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How much cost should reciprocators pay in order to distinguish the opponent's cooperation from the opponent's defection?

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ABSTRACT

Reciprocity is a potential mechanism that encourages the evolution of cooperation. We consider the case where reciprocators' cognitive ability of distinguishing the opponent's cooperation from the opponent's defection imposes a recognition cost. While it is natural to consider how recognition accuracy depends upon the magnitude of the recognition cost, it is rather unclear which amounts of the recognition cost paid by the reciprocator are most likely to evolve. By using the evolutionarily stable strategy analysis, we herein tackle this problem and show that the condition under which reciprocators can resist the invasion of unconditional defectors is most relaxed when they have perfect perception. We further consider a game with three strategies played by unconditional defectors and two types of heterogeneous reciprocators with different perceptual abilities. Our analysis shows that only when execution error rates are large enough, it is possible for reciprocators with lower perceptual ability to resist the invasion of both the unconditional defectors and reciprocators with higher perceptual abilities. These findings advance our understanding of the evolution of perception and its eminent role in the evolution of cooperative behavior.

1. Introduction

Cooperation is costly to a donor while it is beneficial for a receiver; therefore, the existence and abundance of cooperation rightfully demands an explanation [1–16]. The representative mechanism which explains the existence of cooperation is kin selection [15]. However, kin selection cannot explain cooperation which occurs between unrelated individuals. Reciprocity (i.e., cooperation with a cooperator and defection against a defector in a repeated interaction) is a potential mechanism which facilitates the evolution of cooperation between non-kin [9,16,17].

To facilitate reciprocity, it is necessary that cooperators can recognize the opponents' behaviors and distinguish the opponent's cooperation from the opponent's defection [6,8,18–30]. When animals recognize the opponents' behaviors, recognition errors, in which the focal player mistakenly regards the opponent player's cooperation as defection, can occur [6,7,18] and a recognition cost can be imposed to the reciprocator [23,31–33], also. To the best of our knowledge, in previous works, when investigations have been conducted on recognition errors, a recognition cost has not been taken into consideration [6,7], and

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when investigations have been conducted on a recognition cost, recognition errors have not been taken into consideration [23,32,33].

However, it is natural to think that in reality, the accuracy of recognition and recognition cost are correlated (i.e., if an individual pays more recognition cost, then he can recognize the opponent more accurately) and a mutant which pays a partial cost and recognizes the opponent's behavior imperfectly, can also emerge (for a related work, see [34]). In addition, the reciprocators are here facing the dilemma in which they do not wish to pay a high cost, and yet they want to be able to distinguish the opponent's cooperation from the opponent's defection accurately. Consequentially, it is not obvious which action should reciprocators take: to pay only a partial perception cost and get a partial perception level, or to pay a full perception cost and obtain a perfect level of perceptual ability. In the present paper, we study under which conditions are reciprocators who pay only partial perception cost (to receive partial perception) and reciprocators who pay full perception cost (to receive perfect perception) likely to evolve.

The rest of this paper is structured as follows. In Section 2, we first present the details of our model. In Section 3, we consider the competition between reciprocators and unconditional defectors, and apply an evolutionarily stable strategy (ESS) analysis to obtain the condition under which reciprocators are an ESS against the invasion by unconditional defectors. We then investigate which cost magnitude paid by the reciprocator is most likely to evolve. In Section 4, we consider two situations with three strategies; one situation is that there are reciprocators, unconditional cooperators, and unconditional defectors (Section 4.1), and the other situation is with heterogeneous reciprocators having different levels of recognition cost and with unconditional defectors (Section 4.2). In Section 5, we summarize the results, compare them with related previous works, and we suggest several future research directions.

2. Model

We assume that players are paired at random. We consider the simplified prisoner's dilemma game called donor-recipient game [9,35,36]. A player who cooperates gives an opponent an amount b at a personal cost of c, where $b > c > 0$. A player who defects gives nothing. The simplified prisoner's dilemma game is repeated and players choose to either cooperate or defect in each round [7,9]. The probability of the players' interacting just t times in a given pair is $(1-w)w^{t-1}$, where $0 < w < 1$. This assumption leads to that the expected number of interactions is $1/(1-w)$. Thus, as w increases, the number of interactions per pair also increases.

Following earlier works (e.g., [17]), we consider TFT_k for reciprocal strategies. TFT_k recognizes the opponent's cooperation as cooperative with probability k $(0 \le k \le 1)$ (With probability $1-k$, TFT_k fails in recognizing the opponent's cooperation as cooperative and recognizes the opponent's cooperation as defective). In this case, the reciprocator can be seen to recognize the opponent's cooperation more accurately as k increases. On the other hand, TFT_k pays recognition cost $U(k)$ per one repeated interaction. It is reasonable that $U(k=0)=0$ and $U(k=l) \le U(k=m)$ when $l < m$ are satisfied. Additionally, to facilitate calculation, throughout this paper, we assume the following relationship (see [34] for a study putting a similar assumption):

$$U(k) = uk \tag{1}$$

where $u \ge 0$ (see Appendix A for the analysis in the case where (1) is not assumed). It can be said that u measures the difficulty of perception. We assume that irrespective of the value of k, TFT_k always recognizes the opponent's defection as defective.

Moreover, in the first round, TFT_k tries to cooperate with probability 1, while in the following rounds, TFT_k tries to cooperate when TFT_k recognizes the opponent's behavior as cooperative in the last move, and TFT_k defects when TFT_k recognizes the opponent's behavior as defective in the last move.

Besides, we consider ALLD for unconditional defectors. ALLD defects in every round no matter what the opponent does. Additionally, we consider ALLC for unconditional cooperators. ALLC tries to cooperate in every round no matter what the opponent does.

However, every individual fails (i.e., execution errors) with probability μ $(0 \le \mu < 1)$ to successfully cooperate even when he tries to cooperate [37].

3. The competition between two strategies (TFT_k and ALLD)

We explore the competition between two particular strategies: TFT_k and ALLD. Firstly, we investigate the stability for ALLD to be an ESS (i.e., evolutionarily stable strategy) against the invasion by TFT_k. Now we have

$$V(ALLD|ALLD) = 0 \tag{2}$$

$$V(\mathrm{TFT}_k|ALLD) = -c(1-\mu) - U(k) \tag{3}$$

where $V(X|Y)$ is the expected payoff accumulated through a repeated game to X for a game in a group of one X and one Y.

From (2) and (3), we obtain $V(\mathrm{TFT}_k|ALLD) < V(ALLD|ALLD)$ for any k. It means that ALLD is an ESS against the invasion of TFT_k for any k. Second, we investigate the stability for TFT_k to be an ESS against the invasion of ALLD. Here, by using