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Multi-games on interdependent networks and the evolution of cooperation

Zheng-Hong Deng [a,*], Yi-Jie Huang [a], Zhi-Yang Gu [b], Dan Liu [c], Li Gao [d]

[a] School of Automation, Northwestern Polytechnical University, Xi'an 710072, China
[b] Wenzhou Vocational & Technical College, Wenzhou 325035, China
[c] School of Economics and Management, Chang'an University, Xi'an 710064, China
[d] School of Computer Science, Northwestern Polytechnical University, Xi'an 710072, China

HIGHLIGHTS

- Research on multi-games on two coupled networks and the evolution of cooperation.
- On each network, the population is randomly divided into two types.
- Multiple sucker's payoff and bias in utility function both enhance cooperation.

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ABSTRACT

Multi-games have been verified to improve cooperation in social dilemmas, as well as interdependent networks. However, researches on the combination of these two mechanisms are rare. Therefore, we try to introduce mechanism of multi-games on interdependent networks and explore the evolution of cooperation. In our work, the population on both networks is randomly divided into two types, one type players play the Prisoner's Dilemma and the other type players play Snowdrift. We discover that both the diversity of sucker's payoff and bias in the utility function can promote cooperation on each network to some extent. In addition, larger magnitude of sucker's payoff within a certain range could make more cooperation appear on both networks resulting from spatial distribution of strategies. A stronger bias in the utility function could facilitate cooperation on the main network, but restrains cooperation on the other network to a certain degree, which is due to the network reciprocity coming from bias. Besides, on each network, when more players choose to play SD, cooperation on this network can be improved no matter how the other network is classified.

1. Introduction

In some cases, folks may run into more than one social dilemmas at the same time, which brings forth multi-games mechanism [1–3] and motivates the development of evolutionary game theory [4–7]. Furthermore, multi-games have been verified to facilitate cooperation to a certain degree [8,9]. More specially, some individuals choose to play the Prisoner's Dilemma (PD) [10] and the others choose to play Snowdrift (SD) [11], which leads to such a result that players can adopt different payoff matrices in the process of playing games and improve cooperation in the end.

* Corresponding author.
E-mail address: dthree@nwpu.edu.cn (Z.-H. Deng).

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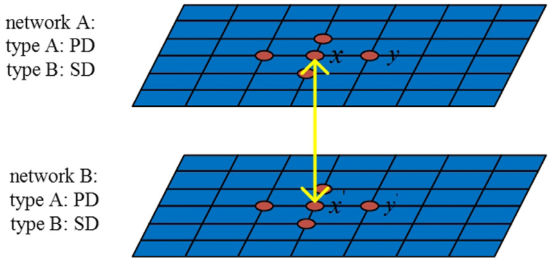

Fig. 1. (Color online). Schematic diagram of multi-games on the interdependent networks (square lattices) denoted as network A and network B. The two networks are designed to the equal size and linked together by the utility function depending on both the player's (x) own payoff and the payoff of its corresponding player (x') on other network. The payoff of each player (x/x') is accumulated through playing games with its four nearest neighbors (y/y') on the same network. Moreover, when each player plays games with one of its neighbors on each network, they could adopt PD or SD stochastically. Besides, strategy transfers can only occur on the same network and be inhibited between the two networks.

However, almost all researches on multi-games are limited to the single networks and hardly involve interdependent networks [12–23]. Besides, coupled networks have been proved to enhance cooperation as well, such as the mechanisms of bias in the utility functions [24], simultaneous formation of correlated cooperator clusters on both networks [25], biased imitation in coupled evolutionary games [26], heterogeneous coupling between interdependent lattice [27], as well as spreading of cooperative behavior across interdependent groups [28]. Just like multi-games, there is also a loophole in the study of interdependent networks that enable only one kind of game to be played. Therefore, it will be of significance, if the two mechanisms of multi-games and interdependent networks are combined together.

PD and SD are both the most classic game models, wherefore the two models are used to compose multi-games in our paper. In PD, two individuals must choose to act as cooperator (C) or defector (D) simultaneously. When both of them select to cooperate (defect), they could receive the reward R (the punishment P). When one plays the role of cooperator and the other plays defector, the cooperator will obtain the suck's payoff S and the defector will get the temptation T. In order to pursue the higher individual interests in a finite well-mixed population [11,29], payoff ranking is set as $T > R > P > S$ with $2R > T + S$. As a result, the final cooperation rate is zero. In SD, individuals interact in the same way as in PD, and the payoff ranking is set as $T > R > S > P$, which leads to the fact that cooperators and defectors coexist.

Furthermore, two coupled square lattices [29] are selected to interpret the interdependent networks in this paper. Besides, the two networks are designed to the equal size and linked together by the utility function depending on both the player's own payoff and the payoff of its corresponding player in other network [24]. And the payoff of the player is accumulated through playing games with its four nearest neighbors on the same network. Moreover, strategy transfers can only occur on the same network and be inhibited between the two networks. Except for these, on each network, some agents are randomly arranged to play PD and the others are randomly arranged to play SD.

Taking all of these into consideration, we wish to perform multi-games on two coupled square lattices denoted as network A and B as shown in Fig. 1. And the population on both networks is randomly divided into two types, denoted by type A and type B. Players of type A on network A (network B), whose proportion is $v\ (tv)$, adopt a negative value of the magnitude of sucker's payoff to play the Prisoner's Dilemma (PD), while players of type B on network A (network B), whose proportion is $1 - v\ (1 - tv)$, adopt a positive value to play Snowdrift (SD).

What is more, the rest of this paper is organized as follows: firstly, we proposed our model of multi-games; subsequently, the main simulation results are shown and discussed in Section 3; lastly we summarize our conclusions in Section 4.

2. Model

As schematically depicted in Fig. 1, each network is square lattice with size N and linked together by the utility function depending on both the player's own payoff and the payoff of its corresponding player in other network. The population on each network is randomly divided into two types denoted by type A and type B. On network A (network B) the proportion of type A is set as $v\ (tv)$ and the proportion of type B is set as $1 - v\ (1 - tv)$. Players of type A choose to play PD and players of type B choose to play SD.

The payoff matrix of multi-games is shown in Table 1. For simplicity without loss of generality, the payoff in PD can be rescaled as $R = 1, P = 0, T = b, S = -\delta$ and the payoff in SD can be rescaled as $R = 1, P = 0, T = b, S = +\delta$.

In accordance with these, it can be easily found that the utility function is the key to study the mechanism of multi-games on two interdependent networks. And we can use Fermi function [30] to interpret the utility function:

$$W\left(s_x \leftarrow s_y\right) = \frac{1}{1 + \exp\left[\left(U_x - U_y\right)/K\right]}, \tag{1}$$

Where $K = 0.1$ quantifies the uncertainty during the process of the strategy transition [31]. In almost all cases, the strategy of a better-performing player will be imitated. On each network, S_x and S_y means the strategy of player on site x and