Chaos, Solitons and Fractals 101 (2017) 100–105

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Frontiers

Leadership by example promotes the emergence of cooperation in public goods game

Zhen Wang*, Tong Chen, Yongjie Wang

College of Management and Economics, Tianjin University, Tianjin 300072, PR China

ARTICLE INFO

Article history:
Received 15 May 2017
Accepted 21 May 2017

Keywords:
Leadership by example
Reputation
Influence scope
Public goods game
Complex network

ABSTRACT

Profit-driven strategies are not always adopted in human society. Reputation, which is often treated as indirect reciprocity, is an important factor to promote cooperation. In this paper, we propose a new kind of reputation mechanism by introducing leadership by example from a complex network perspective. The degree of each node is influenced by reputation value. Leadership by example with higher reputation and greater scope of influence, which could not be ignored, are special group in social network, especially in China. Numerical simulation results are indicated that the evolutionary curves of cooperation are presented an inverted U-shape as the increase of the scope of influence of players. In addition, the relationship are discussed among initial fraction of leadership by example, synergy factors, maximal scope of influence. Whats more, the optimal initial fraction of leadership by example is studied in different conditions. Our work may be beneficial to address the cooperation dilemmas in public goods game (PGG).

1. Introduction

Darwinian evolutionary theory shows that for rational people, it is meaningless to help potential competitors [1]. This means cooperation is irrational therefore extinction is inevitable. However cooperation is ubiquitous in real-world systems ranging from uncountable biological, animals, especially in human societies. Thus scientists across many disciplines have been trying to explain this puzzle for more than a century. Among them, the evolutionary game theory [2–5] provides a competent theoretical framework to illustrate the evolution of cooperation especially in social dilemmas. In this field, over the past decades, several mechanisms for enhancing the collective cooperation have been proposed [6], such as kin selection [7], direct or indirect reciprocity [8–11], group selection [12,13], the impact of noise [14–16] and spatial reciprocity [17–19]. Particularly the spatial reciprocity has been found to promote cooperation and has been confirmed experimentally [20]. The spatial reciprocity has endowed the cooperators to protect themselves against the invasion of defectors by forming clusters via nearest neighbors on the regular lattices and has enhanced the level of cooperation in the dilemmatic circumstances. Yet, the regular lattice is far from characterizing the topology of real-world systems since they are often heterogeneous. Thus, recent studies shift from evolutionary game on regular lattice to evolutionary game on complex networks [21–26]. A mechanism has attracted a huge realm of interest that inspired by the growing relevance in the field of network science and considered a step to more realistic conditions. Santos and Pacheco [27] found that the cooperation is tremendously elevated in scale-free networks since the cooperative clusters are created once the hub nodes who have a large number of neighbors are occupied by the cooperators. This kind of phenomenon of immense enhancement has been observed in prisoners dilemma game (PDG) [28] and public goods game (PGG) [29–31].

The two models have attracted the most attention: the PDG for pairwise interactions and the PGG for group interactions, both games represent a social dilemma. Essentially, the latter is an extention of the pairwise interactions in the former to an arbitrary number of players. In PGG, players decide to cooperate or defect and cooperators contribute to public goods pool by the amplification and distributed equally among players. So mutual cooperation yields the highest collective benefits. However, defectors as free riders can achieve higher payoffs than cooperators. Thus, rational players will choose defection rather than cooperation. Obviously, the contradiction between individual rationality and collective benefits form a social dilemma. In order to solve this social dilemma, many researchers have proposed many mechanisms [30–36], such as punishment mechanism [37–39], reward mechanism [40–43] and reputation effects. Most notably, the role of reputation mechanism has gained more attention recently [44]. Nowak and

* Corresponding author.
E-mail address: acdr_wz@tju.edu.cn (Z. Wang).

http://dx.doi.org/10.1016/j.chaos.2017.05.027
0960-0779/

sigmund unraveled that reputation based on indirect reciprocity can promote the evolution of cooperation [10]. Following this seminal discovery, several studies have proposed on different aspects of cooperation based on this mechanism. Milinski et al. indicated that through alternating rounds of public goods game experiments, the reputation for indirect reciprocity can contribute the public goods at an unexpectedly high level [45]. In addition, many studies have concerned with the evolution of cooperation in heterogeneous populations [46–48]. According to reputation mechanism and heterogeneous populations, Droz et al. reported that the motion of the influential players can improve remarkably the maintenance of cooperation for their low densities [49].

