prisoner's Dilemma game (PDG) presents a typical social dilemma situation [4–6]. Two individuals participate, each choosing between two options: cooperation and defection. Cooperation yields a reward of R, while defection leads to a punishment of P when both parties make the same choice. The defector receives the highest payoff T (i.e., the temptation to defect), while the cooperator receives the sucker's payoff S when they make different choices. The original PDG requires adherence to two inequalities: $T > R > P > S$ and $T + S < 2R$. In a well-mixed population, a rational payoff-driven individual will always decide to defect [7,8]. However, Nowak and May's pioneering work showed that cooperation is more likely to emerge on regular lattices [9], where cooperators can form compact clusters to protect themselves against exploitation from defectors. Since then, how networks with varying topologies impact cooperation has received extensive investigation from researchers. It has been confirmed that complex networks, such as small-world networks [10] and scale-free networks [11], could support cooperation due to network reciprocity.

So far, most previous studies assume that the motivation for imitation is payoff-based bias, i.e., individuals prefer to adopt the strategy with a higher payoff [5,12,13]. However, several studies in behavioral game theory offer alternative explanations for changes in individual behavior [14,15]. In a game, individuals exhibit different psychological biases, indicating that they are not solely concerned with the payoffs they receive but also with the actions of others [16–18]. An experiment has indicated that behavioral information from nearby participants holds more sway over the evolution of cooperative behavior in the PDG than the actual payoffs received by players [19]. In particular, it has been proposed that conformist bias [20], which is the tendency to imitate prevailing behaviors, plays a significant role in our social life [21,22]. As a common phenomenon among humans and social animals [23], conformity refers to the phenomenon in which an individual's actions or choices are influenced by those of others within a group. People observe the behavior of others as a witness and imitate (or adopt) the majority's behavior (or

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strategy). Their purpose is to acquire social acceptance and generate a sense of belonging [24], cut the cost of individual learning [25], or they are influenced by cultural values or even a fashionable tendency [23].

The effects of conformity on cooperation in evolutionary games have attracted more and more interest [26]. Conformity-driven individuals adjust their C or D strategies to align their behavior with the majority, which minimizes their risk and ensures that their payoffs do not diverge from the average. Most previous studies have confirmed that the presentation of conformity-driven individuals can promote cooperation [27,28]. Szolnoki and Perc found that when an appropriate proportion of conformity is added to a payoff-driven rational group, an effective surface tension is created around the cooperative cluster and ensures a smooth interface between different strategic domains, thus significantly enhancing network reciprocity [29]. In addition, they have further found that leaders in heterogeneous networks, such as scale-free networks, must be able to create a follower such that network reciprocity is optimally enhanced through conformity, which would otherwise damage cooperation evolution [30]. Based on these two pioneering works, a large stream of research on conformity has emerged in recent years. When the motivation of payoff and conformity both work on strategy updating, Yang and Tian found that the conformity-driven reproductive ability can also greatly enhance cooperation [31]. Also, Niu *et al.* have found that rational conformity that considers these two factors is conducive to promoting cooperation [32]. Meanwhile, the synergistic evolutionary model based on strategies and learning protocols enriches the diversity of strategy updating, revealing the qualitatively different pattern formation mechanisms [33]. Recently, some examinations have considered introducing appropriate conformity populations to evolve multiple games, which can also promote cooperation [34]. In addition, Liu *et al.* have investigated the effects of the conformity threshold on cooperation in evolutionary games; they found that there always exists an optimal conformity threshold for the population to maximize the cooperation level [35]. Most of these studies have proven that conformity can enhance cooperation, while some behavioral experiments have proven that social learning can impair collective performance [36,37].

The investigations of conformity in evolutionary games are added with many colorful and complex realistic factors. However, few studies have considered the effects of the types of conformity on cooperation. Actually, the conformity response degree depends on the motivation of the conformity behavior [38], which is associated with the observed frequency of a specific behavior [20]. There is a phenomenon in which conformity-driven individuals acquire useful information from others who provide the only source of information, called informational conformity, while some conformity-driven individuals could be influenced by the social environment, such as specific normative management, called normative conformity [39]. To be more specific, informational conformity is concerned with the search for information about reality. For example, when a person is home alone without social influence, there is the same probability of drinking tea or coffee. However, when ordering in line at a restaurant, the probability of ordering tea or coffee is influenced by the person in front of them, but only slightly [39]. For normative conformity, individuals conform to social rules to maintain and develop their group identity. Maeda [24] studied rural communities in Japan and found that those who valued group belonging and group identity were more likely to conform than Malays, who were much more flexible in their group identity and belonging. The distinction of informational and normative conformity rests on solid empirical and theoretical grounds, which have been proven by many researchers [40–42]. Recently, an integration function constituted by this conformity response curve was extended to the collective decisions in a binary choice. It has simplified complex factors such as the social influence processes (normative and informational conformity), cognitive strategies (individual and social learning), and task attributes into a systematic mathematical framework that can better reveal the effect of these complex interactions [43]. However, few experiments have focused on systematically comparing these two types of conformity in evolutionary games.

