Ecological Complexity 36 (2018) 196–205

Contents lists available at ScienceDirect

Ecological Complexity

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

The occasional absence of resources for cooperation and its role in the evolution of direct reciprocity

Shun Kurokawa[a,b,c,*]

[a] Graduate School of Agriculture, Kyoto University, Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto 606-8502, Japan
[b] Key Lab of Animal Ecology and Conservation Biology, Institute of Zoology, Chinese Academy of Science, Datun Road, Chaoyang, Beijing 100101, PR China
[c] School of Economics and Management, Kochi University of Technology, Kochi 780-8515, Japan

ARTICLE INFO

Keywords:
Evolutionary game theory
Cooperation
Donor-recipient game
Direct reciprocity
Memory-one strategy
Lying strategy

ABSTRACT

Reciprocity is regarded as a mechanism that possibly explains the evolution of cooperation in repeated encounters. Occasionally, even if individuals want to cooperate, they can lack the necessary resources for providing help to others, thereby preventing them from the engagement in benevolent interactions. Unlike previous investigations, the present study examines the situation where a player sometimes knows whether the opponent player had resources for cooperation or not. Using an evolutionary stable strategy (ESS) analysis to obtain the memory-one strategy whose stability condition against the invasion by unconditional defectors is the loosest, we find that forgiveness does not influence the evolutionary outcomes whereas persistence (whereby players imitate their own behavior when knowing that the opponents did not have resources for cooperation and defected) facilitates the evolution of cooperation. Forgiveness in our model means that a player decides to cooperate if the opponent did not have the resources for cooperation and defected previously. In addition, we introduce lying strategists who can pretend having no resources for cooperation, and we analyze the three-strategy game played by lying strategists, the honest naive strategists, and unconditional defectors, finding that at low cost-to-benefit ratios, unconditional defection and the lying strategy can be stable, while the honest naive strategists diminish. Our results highlight the importance of accessibility of information about opponent's resources for cooperation and its effects on the evolutionary dynamics of direct reciprocity.

1. Introduction

According to Darwin's theory, the existence of cooperation is mysterious and needs explanation (Axelrod and Hamilton, 1981; Axelrod, 1984; Hamilton, 1964; McElreath and Boyd, 2007; Nowak, 2006; Sigmund, 2010). If two players interact repeatedly such that a cooperator defects when the opponent is a defector and cooperates when the opponent is a cooperator, then a cooperator can harness future cooperation from the opponent player while a defector cannot. Hence, a cooperator can be better off than a defector, and cooperative behavior can pay. This is called direct reciprocity, and represents one of the potential mechanisms that make the evolution of cooperation possible (Axelrod and Hamilton, 1981; Axelrod, 1984; Trivers, 1971; Wilkinson, 1984).

Even if humans or individual units of a given biological and ecological system want to cooperate, they sometimes lack the resources (e.g., time, energy) to benefit others, and as a result, they can fail to cooperate, which is a topic that has been addressed in previous studies of cooperative behavior (Brandt and Sigmund, 2004; Fishman, 2006, 2003; Fishman et al., 2001; Hadzibeganovic and Xia, 2016; Lotem et al., 1999; Roberts, 2008; Santos et al., 2016; Sherratt and Roberts, 2001; Sigmund, 2012). How should direct reciprocators behave when resources for cooperation are sometimes absent? Fishman (2006) addressed this question by examining the situation in which players do not always have resources for cooperation and interactions between the same players are repeated. It was found that direct reciprocators are likely to evolve when they penalize the opponents by switching from cooperation to defection in response to every defection, unless it was preceded by their own defection (i.e., when they have empathy).

It is reasonable to assume that the information on the presence or absence of resources can also be available to the opponent player (say, if an animal's stomach looks full, then the other animals can judge that the animal can afford to give food or have resources for cooperation), which may be useful information when making action at subsequent encounters. Especially when the opponent player defected but he (she) did not have resources for cooperation, the information that he (she)

* Corresponding author at: School of Economics and Management, Kochi University of Technology, Kochi 780-8515, Japan.
E-mail address: kurokawa.shun@kochi-tech.ac.jp.

https://doi.org/10.1016/j.ecocom.2018.08.007
Received 22 May 2018; Received in revised form 7 July 2018; Accepted 5 August 2018
1476-945X/

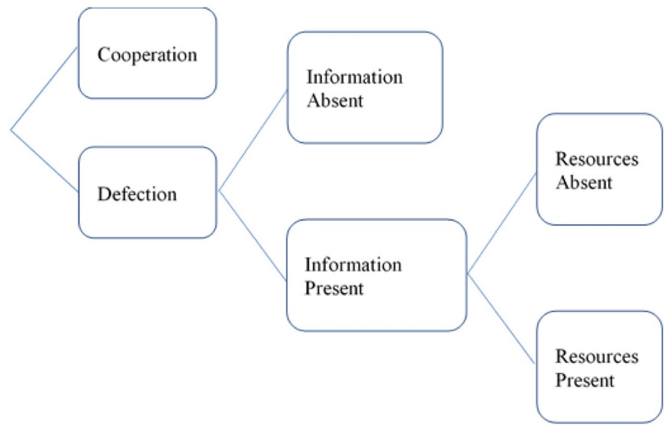

Fig. 1. *Possible interaction cases in our model.* A player receives two kinds of information: One is about opponent player's cooperation or defection in the last move. This information is always accessible. The other type of information is about opponent player's resources for cooperation. This information is either accessible or inaccessible. The first branching is between cooperation and defection. The branch of cooperation does not require any additional cases because a player can know that the opponent had resources for cooperation when the opponent cooperated in the previous round, while if defected, we have another branching about information on availability of resources (present vs absent). If this information is present, it could branch again into resources present vs. resources absent. This should result in the four cases of interest at the leaves of the tree.

did not have resources for cooperation may be beneficial when making action at subsequent encounters. And we speculate that direct reciprocators may be favored by natural selection not only when having empathy but also when using such information appropriately. This is the topic that we attempt to tackle in the present work.