In the present paper, we will study the role of heterogeneity of population on the evolution of cooperation in the PGG through introducing some influential individuals as leadership by example on complex network. Leadership by example are defined as influential leaders who are set example for the rest of group [50,51]. They are strategically active and behave in an examplary manner. In addition, they are all unconditional cooperators and influence the other players around them through their own actions. The leadership by example is also ubiquitous in real human societies, such as the organizer in the village opera [52], leaders set example in a voluntary contribution game [53] and so on. In the model, the leadership by example have high reputation value and the influence scope are decided by reputation value, namely the larger reputation value, the greater influence scope. Players with greater influence scope will have more neighbors. These players play a vital role in the evolution of cooperation because their strategies have a greater chance to be adopted by their neighbors. The mechanism can support cooperation for the models which a part of players have enhanced activity in spreading their own strategies on their own neighborhood [54]. Motivated by these, we propose a computational model to combine these factors. Through scientific computer simulations , we demonstrate that the existence of leadership by example promotes the evolution of cooperation and as long as there is a small number of such players able to greatly enhance the level of cooperation. In addition, we will find the optimal example proportion and the optimal scope of influence for promoting cooperation. Finally, we conclude that the existence of leadership by example provides a viable route to resolve social dilemmas which will inspire further studies.

The rest of this paper is organized as follows. We describe in detail the PGG model in Section 2. Section 3 presents the numerical simulation results. At last discussions on the obtained results and conclusion is provided in Section 4.

2. The model

In our public goods game model, there are three types of players, recorded as players A, B and C. Initially, the players A(as cooperators) and the players B (as defectors) are randomly distributed with the 50% probability respectively on the model. Then we turn the θ percent of players A into players C (as a leadership by example). Meanwhile, each player A and player B is endowed with a random integer taking from the interval [1, 100], which denotes the value of individual reputation. Player C is endowed with a random integer taking from the interval [50, 100]. The value of reputation will be increased or decreased one unit respectively if players decides to cooperate or defect at each time step during the simulations [10]. Furthermore each individual will be accumulated the reputation value until 100 or decreased the reputation value until 1. In our model, the number of players' neighbors are not fixed, but according to the players' influence scope to change. Namely, the player with large influence scope have more neighbors. In addition, We define that the size of the influence scope is related to the value of the personal reputation. Accordingly, the relation between player's reputation value and influence scope as follow,

$$D = 1 + \frac{rv}{100} \times MD$$

Where D stands for the influence scope and 1 stands for the basic influence scope, MD stands for the maximum scope of affecting neighbors and rv stands for the player's reputation value. This means that the player's influence scope is determined by the player's reputation value and maximum scope. According to this mechanism, the influence scope of leadership by example is more and more large, so that there are more neighbors can be affected. On the contrary, the defector's influence scope is more and more small, thus isolated by the players around. So the neighbor of the defector only has leadership by example, which the defector can only to imitate the strategies of the leadership by example.

Then, the accumulation of payoffs Px for each player will follow the same standard procedure according to the PGG rule. That is, each agent will participate in $G = k + 1$ PGG groups where one group is centered around himself (i.e., focal player) and other k groups focus on the focal player k nearest neighbors. In every PGG group, all players will decide at the same time whether to invest a fixed share into the public pool. Without loss of generality, the player will contribute one unit if adopting the cooperation strategy ($S_A = 1$), otherwise not contribute anything($S_B = 0$). Afterwards, the total contribution which is multiplied by a synergy factor (r) will be distributed evenly over all players in the same group, irrespective of their contribution. Therefore, after a round PGG, the payoff of players will be obtained as follows,

$$P_A = \frac{r \cdot (n_A + n_C)}{k+1} - 1$$

$$P_B = \frac{r \cdot (n_A + n_C)}{\mathrm{k}+1}$$

$$P_C = \frac{r \cdot (n_A + n_C)}{\mathrm{k}+1} - 1$$

Where P_A, P_B and P_c denote the payoff of different players respectively, n_A and n_C is the number of players A and players C respectively, r is the synergy factor which is greater than 1.0 and k is the total number of the player's neighbors. Then player i randomly chooses neighbor j and adopts the selected neighbor strategy of j with the following probability:

$$\Pr\mathrm{ob}(s_i \leftarrow s_j) = \frac{1}{1 + \exp[(P_i - P_j)/K]}$$

Where $(P_i - P_j)$ characterizes the difference of payoffs between player i and player j, K defines the amplitude of the noise, without lacking the generality, we set $K = 1$.

As we can see in real world, reputable people have more friends, so we assume that players with higher reputation value will have more neighbors. The mechanism of this hypothesis is that the high reputation of players are more likely to influence other players strategies. In the model, the player randomly chooses neighbor and adopts the selected neighbors strategy with Fermi probability function. Then we introduce the players C as leadership by example in the model, we observe the impact of introduction of leadership by example on the model. The model of the network is shown in the Fig. 1. Through the comparison of the two graphs we can see that the leadership by example because of their own high reputation have a greater influence scope to influence their neighbors.

A full Monte Carlo step (MCS) includes the above-depicted basic steps, and each player has a chance to modify the current strategy into that of one of neighbors. The MCS will be interacted until the stationary state will be reached. In addition, all of simulation results are averaged through 20 independent runs so as to reduce