Inspired by the above studies, we divide individuals into two categories based on different attributes, i.e., the payoff-driven individuals who ensure the highest payoff and the conformity-driven individuals who are only concerned with the frequency of their neighbors' behavior. They are mixed and play the PDG, simulating a pluralistic social structure. In particular, we systematically compare informational and normative conformity. The simulations show that the two types of conformity have a dual effect on the evolution of cooperation. Informational conformity has processes of inhibiting network reciprocity and slightly promoting cooperation, reflecting a nonlinear character. Behavioral diversity can remain stable under the appropriate conditions, while normative conformity maximally promotes network reciprocity at appropriate proportions. Moreover, it can lead to within-cluster behavioral homogeneity. The behavioral diversity gradually disappears as the conformity population increases. These interesting phenomena are essential for separately exploring their evolutionary origins and consequences for cultural evolution.

II. MODEL

In this paper, we assume that a number of nodes are uniformly distributed in a square lattice of size $L \times L$ ($L = 100$) with periodic boundary conditions. These nodes represent individuals with different attributes who face the choice of two alternative behaviors (cooperative behavior and defective behavior). Each individual interacts only with the four neighbors surrounding him/her and plays a weak PDG in which we set T ($T \geqslant 1$), $R = 1$, and $P = S = 0$, for simplicity. We consider two different scenarios where the two types of conformity-driven individuals and payoff-driven individuals are mixed. The density of conformists in a mixed population is characterized by $\rho(\rho \in [0, 1])$, and the proportion of payoff-driven individuals is denoted by $1 - \rho$. The system turns to the traditional weak PDG procedure at $\rho = 0$ and fills with conformists at $\rho = 1$.

A payoff-driven individual i will randomly select a neighbor j who also acquires the cumulative payoff in the same way as i. The j's strategy, named s_j, is adopted as i's next strategy, with the probability determined by the Fermi function as follows:

$$P(s_i \leftarrow s_j) = 1/\{1 + \exp[(\Phi_i - \Phi_j)/K]\}, \tag{1}$$

where Φ_i and Φ_j denote the cumulative payoff of the individual i and j. K denotes the uncertainty during choosing a strategy, which takes a constant value with 0.1. It is noteworthy that the transition of individuals' strategies depends on their accumulated payoffs. No matter what strategy the opponent chooses, the defect is always the best choice for a rational individual. Therefore, when T gradually increases, the group will constantly evolve toward the direction of defect, inevitably leading to total defect. Traditionally, it is known from [29] that the maximum value of f_C can reach 0.64 at $T = 1$, and defectors dominate completely at $T = 1.037$.

As for the mentioned scenario for conformity driven, a factor analysis revealed that the variety of learning processes induced by conformity constitutes two distinct factors: normative conformity and informational conformity [43]. Since most behaviors of informational conformity are followed due to information asymmetry, the strength of normative conformity, which is moderated by norm enforcement of the environment, is stronger than that of informational conformity. Therefore, we extend the framework of conformity, specifically for conditions of normative behaviors.

If i is a conformity-driven individual, his/her current strategy will become more confirmed if s_i is the most prevalent behavior among the neighbors. Instead, the individual will turn to another strategy by imitating the most common behavior if he/she observes that his/her own behavior has broken away from the majority. The observed frequency represents the proportion of s_i among all behaviors witnessed by i. The more popular the behavior is, the larger the observed frequency will be. Then, the individual is more likely to persist with the strategy s_i. Although the effect of the frequency is both positive for conformity-driven individuals and leads them to follow the majority, different motivations can produce different types of conformity responses. A crucial consideration is how to distinguish different motivations which are reflected in conformity-driven response types. Inspired by [43], we consider the following conformity function to describe the different mathematical forms of conformity types:

$$f(x_{s_i}) = \begin{cases} (2x_{s_i})^\alpha/2, & 0 \leqslant x_{s_i} \leqslant 0.5 \\ 1 - [2(1 - x_{s_i})]^\alpha/2, & 0.5 \leqslant x_{s_i} \leqslant 1, \end{cases} \tag{2}$$

where $f(x_{s_i})$ denotes the probability that the individual i perseveres in his/her strategy for the next time step, and x_{s_i} denotes the frequency of s_i that neighbors behave. According to the characteristics of the square lattice, the value of $x_{s_i} \in \{0, 0.25, 0.5, 0.75, 1\}$. Therefore, the probability of a transforming strategy is $1 - f(x_{s_i})$, which denotes the probability that i turns to an alternative option. The conformists will become more insistent on their strategies as $f(x_{s_i})$ increases. The characteristic of different conformity response types is parameterized by α; see Fig. 1.

