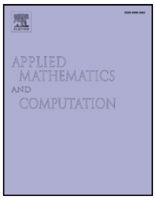
Applied Mathematics and Computation 320 (2018) 621–632

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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



Effect of the migration mechanism based on risk preference on the evolution of cooperation

Yan Li[a,b,*], Hang Ye[a,b,c]

[a] School of Economics, Zhejiang University of Finance & Economics, Hangzhou 310018, PR China
[b] Center for Economic Behavior & Decision-making(CEBD), Zhejiang University of Finance & Economics, Hangzhou 310018, PR China
[c] College of Economics and Interdisciplinary Center for Social Sciences (ICSS), Zhejiang University, Hangzhou 310027, PR China

ARTICLE INFO

Keywords:
Cooperation
Migration
Risk preference
Spatial prisoner's dilemma game

ABSTRACT

Individual migration is an effective means of promoting cooperation in the spatial structure. We can think of migration as a kind of risky investment, so risk attitudes can produce an effect on the migration decision. In order to understand the relationship between risk preference and the evolution of cooperation, the spatial prisoner's dilemma game model with individual migration based on risk preference is established. By introducing the homogeneity of risk preference, we find that lower risk aversion values keep a high level of cooperation under a larger defection parameter, while the cooperation level can be raised when the whole population is risk-seeking and at lower risk aversion values under a smaller defection parameter. Under the heterogeneous risk preference assumption, simulation results indicate that the cooperation strategy is a winning strategy in a steady state for a wide parameter space and the cooperation level decreases with increasing in the variance of risk preference. From typical snapshots, we can see that co-evolution of the network structure and cooperation strategy has been realized. Cooperative clusters can also be found in the typical snapshots, which have proved the migration mechanism based on risk to be effective in favoring the evolution of cooperation.

1. Introduction

Cooperation is altruistic behavior which can increase the fitness of others but reduce their own fitness during evolution. If evolution is survival of the fittest, the cooperators will be eliminated through a process of natural selection. However, cooperation is a widespread phenomenon in social life. From an evolutionary perspective, how this behavior can evolve is a difficult question to explain. Many mechanisms have been proposed by scholars from various perspectives, such as economics [1,2], biology [3] and statistical physics [4-7], to resolve the evolution of cooperation. Kin selection, direct reciprocity, indirect reciprocity, multilevel selection and spatial selection are the five main mechanisms discussed by Nowak [8]. Kin selection is used for explaining the cooperative phenomenon with a genetic relationship between individuals; direct reciprocity is aimed at explaining the cooperation in the repeated game; indirect reciprocity is mainly reputation-based mechanisms; multilevel selection studies cooperation in view of group theory. However, the research perspectives mentioned above cannot explain the cooperative behavior in a one-shot prisoner's dilemma game. The evolution of cooperation based on the

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[*] Corresponding author at: School of Economics, Zhejiang University of Finance & Economics, Hangzhou 310018, PR China.
E-mail address: liyanzi@zufe.edu.cn (Y. Li).

https://doi.org/10.1016/j.amc.2017.10.023

perspective of spatial selection has become an important research direction [9-16]. In such studies, evolutionary game theory is a theoretical tool [17,18]; network structure is a carrier [19-23]; computer simulation is the main research method [24,25].

Spatial selection is able to promote the emergency of cooperation because network structure provides favorable conditions for the formation of cooperative clusters [26]. Individual migration is an important mechanism that can promote the survival and even enlargement of cooperator clusters [27-35]. For example, the walk-away migration strategy [36,37], the success-driven migration [38], the always-move rule [39]. In addition, collective-risk social dilemma in the public game addresses the effect of self-organizing risk-driven migration on the evolution of cooperation [40-43]. Other migration mechanisms have also been used to discuss the evolution of cooperation [44-46]. Migration changes the partners of the game and the learning strategy, resulting in changes in the co-evolution of cooperation. The co-evolutionary model which allows strategy updating and network updating is closer to reality [47,48], such as the co-evolution based on reputation [49] and the co-evolution dependent on random mobility [44]. Individual migration is an important method for the formation of co-evolution and cooperative clumps.