More specifically, we consider the case where the information about player's previous action (i.e. whether the player cooperated or defected) spreads to the opponent with probability 1 (see also Discussion), whereas the information on the presence or absence of resources for cooperation is conveyed with probability between 0 and 1. Namely, the information an opponent receives about player's resources is the one of the following three kinds: (a) the player had resources in the last move, (b) the player had no resources in the last move, and (c) the information about the presence or absence of resources in the last move is not available (see Fig. 1).

When the opponent receives the information that the player cooperated in the last move, the opponent then knows that the player did have the resources for cooperation, and therefore, the number of combinations is four: (i) The focal player knows that the opponent cooperated with the focal player, (ii) the focal player does not know whether the opponent had resources for cooperation or not, but he knows that the opponent player defected in the previous round, (iii) the focal player knows that the opponent had resources for cooperation and that the opponent defected previously, and finally, (iv) the focal player knows that the opponent did not have resources for cooperation and that the opponent defected with the focal player. When players face the case (iv), then how should they optimally behave? In this paper, we study the case where a conditional cooperator takes into account only opponent's move and specify the strategy that is likely to evolve under such a condition (Section 2.1). Moreover, we study the case where a conditional cooperator refers to and takes into account his own move as well as his opponent's move (Section 2.2). When a player behaves in a reciprocal manner, the previous act of the focal player is similar with the act of the opponent two rounds ago. Hence, referring to the focal player's own previous behavior and trying to repeat the action in the last move (i.e., behaving persistently) is like referring to the act of the opponent two rounds ago. Hence, persistence can be regarded as a kind of reciprocity that boosts up the role of reciprocity; therefore, the evolution of the persistent strategy may be likely (see also Kurokawa, 2017a).

Furthermore, we initially assumed that the transmitted information about resources for cooperation is accurate; however, this information is knowingly not always accurate (Bockstaele et al., 2012; Byrne and Corp, 2004; McNally and Jackson, 2013; Nakamaru and Kawata, 2004; Seki and Nakamaru, 2016; Vrij et al., 2011, 2006; Whiten and Byrne, 1988; Zahavi, 1977). Specifically, a liar which pretends not to have had resources for cooperation, even though he actually had them, may emerge. Moreover, such a liar may successfully invade and take over the population of honest, naive strategists. In this paper, we also investigate this possibility.

The rest of this paper is structured as follows. Section 2 is devoted to the description of the models and analysis. In Section 2.1, we deal with the case where a single ALLD-strategy mutant (i.e., with unconditional defection) invades the population of memory-one (i.e., remembering the last move in a repeated game) conditional strategists which do not refer to their own moves, and obtain the strategy whose stability condition is the loosest among conditional strategies. In Section 2.2, we study the case where conditional strategists which refer to their own moves. In Section 2.3, we introduce a lying strategy and study the three-strategy game played by naive honest strategists, liars, and unconditional defectors. In Section 3, we summarize the results and discuss them in the context of previous studies.

2. Model & results

2.1. The evolutionary stability against unconditional defectors: the case of conditional cooperators not referring to their own moves

The population size is infinite and inter-individual interactions occur randomly. We consider the repeated donor-recipient game, which is a simplified version of the repeated prisoner's dilemma game (Nowak, 2006; Tanimoto, 2015; Tanimoto and Sagara, 2007; Wang et al., 2015). Individuals choose to cooperate or defect in each round. While a defector does nothing, a cooperator provides a benefit b at a personal cost c, such that $b > c > 0$. By δ, we denote the probability that in each interaction, any given pair continues to play the donor-recipient game, where $0 < \delta < 1$. Their relationship terminates with probability $1 - \delta$.

Individuals sometimes fail to cooperate even if they initially intended to cooperate, which can occur due to the lack of resources for cooperation. By r, we denote the probability that players have no resources for cooperation in each round. In that case, players are not able to cooperate even if they wish to do so, where $0 < r < 1$. With probability $1 - r$, players have the resources for cooperation and choose to cooperate or defect in each round. We assume that the value of the parameter (r) is independent of players throughout this paper (see also Discussion).

Let us consider the case where the information about player's chosen action (cooperation or defection) spreads to the opponent player with probability 1. Furthermore, let us consider the case where the information about player's resources for cooperation spreads to the opponent player in each round and accurately with some constant probability e, where $0 \le e \le 1$. With 1-e, the information about player's resources does not spread to the opponent player. Note that previous studies examined the case where $e = 0$ (i.e., the information about player's resources for cooperation does not spread to the opponent