(1) For $\alpha < 1$, conformity belongs to informational conformity, which shows that the probability that an individual performs the most- (less-)frequent behavior is smaller (larger) than the observed frequency of that behavior in others, but still larger than the probability of performing the less frequent behavior. The dash-dotted blue line represents the conformity function inverse-S-shaped curve that takes the values of $\alpha = 0.3$. It shows a weak reaction. The influence of observed frequency for individuals is slight, and conformists are only slightly more likely to adopt the most frequent behavior than the other alternative [39]. When $\alpha \to 0$, the curve of $f(x_{s_i})$ becomes very flat and approaches to 0.5, indicating that conformists randomly decide whether or not to change their strategies.

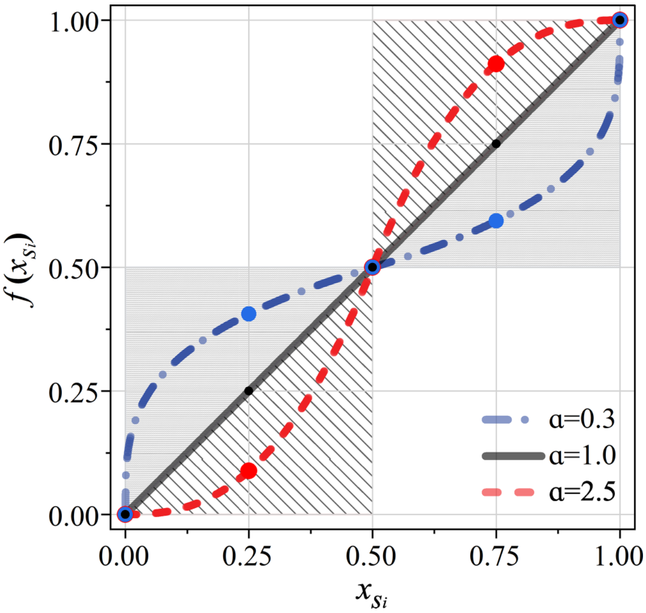

FIG. 1. There are three dynamics in the conformity domain: informational conformity (shadow domain: the dash-dotted blue line as an example), linear conformity (black line), and normative conformity (diagonal domain: the dashed red line as an example). The conformity function $f(x_{s_i})$ can take a few values of $x_{s_i} \in \{0, 0.25, 0.5, 0.75, 1\}$.

(2) For $\alpha = 1$, conformity belongs to linear conformity or informational conformity [39]. The likelihood that an individual behaves the most-frequent behavior is equal to the frequency of the behavior in a group; see the oblique black line in Fig. 1.

(3) For $\alpha > 1$, it belongs to normative conformity, which shows that the likelihood of behaving the most-frequent behavior is larger than the observed frequency in a group [39]. In this case, the conformity function exhibits the S-shaped relationship with the observed frequency (see the solid red curve that takes the values of $\alpha = 2.5$ in Fig. 1). When the frequency x_{s_i} is larger (less) than half, the individuals will adapt to the majority with an exaggerated tendency to increase (reduce) the likelihood of persevering in their strategies. When $\alpha \to \infty$, the conformity function $f(x_{s_i})$ is close to a step function. It takes 0 or 1 as long as x_{s_i} deviates from 0.5 a little. In this case, the conformist will deterministically change (adhere to) this strategy when the strategy is in the minority (majority) among his/her neighbors.

Consequently, different from the payoff-driven individuals, informational or normative conformity-driven individuals tend to imitate the strategies adopted by the majority of neighbors. In this work, we focus on the effects of these

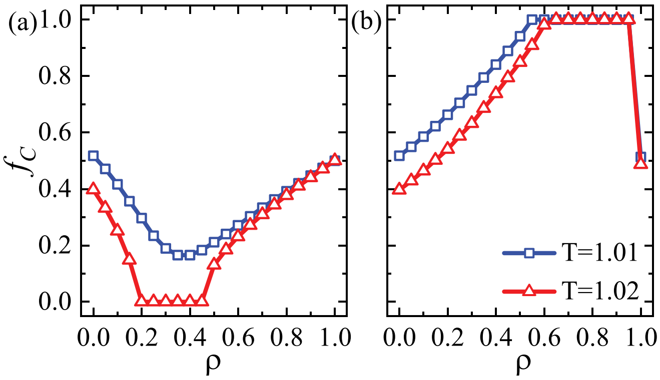

FIG. 2. The fraction of cooperator f_C as a function of ρ under $T = 1.01$ (blue) and $T = 1.02$ (red). Pluralistic social structure for (a) payoff-driven individual and informational conformity taken by $\alpha = 0.3$, and (b) payoff-driven individual and normative conformity taken by $\alpha = 2.5$.

two different types of conformity response on the evolution of cooperation. We simulate the model in accordance with the standard Monte Carlo (MC) simulation procedure. Initially, individuals are randomly distributed in the square lattice, choosing C or D as their strategies with equal probability. Each individual is designated as a conformist and a payoff-driven individual with the probability of ρ and $(1 - \rho)$, respectively. Each MC simulation procedure is comprised of the following stages. First, an individual i is randomly selected. Next, individual i updates his strategy according to his/her attribute (conformity driven or payoff driven). Here, we consider two types of conformity response, namely, informational conformity and normative conformity. The system is updated asynchronously. Each of the data is gained by averaging over 10^3 MC steps after a sufficiently long transient up to 10^5 MC steps and averaging over 50 different realizations.

