Physica A 445 (2016) 48–56

Contents lists available at ScienceDirect

Physica A

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

Evolution of cooperation driven by social-welfare-based migration

Yan Li, Hang Ye, Hong Zhang *

College of Economics and Interdisciplinary Center for Social Sciences (ICSS), Zhejiang University, Hangzhou 310027, PR China

HIGHLIGHTS

- Individuals use social welfare evaluation to determine their migration behavior.
- The effects of different social welfare functions on cooperation are investigated.
- Social welfare functions have different relative efficiency for supporting cooperation under different parameter ranges.
- Inequality aversion plays an important role in the evolution of cooperation.

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 29 September 2015
Available online 4 November 2015

Keywords:
Social welfare
Inequality aversion
Migration
Prisoner's dilemma
Social cooperation

ABSTRACT

Individuals' migration behavior may play a significant role in the evolution of cooperation. In reality, individuals' migration behavior may depend on their perceptions of social welfare. To study the relationship between social-welfare-based migration and the evolution of cooperation, we consider an evolutionary prisoner's dilemma game (PDG) in which an individual's migration depends on social welfare but not on the individual's own payoff. By introducing three important social welfare functions (SWFs) that are commonly studied in social science, we find that social-welfare-based migration can promote cooperation under a wide range of parameter values. In addition, these three SWFs have different effects on cooperation, especially through the different spatial patterns formed by migration. Because the relative efficiency of the three SWFs will change if the parameter values are changed, we cannot determine which SWF is optimal for supporting cooperation. We also show that memory capacity, which is needed to evaluate individual welfare, may affect cooperation levels in opposite directions under different SWFs. Our work should be helpful for understanding the evolution of human cooperation and bridging the chasm between studies of social preferences and studies of social cooperation.

1. Introduction

Cooperation is a ubiquitous phenomenon in both human society and animal world. It is a fascinating challenge in both natural science and social science to understand how cooperation can emerge and be maintained in communities of selfish individuals [1–6]. The evolutionary prisoner's dilemma game (PDG) has been a widely used metaphor for understanding cooperation between unrelated individuals. In a one-shot PDG, two players simultaneously choose between two strategies: cooperation and defection. Although mutual cooperation leads to the optimal outcome, defection is always a better choice for any self-interested individual regardless of the partner's choice. To understand how cooperation can be favored in nature and

* Corresponding author.
E-mail address: poyeker@gmail.com (H. Zhang).

http://dx.doi.org/10.1016/j.physa.2015.10.107
0378-4371/

human society, five major mechanisms for supporting cooperation have been proposed, including kin selection [7], direct reciprocity [8], indirect reciprocity [9], spatial selection [10] and multilevel selection [11]. A central problem in investigations of these mechanisms is how assortment among individuals can emerge in the process of evolution. If such assortment is at work, cooperators can interact more frequently with other cooperators but not with defectors. As a remarkable example, in the spatial PDG, cooperation can emerge and be maintained if cooperators can form clusters such that they have greater payoffs than defectors due to the effect of spatial reciprocity.

In recent years, as an important factor in the spatial PDG, the migration of players under various conditions has been introduced and investigated. For example, Vainstein et al. [12] introduced empty sites and random migration in a spatial PDG and found that such movement can enhance cooperation under a wide variety of conditions. Vainstein and Arenzon [13] extended such random migration to Snowdrift games. In addition to random migration, some forms of adaptive or contingent migration also have been investigated. Aktipis proposed a walk-away strategy whereby individuals can avoid repeated interactions with defectors [14]. Helbing et al. proposed a model of success-driven migration in which individuals prefer moving to sites with high expected payoffs [15]. Liu et al. [16] added the factor of migration cost to the success-driven model and found that migration cost does not suppress the emergence of cooperative behavior. Yang et al. [17] considered a migration mechanism based on wealth, and Cong et al. [18] discussed reputation-based migration on the lattice. In addition to migration on a square lattice, studies have also discussed the effect of migration in continuous two-dimensional space where agents interacted and moved on a plane [19–22]. Various other forms of migration can enhance cooperation under certain parameter ranges [23–28]. These investigations are meaningful not only because migration provides a new approach to understanding the evolution of cooperation but also because migration itself is a key property of humans and a fundamental problem in understanding population dynamics [29,30].

In most previous studies of contingent migration, the migration behavior of each individual is entirely based on the individual's own situation and not on the situations of other individuals. This means that individuals care about information concerning other individuals only when this information can influence their own situation. However, in real society, people often have social preferences [31,32,2,33], by which an individual may consider another individual's payoff in addition to its own. Chen et al. [34] and Wang et al. [35] considered the neighbor's payoff and information during strategy updating and found that these mechanisms can enhance cooperation under certain parameters. Bo [36] discussed the effect of inequality aversion, which is a commonly used form of social preferences in the PDG on complex networks. Lu et al. [37] also considered the effect of a version of social preferences on the evolution of cooperation in a self-questioning game. Cushing [38] discussed the relationship between migration and social welfare under certain conditions using data from US and found that social welfare has an effect on migration decisions. In this paper, we introduce social welfare evaluation as a type of social preferences into individuals' contingent migration decisions and investigate how different social welfare evaluation modes affect migration patterns and cooperation. By social welfare, we mean individuals' evaluation of the situation of a given site in the lattice. In previous works about adaptive migration [15,26], a focal player need to know the strategies of the players in the empty site's neighborhood to decide whether to migrate. Unlike this information setting, in our model the information needed for deciding the migration behavior is only the aggregated social welfare of the site under consideration. Although the social welfare of a given site is derived from the past history of the payoffs of the players in the neighborhood, the focal player does not need to know any information about the strategies or payoffs of other players. We assume that individuals are ignorant of their own welfare when they decide to improve their environment, which means that this evaluation depends solely on the welfare of neighboring individuals and not on that of the focal individual who chose to migrate. Because social welfare depends on all the welfare of individuals under consideration, we face the problem of how to measure social welfare using some aggregation method [39–41]. To address this problem in our model, three types of cardinal social welfare functions (SWFs) are considered: the Utilitarian SWF, Bernoulli–Nash SWF, and Rawlsian SWF. According to these SWFs, each individual's migration behavior will be contingent on the welfare of other individuals and may affect the individual's strategy updating. Interestingly, we find that the three SWFs have different effects on both the migration patterns and the evolution of cooperation. This paper proceeds as follows: we first describe the model and then present our findings in detail.

2. Model

In a one-shot PDG, each player independently chooses either cooperation or defection. R ("reward") represents the payoff for mutual cooperation, while P ("punishment") represents the payoff for mutual defection. T ("temptation") represents the payoff for unilateral defection, which leads to the payoff S ("sucker") for the cooperative individual. If the inequalities $T > R > P > S$ and $2R > T+S$ both hold, the payoff structure satisfies the conditions of the classical PDG. For simplicity, although there are some alternative scaling methods for the PDG [42], we adopt the re-scaled payoff matrix: $T = b > 1$, $R = 1$, and $P = S = 0$ to allow us to study the game as a function of a single "temptation" parameter b. We consider an evolutionary PDG on an $L \times L = N$ square lattice (L is fixed at 50 in our simulations) with periodic boundary conditions [10,43]. Each site on the lattice is either empty or occupied by an individual. We define the density of players $\rho = n/N$ as a parameter, where n is the number of all individuals. Initially, individuals are randomly located on the lattice, and their strategies (cooperation or defection) are assigned with equivalent probability.

Individuals are updated asynchronously in a random sequential order at each time step. The randomly selected individual engages in interactions with its 4 nearest neighbors (the von Neumann neighborhood) and compares its payoff with that