



## The evolution of cooperation in spatial multigame with voluntary participation

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### ABSTRACT

In the real life, we often simultaneously encounter various social dilemmas, which are also inclined to be voluntarily participated in, instead of previous assumption's compulsory participation in. Accounting on this realistic scenario, we have introduced the mechanism that the individuals have access to different payoff matrices corresponding to different social dilemmas to participate in the multigame with three strategies to choose, including cooperation, defection, going it alone. Furthermore, we set a proportion  $\psi/2$  of the population to play the Prisoner's Dilemma, a proportion  $\psi/2$  of the population to play Snowdrift and a proportion  $1 - \psi$  of the population to play the weak Prisoner's Dilemma, which results in the fact that the mean payoff matrix returns to the basic weak PD. Though numerical simulations, we find that for the smaller temptation to defect, the cooperation can be enhanced by the diversity of the sucker's payoff in the multigame contrast to the basic case. In addition, when the contribution of sucker's payoff is larger or more players choose to play the Prisoner's Dilemma and Snowdrift, the cooperators become more dominated.

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### 1. Introduction

Nowadays, the research of cooperation is ubiquitous in socioeconomics and evolutionary biology [1] allowing for the fact that the thriving of cooperation is one of the most significant conundrum to Darwin's theory of natural selection [2,3]. The effective framework named evolutionary game theory is accessible to investigate how to speculate the emergence of cooperative behavior among selfish players [4–11], whose going after short-term individual benefits, to a certain degree, might give rise to the tragedy of the commons [12]. Among all game models within this framework, none has received as much attention as the examples the Prisoner's Dilemma (PD) [13] and Snowdrift (SD) [14].

In PD, two individuals have to simultaneously decide whether they want to cooperate (C) or defect (D). They both receive the reward  $R$  for mutual cooperation and the punishment  $P$  for mutual defection. And when confronting a defector, the cooperator will obtain the sucker's payoff  $S$ , while the defector will get the temptation  $T$  confronting a cooperator. The payoff ranking is set as  $T > R > P > S$  with  $2R > T + S$  so that defection is the optimal strategy to choose regardless of the opponent's strategies in a finite well-mixed pop-

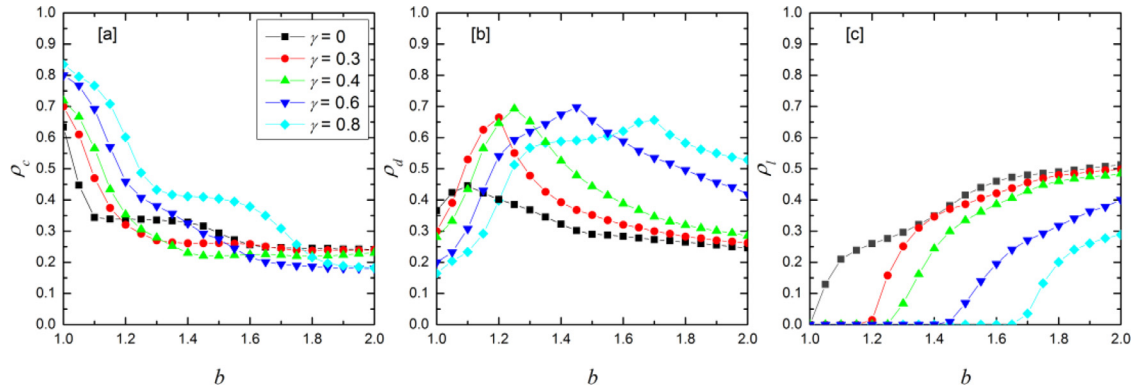
ulation, which always leads to the extinction of cooperation. In SD, the individuals interact in a similar way with the payoff ranking as  $T > R > S > P$ , which results in the significant scenario where both the cooperation and defection will exist in the well-mixed population.

As we all know, both of the individuals have been driven to compulsorily participant in both of the two classical social dilemmas in which they are torn between what is best for themselves and what is best for the society. That is to say, they just need to make a choice between the two strategies of which one is cooperation and the other is defection. In many cases, nevertheless, individuals often may drop out of unpromising and risky social enterprises and instead rely on the perhaps smaller but at least secure earnings based on their individual efforts [15]. And the risk-averse individuals are defined as the loners (L) who are inclined to voluntarily participate in the social dilemmas, which leads to the birth of the more complex three strategies consisting of the cooperation, defection, and going it alone.

It's worth mentioning that in real life there is not only a kind of social dilemma existing, in more than one of which individuals are always involved at the same time. In accordance with, evolutionary multigame [16,17] becomes more and more prevailing in evolutionary game theory [18–20], in which the individuals utilize different payoff matrices corresponding to different social dilem-

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**Fig. 1.** Fraction of cooperators  $\rho_c$  ([a]), defectors  $\rho_d$  ([b]), and loners  $\rho_l$  ([c]) in dependence on the temptation to defect  $b$  for  $\psi = 1$  and different values of parameter  $\gamma$ , as indicated in the legend.  $\psi = 1$  means that half of the individuals play the PD, the remaining half play the SD, and none play the weak PD.