III. RESULTS AND ANALYSIS

In order to explore how informational and normative conformity individuals affect the evolution of cooperation, we plot the cooperation level f_C against ρ in Fig. 2 for two different T. One can see that the larger the value of T, the smaller f_C will be. More individuals would like to choose C as their strategy when the crowd of conformity is more than one-half population ($\rho > 0.5$), leading to the enhancement of f_C. Actually, the weak facilitative effect of informational conformity still fails to reach the highest f_C compared with the traditional model ($\rho = 0$), inhibiting the strategy selection of cooperation. However, when the population pressure of conformity is small ($\rho < 0.5$), normative conformity still promotes cooperation, while informational conformity individuals generate a negative impact. Note that this negative effect persists up to a threshold value of 0.5 around, which we call the "trigger point." As T increases, it appears with a higher value of ρ. The appropriate conformity-driven individuals perform as "connectors" from all D states to the survival of C, leading to a dramatic and unexpected change in evolutionary trends through the conformity mechanism, shown in Fig. 2(a). The richness and complexity of this phenomenon will be further presented in Fig. 3. When all individuals are conformists ($\rho = 1$), f_C reaches 0.5 for both types of conformity. At that time, everyone loses interest in payoffs, and the evolution is just a random drift [29]; see Fig. 2(b). Consequently, the group sensitive to the initial conditions will appear in a full C or full D state, and the average values of f_C falls to around 0.5.

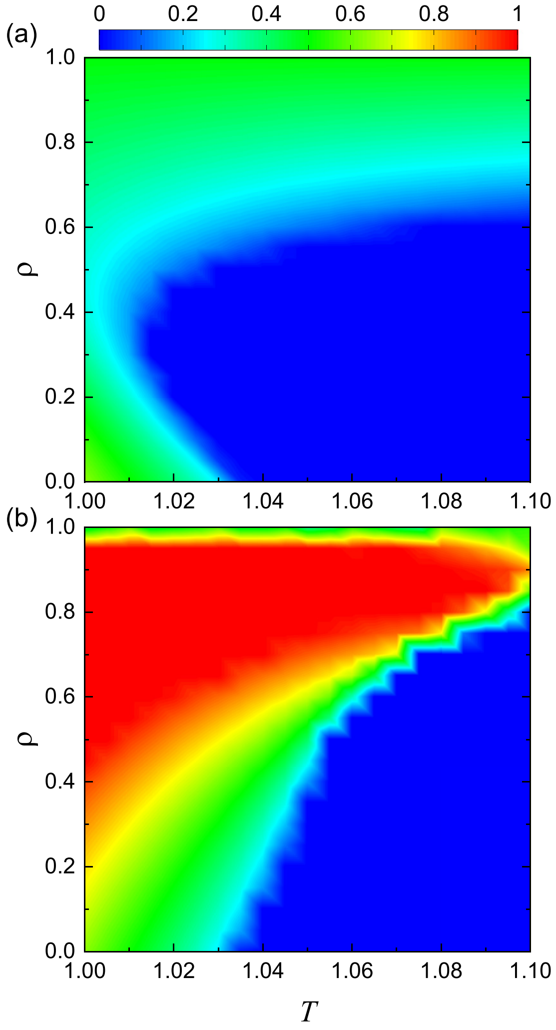

FIG. 3. Phase diagrams on the $T - \rho$ plane for the spatial weak PDG with combining the payoff-driven and conformity-driven individuals. The phase diagram color indicates the cooperation level f_C when a system reaches a steady state. Two different types of conformity responses are considered: (a) $\alpha = 0.3$ and (b) $\alpha = 2.5$.

To provide a comprehensive description of the effects of the temptation to defect T and the density of conformists ρ under two different conformity types, we present the contour plots for the fraction of cooperation f_C in T-ρ space in Fig. 3. One can see that in the blue domains, cooperators cannot survive under high T and a small proportion of conformity. When all individuals are payoff driven, the highest f_C in the group can only reach around 0.64, and strongly reduces to 0 when $T = 1.037$. This situation is consistent with the traditional weak Prisoner's Dilemma model [29]. Normative conformity still plays a crucial role in improving cooperation even under tremendous pressure from large temptation values. The varied proportions of two different conformity types have