Risk preference is defined as the attitudes toward facing risk, which is another important factor affecting the decision of migration. The effect of risk preference on the evolution of cooperation has been discussed, and the relationship between risk and cooperation is that risk averse players are beneficial for the emergency of cooperation [50-53]. However, the above research is discussed on a static network structure, and the migration mechanism based on risk preference types has rarely been investigated in previous studies. Because we can think of migration as a kind of risky investment, risk attitudes can produce an effect on the decision of migration. It is documented that risk seekers are more likely to migrate than risk averse players [54,55]. In reality, risk averse players, risk-seeking players and risk neutral players are the three main risk preference types.

In order to further improve the research on risk and cooperation, and understand the relationship between movement-based risk preference and the evolution of cooperation, referring to the study of Flache and Jaeger et al. [51,54], we establish such a model; in this model, whether an agent migrates depends on his risk preference style and his surroundings. To be specific, the migration rate of the agent shows positive correlation with payoff and negative correlation with migration cost, and the risk seeker has a higher migration rate than risk averse ones. The characteristic of this model considers not only objective factors-migration cost and the wealth of the individual but also subjective factors-risk preference styles of the individual. Then, can movement based on risk preference promote the emergency of cooperation? How does the heterogeneity of risk preference affect the cooperation level? In order to answer these questions, we consider individual migration based on the homogeneity of risk preference and the heterogeneity of risk preference in the spatial prisoner's dilemma game. The simulation results demonstrate that risk preference migration is an effective mechanism for promoting cooperative behavior under certain conditions.

The rest of the paper is organized as follows. In Section 2, we present the related network structure and Spatial Prisoner's Dilemma Game model with the introduction of migration based on risk preference. In Section 3, the simulation results and analysis of their implications are given. In Section 4, we summarize the main conclusions and discuss further research directions.

2. Model

We adopt a regular $L \times L$ square lattice with periodic boundary conditions and Von Neuman neighborhood, where each site is either empty or occupied by an agent and the agents are uniformly distributed at random in the initial situation. We define $\rho = N/L \times L$ as the density of the population, where N is the number of agents in the spatial structure and $L \times L$ is the size of the square lattice. We consider an evolutionary Prisoners' dilemma game (PDG) in the following studies. In the evolutionary Prisoners' dilemma game, each agent i, designated either as cooperation(C) or defection(D) with equal probability, plays games with his neighbors and obtains the total payoff P_i, which depends on the payoff matrix A and the strategies of his neighbors. The payoff matrix A is given below:

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} R & S \\ T & P \end{pmatrix} \end{array}$$

where R is the payoff for mutual cooperation, while P is the payoff for mutual defection. When a cooperator meets a defector, S is the payoff for the cooperator, and T is the payoff for the defector. Equalities $T > R > P > S$ and $2R > T + S$ are the conditions for the PDG. We adopt the simple re-scaled payoff matrix: $T = b$, $R = 1.0$, $P = .1$ and $S = 0.0$ according to [22,26]. Besides, we want to point out one aspect here: according to [56,57], scaling parameters, Dg' and Dr', for the dilemma strength in our presumed PD games satisfies $Dg' > 0$ and $Dr' = 0.1/0.9$. In this case, the condition is not exactly the same as that of boundary games with pure chicken games.

In addition to the network structure and the evolutionary game model, the migration mechanism is another important part of our model. The migration mechanism considering strategy, migration costs and risk preference may reflect real-world setups to some extent. The rate of migration is given as follows.

$$v_i = \begin{cases} 0, & if \;\; N_D = 0 \\ \left(\frac{P_i}{P_i + c}\right)^{2^{\alpha_i}}, & if \;\; N_D > 0 \end{cases} \tag{1}$$