**Table 1**

Payoff matrix of the studied evolutionary game. The three strategies are cooperation (C), defection (D) and punishment (L).

	C	D	L
C	R	S	$\sigma$
D	T	P	$\sigma$
L	$\sigma$	$\sigma$	$\sigma$

mas. Furthermore, Wang et al. [21] has given the mechanism that the cooperation level can be influenced by the different payoff matrices based on that the individuals compulsorily participant in the multigame with two strategies consisting of cooperation and defection. Taking this into account, in this paper, we will study the mechanism that the individuals voluntarily join in the multigame with three strategies consisting of cooperation, defection and going it alone. Moreover, we will allocate the proportions of the multigame just as what Wang has mentioned. In other words, a fraction of the whole population is randomly divided to play the weak Prisoner's Dilemma, a half of the remaining population play the Prisoner's Dilemma, and the other half of the remaining play the Snowdrift, which makes the multigame returns to the weak Prisoner's Dilemma as the baseline.

Now, in our paper, we will study the evolution of cooperation in multigame with voluntary participation on the square lattice [22]. Specifically, all the individuals will voluntarily and uniformly play the multigame – the weak Prisoner's Dilemma, Prisoner's Dilemma and Snowdrift – with three strategies containing the cooperation strategy, the defection strategy, as well as the going it alone strategy. The rest of this paper is organized as follows: firstly, we proposed our model of voluntary multigame; subsequently, the main simulation results are shown in Section 3; lastly we summarize our conclusions in Section 4.

## 2. The model of voluntary multigame

In the model, the third strategy loner (L) is appended to the PD and SD. When encountering the cooperator, the defector or the loner itself, the loner receives the payoff  $\sigma$ . When playing against the loner, both of the cooperator and defector also could get the payoff  $\sigma$ . As proposed in literature [15], the value always can be set as  $\sigma = 0.3$ . And in the Table 1 dose list the payoff matrix of PD and SD.

For simplicity and not loss of the generality, In PD the payoffs can be defined as  $R = 1$ ,  $P = 0$ ,  $T = b > 1$ ,  $S = -\gamma$ ,  $\sigma = 0.3$ . In SD the payoffs can be defined as  $R = 1$ ,  $P = 0$ ,  $T = b > 1$ ,  $S = +\gamma$ ,  $\sigma =$

0.3. In weak PD the payoffs can be defined as  $R = 1$ ,  $P = S = 0$ ,  $T = b > 1$ ,  $\sigma = 0.3$ .

Furthermore, a proportion  $\psi/2$  of the population are uniformly assigned to play the PD, a proportion  $\psi/2$  of the population are uniformly assigned to play the SD and a proportion  $1 - \psi$  of the population are also uniformly assigned to play the weak PD, which results in the fact that the mean payoff matrix returns to the basic weak PD as the baseline.

In our simulation, the individuals are uniformly distributed to the square lattice with four nearest neighbors. The player at site  $x$  is randomly selected, and the utility  $U_x$  of player  $x$  is acquired by the payoffs accumulated through playing games with his four nearest neighbors. In the same way, the utility  $U_y$  of player  $y$  randomly selected from the four nearest neighbors of player  $x$  will also be acquired. Then the strategies  $S_x$  and  $S_y$  of players can transform from each other based on the difference between the utility  $U_x$  and  $U_y$ . Thus, the player  $x$  adopts the strategy  $S_y$  from player  $y$  with the transition probability [23]:

$$W(S_x \leftarrow S_y) = \frac{1}{1 + \exp[(U_x - U_y)/K]}, \quad (1)$$

where  $K = 0.1$  describes the uncertainty during the process of the strategy transition [24,25]. Under normal circumstances, the strategy of the better performing player will be adopted. However, there is also the rare exception that the strategy of the worse performing player will be adopted.

The size of the square lattice is set as  $500 \times 500$  on which the Monte Carlo simulations with 2000 steps are performed. In fact, before we finally decide which square lattice size to choose, we have tested a sequence of sizes, finding that their finally results are almost the same but with different steady-state simulations steps and for the larger sizes the steps are relatively smaller speeding up the convergence rate. In addition to this,  $\rho_c$ ,  $\rho_d$ ,  $\rho_l$  is taken as the fraction of cooperators, defectors, loners respectively, and all of the values are calculated through being averaged over the last 200 independent steps elevating the values' accuracy because of the stable state.

## 3. Results

Now let's begin to discuss our simulation results by observing the influence of parameter  $\gamma$  on the evolution of cooperation, defection and going it alone in multigame. In Fig. 1, we display fraction of cooperators  $\rho_c$ , defectors  $\rho_d$ , and loners  $\rho_l$  in dependence on the temptation to defect  $b$  for different values of parameter  $\gamma$ . When  $\gamma = 0$ , it will return to the basic case where no sucker's payoff is involved, and three strategies coexist for the whole range of temptation  $b$ . However it can be observed that the positive  $\gamma$

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