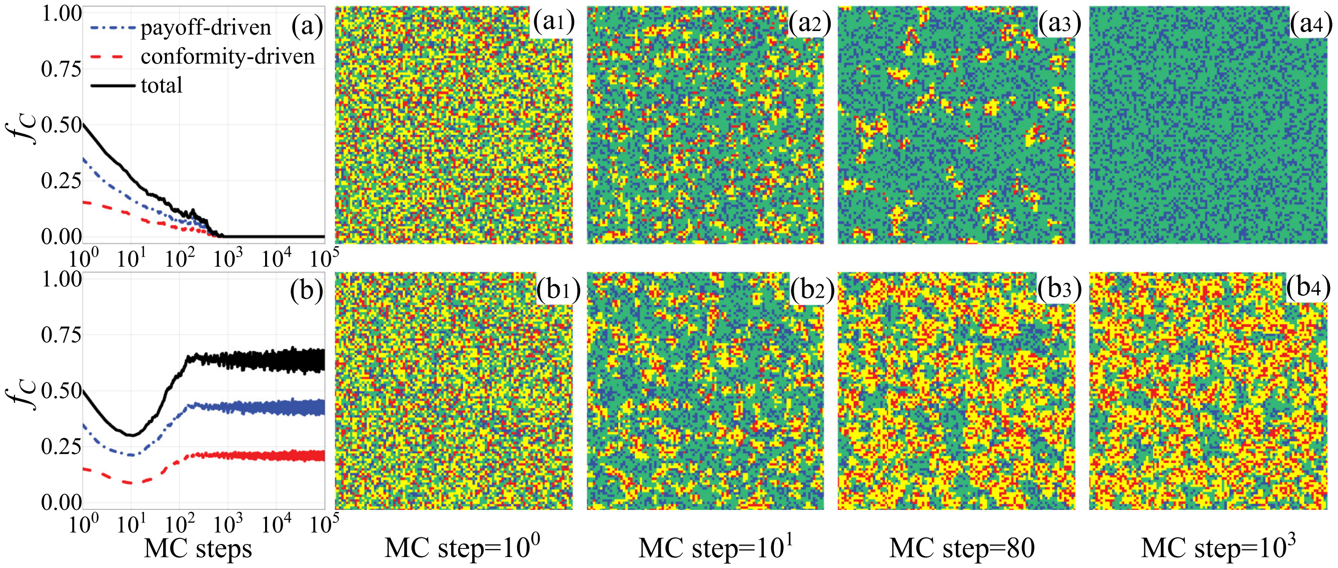

FIG. 4. The characteristic spatial patterns for (a1)–(a4) $\alpha = 0.3$ and (b1)–(b4) $\alpha = 2.5$. Initially, both cooperators and defectors are randomly distributed with a probability of 0.5, and individuals are distributed at a fixed proportion. Different colors are used for payoff-driven cooperators (yellow) and defectors (green), and conformity-driven cooperators (red) and defectors (blue), for both informational and normative conformity. The corresponding time series graphs are shown in (a) and (b), recording the time evolution of payoff-driven and conformity-driven individuals and the total. Other parameters: $\rho = 0.3$, $T = 1.02$.

different effects on the group evolution outcomes at the fixed T values. In Fig. 3(a), f_C decreases as ρ increases when ρ is less than 0.5; otherwise, it increases but cannot exceed 0.7. It shows that informational conformity has a slight promotion process for cooperation, but also has a solid inhibitory strength. So it is not conducive to the evolution of cooperation. Interestingly, a light-blue arc is formed, f_C first decreases and then increases with ρ, which is consistent with the results depicted in Fig. 2(a). In Fig. 3(b), f_C continuously increases while ρ increases. The group is occupied by cooperators (such as the red domain) when there are enough normative conformity individuals. The threshold value is marked as ρ^*, which increases while T increases. However, f_C would be inhibited when the crowd of conformism is too large, dropping down to 0.5 at $\rho = 1$, for instance. There is a sizable transitional interval between full C and full D domains, enhancing the between-cluster diversity of strategies in the population. And the behavioral diversity gradually disappears as ρ increases. In conclusion, normative conformity can be used as an honest signal of group membership, while informational conformity is motivated to find the best possible solution to a particular problem [39]. The former act as active advocators of cooperation in our model and can produce optimal cooperation facilitation in the appropriate proportion. On the other hand, the latter act as crafty opportunists with a slight cooperative support process, but are more inclined to defect generally.

To better explore the typical microscopic mechanisms of the evolutionary processes, we plot snapshots performed by individuals with different attributes in Figs. 4 and 5. Defectors survive and expand by achieving higher payoffs at the beginning of evolution, leading to decreased f_C. However, some cooperators can survive through network reciprocity and even invade adjacent territories occupied by defectors with the strength of conformity, so that f_C begins to gradually increase, as shown in Figs. 4(b1)–4(b4) and Figs. 5(b1)–5(b4). Cooperators survive by forming some compact clusters, even if most individuals pursue profits (e.g., $\rho = 0.3$). They can even form a large reticulate continuous cluster to erode the defector cluster when it increases to an appropriate value (e.g., $\rho = 0.8$). The larger ρ, the more pronounced the promotion effect is at fixed T. So normative conformity significantly enhances network reciprocity and even enables optimal cooperation promotion. As one can see, the mixture of normative conformity and payoff-driven individuals restores the situation of network reciprocity in the traditional model and enhances within-cluster behavioral homogeneity. In contrast, informational conformity directly inhibits its positive effects and exacerbates the defect tragedy. As shown in Figs. 4(a1)–4(a4), payoff-driven individuals become mainstream when ρ is small. The informational conformity is exploited by the defectors and becomes an assistant in spreading the D strategy. Individuals rapidly form defectors' clusters, whose structure is stable and expands outward, gradually dominating and eventually reaching the full D state. When there is a large ρ in Figs. 5(a1)–5(a4), cooperator and defector clusters are formed in dynamic equilibrium with the clusters, which leads to a stable behavioral diversity inside the groups. The presence of more conformity maintains a certain f_C and avoids the situation of a full D state. Thus, normative conformity favors the emergence of cooperation, while informational conformity, as the unreliable allies of cooperators, is more inclined to defect when their population is small.

To explore the nonlinear characteristics of informational conformity on the level of group cooperation, we have investigated the microscopic evolutionary mechanisms; see Figs. 6 and 7. We can observe that the effect of ρ on the

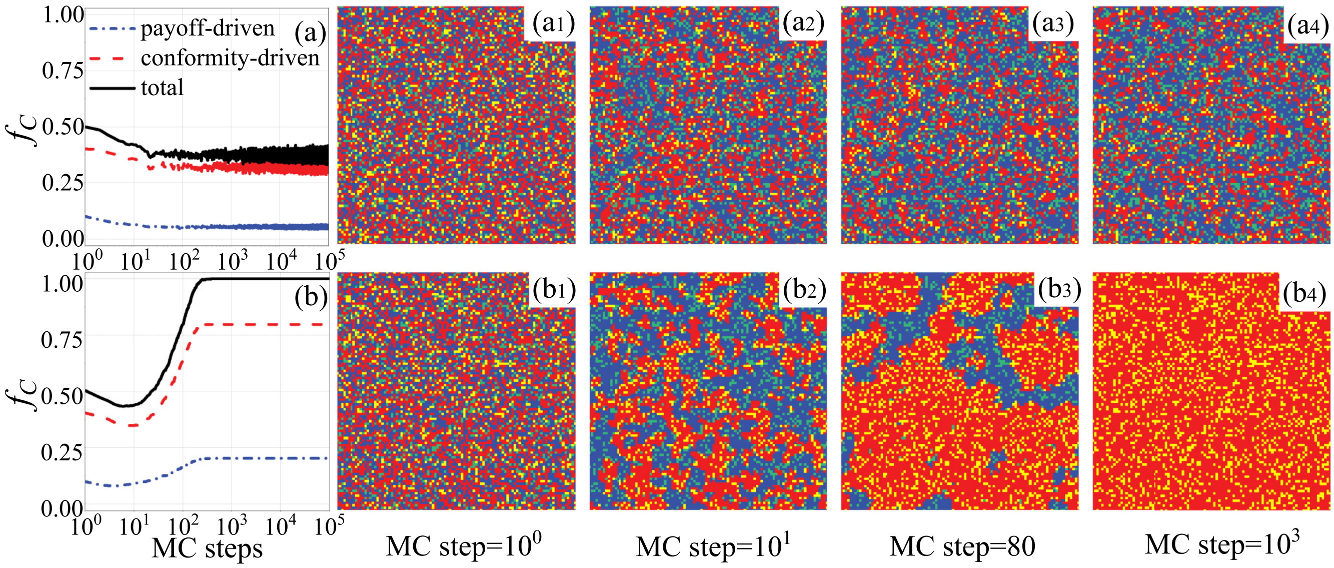

FIG. 5. The characteristic spatial patterns for (a1)–(a4) $\alpha = 0.3$ and (b1)–(b4) $\alpha = 2.5$. Initially, both cooperators and defectors are randomly distributed with a probability of 0.5, and individuals are distributed at a fixed proportion. Different colors are used for payoff-driven cooperators (yellow) and defectors (green), and conformity-driven cooperators (red) and defectors (blue), for both informational and normative conformity. The corresponding time series graphs are shown in (a) and (b), recording the time evolution of payoff-driven and conformity-driven individuals and the total. Other parameters: $\rho = 0.8$, $T = 1.02$.

evolution of cooperation is characterized by two processes, i.e., inhibiting network reciprocity and moderating defectors' aggression. When $\rho < 0.5$, these conformity-driven minorities become defectors' puppets, facilitating the spread of the D strategy. Compared with the traditional model, network reciprocity is gradually weakened as ρ increases. The cooperators have difficulty surviving and only form small isolated patches or even die out. The D strategy prevails when $\rho \geqslant 0.5$. Because informational conformity realizes a weak response to observed frequency, it is only slightly more likely to

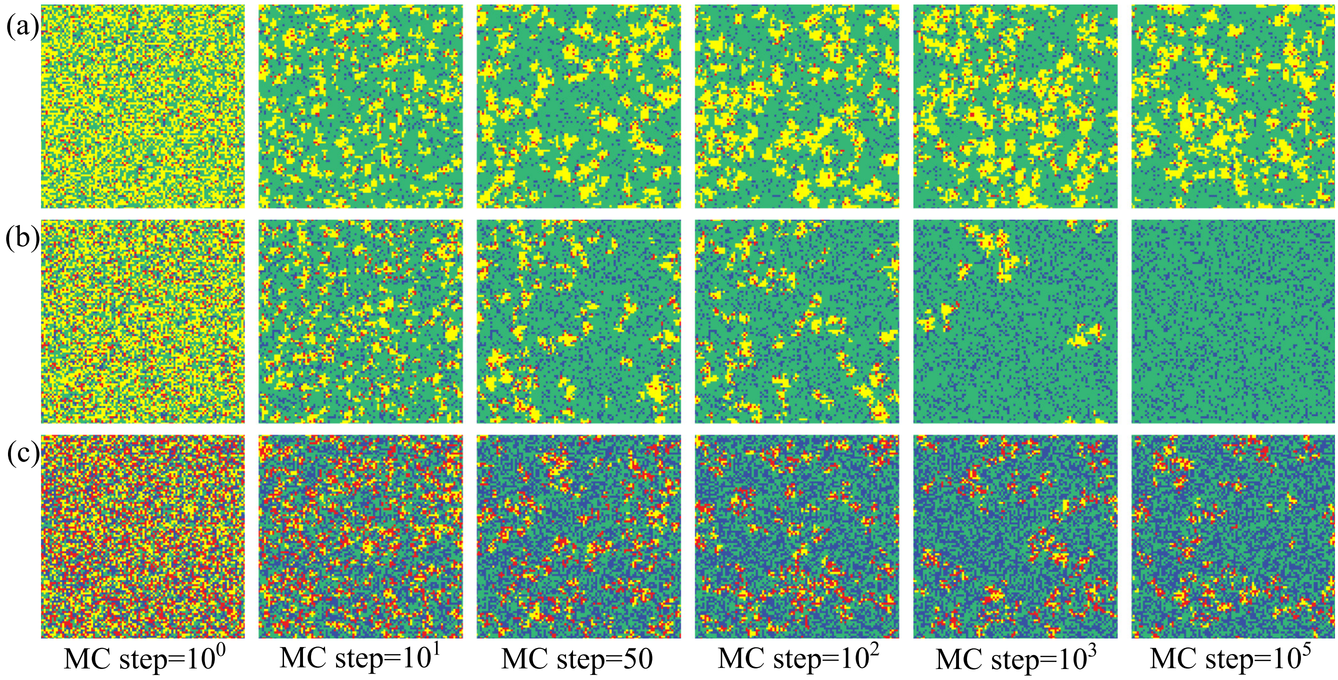

FIG. 6. The characteristic spatial patterns for (a) $\rho = 0.1$, (b) $\rho = 0.2$, and (c) $\rho = 0.5$. Initially, both cooperators and defectors are randomly distributed with a probability of 0.5. Different colors are used for payoff-driven cooperators (yellow) and defectors (green), and informational conformity-driven cooperators (red) and defectors (blue). Other parameters: $\alpha = 0.3$, $T = 1.02$.

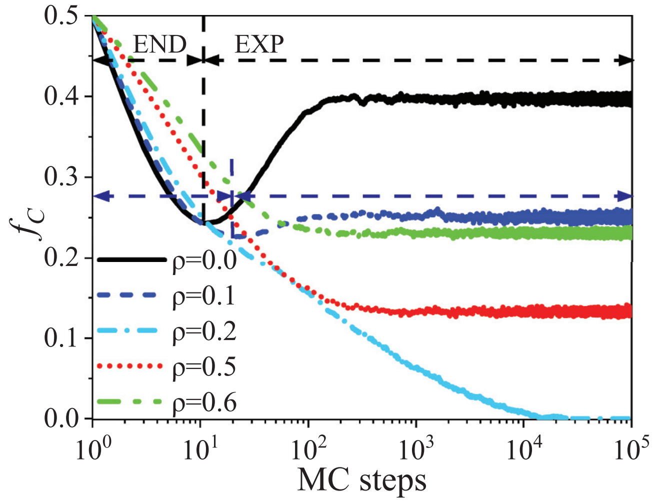

FIG. 7. Time series of the cooperation level for several different values of ρ. The temptation to defect $T = 1.02$ and conformity function parameter $\alpha = 0.3$.

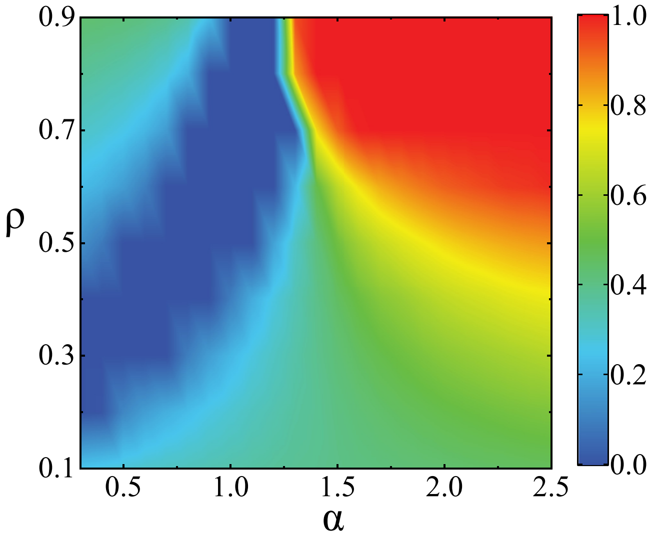

FIG. 8. Phase diagram on the $\alpha - \rho$ plane for the spatial PDG, combining the payoff-driven and conformity-driven individuals. The phase diagram color indicates the cooperation level f_C when a system reaches a steady state. Other parameter: $T = 1.02$.

imitate the most common defect behavior than the observed frequency. The weak persistence of these conformity-driven majorities at the defect clusters' boundary provides a survival respite for the cooperators. Meanwhile, the large amount of conformity increases the activeness of strategy updating. It destroys the clusters' stability, leading to no large persistent clusters and making the group not tilted to any side at will. Cooperators can only form small isolated patches to cut loss. The effect of these clusters allows cooperators and defectors to coexist on the square lattice [44]. We show, in Fig. 7, the time series of the cooperation level f_C for five different ρ. From Fig. 7, one can clearly find that a two-stage process can be inferred by following the time series of f_C, which was usually explored to give insight into the mechanism underlying the promotion of cooperation [45–47]. The two-stage process observed earlier in Refs. [45–47] can divide into the nonequilibrium stage and the local equilibrium stage, which are later also called the enduring (END) period and the expanding (EXP) period [48,49], respectively. In the END period, f_C decreases with time and cooperators try to endure the defectors' invasion. For $\rho = 0$, the absence of informational conformity individual can lead to a shortest END period and a lasting EXP period, which result in the highest cooperation level f_C. One can also observe that the introduction of informational conformity ($\rho > 0$) will prolong the period of END, and a moderate ρ leads to a longest END period and a lowest f_C.

Finally, we explored the cooperation levels for different values of α and the proportion of conformity-driven individuals, taking $T = 1.02$ in Fig. 8. One can see that normative conformity significantly enhances network reciprocity and achieves optimal cooperation facilitation. On the other hand, informational conformity has an inhibitory effect and can make the traditional weak PDG more likely to reach the full D state. These two types of conformity have a dual impact on the evolution of cooperation, reflecting symmetry. Under the pressure of T, this symmetry is not strictly divided according to a simple value such as $\alpha = 1$. Notice that there is a narrow transitional band across the blue and red regions, which can be predicted to keep getting smaller and shifting to the right as T increases. In addition, the nonlinear characteristics of informational conformity can be clearly observed only for specific values of T and α. The effect of different α on the evolution of cooperation deserves further exploration.

IV. CONCLUSION

Conformity is considered to play an essential role in promoting group cooperation in evolutionary games. We consider a pluralistic social structure in which the population is divided into payoff-driven and conformity-driven individuals according to their attributes. The former conducts strategy learning based on payoff, while the latter performs social learning by observing others' behavior around them. It reflects the reality that diverse societies may have both monetarism, which is only interested in money, and conformism, which only cares about whether the behavior is consistent with others. In particular, we classified informational and normative conformity depending on the degree of response to the observed frequency.

Different from the results of most previous studies, we find that informational conformity has an inhibitory effect on the evolution of cooperation. There are two processes of inhibiting network reciprocity and moderating defectors' aggression as the conformity-driven population increases. We explored this nonlinear character on a microscopic scale. On the other hand, normative conformity greatly enhances network reciprocity and produces optimal cooperation promotion. However, its effectiveness depends on the fraction of conformity-driven individuals, and a moderate fraction is the best consideration. Moreover, we find that normative conformity can lead to within-cluster behavioral homogeneity and between-cluster behavioral diversity. As the conformity population increases, its behavioral diversity between clusters gradually disappears. In contrast, informational conformity leads to stable within-cluster behavioral diversity [39,42]. Furthermore, it should be noted that the above simulations are carried out for the temptation level below $T = 1.1$, which is not really a huge advantage for defectors. For the normative conformity, a larger temptation level does not affect the qualitative results, i.e., there exists an optimal value of the fraction of conformity-driven individuals at which the cooperation level reaches its maximum, while for the population with informational conformity-driven individuals, a low fraction of conformist-driven individuals cannot support the cooperative behaviors when the temptation to defect is large enough.

In closing, we stress that the main results obtained by employing the weak Prisoner's Dilemma can be extended in more general settings of the Prisoner's Dilemma (e.g., the true Prisoner's Dilemma game). The dual effects of conformity on the evolution of cooperation can also be found in the true Prisoner's Dilemma game. We believe that the model proposed in this study holds relevance to actual social dynamics and that our findings are valuable in gaining a deeper comprehension of cooperative behaviors occurring in both natural and human societies. Our research may provide more comprehensive insight into the cooperation behavior in populations with conformists. We hope that this work can motivate more future studies for resolving social dilemmas along this line.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China under Grant No. 12005043 and by the Natural Science Foundation of Guangxi under Grant No. 2022GXNSFBA035615.

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