



# Which facilitates the evolution of cooperation more, retaliation or persistence?



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## ABSTRACT

The existence of cooperation in this world is a mysterious phenomenon. One of the mechanisms that explain the evolution of cooperation is repeated interaction. If interactions between the same individuals repeat and individuals cooperate conditionally, cooperation can evolve. A previous study pointed out that if individuals have persistence (i.e., imitate its “own” behavior in the last move), cooperation can evolve. However, retaliation and persistence are not mutually exclusive decisions, but rather a trade-off in the decision making process of individuals. Players can refer to the opponent's behavior and if the actor and the opponent opted for the different alternative in the last move, conditional cooperators have to give up either retaliation or persistence. The previous study also investigated this, and has revealed that the individual should give more importance to retaliation than to persistence. However, this study has assumed that the errors in perception are absent. In this world, errors in perception are present, and trying to imitate the opponent player can sometimes end in failure. And, it might be that imitating the focal player, which definitely ends in success, is more beneficial than trying to imitate the opponent player, which can end in failure especially when the error rate in recognition is large. Here, this paper uses evolutionarily stable strategy (ESS) analysis and analyzes the stability for reactive strategies against the invasion by unconditional defectors in the iterated prisoner's dilemma game. And our analysis reveals that even if we take errors in perception into consideration, retaliation facilitates the evolution of cooperation more than persistence unexpectedly. In addition, we analyze the stability for reactive cooperators against the invasion by a strategy other than unconditional defectors. Moreover, we also analyze the deterministic model in which unconditional cooperators, unconditional defectors, and the reactive strategy at the same time.

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## 1. Introduction

Cooperation is defined as the act which is costly to the actor and beneficial to the recipient [38]. If we consider cooperation in terms of natural selection, it is expected that cooperation will diminish as time goes by. However, cooperation is abundant in this world. We can see that there is a contradiction and this mysterious phenomenon has been a major topic in evolutionary biology [16,38,39,50].

Thus far, some mechanisms that explain the evolution of cooperation have been proposed. One of the mechanisms is direct reciprocity [1,50]. Trivers [50] mentioned that if interactions repeat and individuals have retaliation (i.e., behave cooperatively with a higher probability when the opponent cooperated in the last move than in the case wherein the opponent defected in the last move),

the evolution of cooperation is facilitated in the sense of evolutionarily stability against the invasion by unconditional defectors. This is because a reciprocator can elicit future cooperation from the opponent reciprocator, while a defector cannot elicit future cooperation from the opponent reciprocator. Retaliation facilitates the evolution of cooperation [50] (but see also [8,22]).

Cooperation in repeated interactions can be studied by using the framework called the iterated prisoner's dilemma game (IPD) [1]. Assume that individuals are paired at random. Individuals choose to either cooperate or defect in each round. An individual who cooperates will give an opponent an amount  $b$  at a personal cost of  $c$ , where  $b > c > 0$ , while an individual who defects will give nothing. The probability that the individuals interact more than  $t$  times in a given pair is given as  $w^t$ , where  $0 < w < 1$ . As  $w$  increases, so does the number of interactions per pair. It is straightforward to obtain that the expected number of interactions is  $1/(1 - w)$ .

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Relevant to direct reciprocity is imperfect information [4,19,20,22,23,25,28]. Information is sometimes absent in this world, and in such cases players cannot imitate the opponent's behavior. How should players behave when information about the opponent is unavailable?

Kurokawa [25], by using a mathematical model, examined the case wherein interactions repeat and information is sometimes absent. And Kurokawa [25] found that if individuals have persistence (i.e., behave cooperatively with a higher probability in the case wherein the actor cooperated in the last move than in the case wherein the actor defected in the last move) when information about the opponent is unavailable, the evolution of cooperation is facilitated in the sense of evolutionarily stability against the invasion by unconditional defectors.

This result can be interpreted as follows. When the conditional cooperator behaves retaliatory as well as with persistence, imitating the actor's behavior finally can lead to imitating the opponent's behavior; hence, a conditional cooperator with persistence can elicit future cooperation from the opponent cooperator. Persistence can be one type of retaliation and facilitates the evolution of cooperation. And persistence has very recently been examined theoretically and empirically [15,25].

Does having persistence when information about the opponent is present facilitate the evolution of cooperation? It might be that they think that having persistence when information about the opponent is present facilitate the evolution of cooperation since that logic is applicable also for the case wherein information is available. However, the situation wherein information about the opponent is present and the situation wherein information about the opponent is absent are qualitatively different. Let us explain the difference in the following.

If both the actor and the opponent cooperated in the last move, conditional cooperators should cooperate in the following round. If so, conditional cooperators can give importance to both retaliation and persistence. If both the actor and the opponent defected in the last move, the individual should defect in the following round. If so, conditional cooperators can give importance to both retaliation and persistence. These two cases are easy for the individual to choose a behavior.

Difficult are the following case. If the actor and the opponent opted for the different alternative in the last move, what should conditional cooperators do in the following round? If conditional cooperators give importance to retaliation, conditional cooperators have to give up persistence. Similarly, if conditional cooperators give importance to persistence, conditional cooperators have to give up retaliation. That is, retaliation and persistence are not mutually exclusive decisions, but rather a trade-off in the decision making process of individuals. Thus, what the individual should do in the following round in the case wherein the actor and the opponent opted for the different alternative in the last move is not easily determined.

Kurokawa [25] also tackled on this topic, and found that under some condition (revisit this in more detail in Model section) if individuals put more importance on retaliation than on persistence, the evolution of cooperation is facilitated.

This result can be interpreted as follows. Imitating the actor's behavior finally can lead to imitating the opponent's behavior; therefore, imitating the actor's behavior is beneficial. This is the mechanism for which imitating the actor's behavior is beneficial. Therefore, imitating the opponent's behavior directly is more beneficial than imitating the actor's behavior if players can refer not only to the opponent's behavior but also to the actor's behavior [25].

However, this study contained the following assumption. Our previous work assumed that the players always succeed in regarding cooperation by the opponent as cooperation. However, in this

world, it can be considered that there exist errors in perception [2,3,18,36,37,41]. Even when taking the existence of perception errors into consideration, is referring to the opponent's behavior still more beneficial than referring to the focal player's behavior? When errors in recognition are present, since players sometimes recognize the opponent player's cooperation as defection, trying to imitate the opponent's player does not always result in succeeding in imitating the opponent player. That is, in the presence of errors in recognition, the player can defect even when the opponent player cooperated in the previous round because of errors in recognition. Thus, when errors in recognition are present, players cannot always succeed in imitating the opponent player. And it is not obvious which is more beneficial, to try to imitate the opponent player, which can end in failure, or to imitate the focal player, which definitely ends in success. Especially when the error rate in recognition is large, imitating the opponent player ends in failure with a high probability. Hence, we presume that in such a case imitating the focal player, which definitely ends in success, is more beneficial than trying to imitate the opponent player, which can end in failure with a high probability.

In this paper, we tackle on the following question: Is the statement in our previous paper “Retaliation facilitates the evolution of cooperation more than persistence” still robust when we take errors in perception into consideration?

The rest of the paper is structured as follows. In Section 2, we describe a model. In Section 3, we introduce our previous work, which assumed that errors in perception are absent. In Section 4, we consider the case where errors in perception can occur. Especially, in Section 4.1, we consider the case where an ALLD mutant invades the population consisting of strategies with a variety of persistence (or retaliation), and use evolutionarily stable strategy (ESS) analysis. And we examine how perception errors affect the evolutionary outcome. Subsequently, in Section 4.2, we consider the case where a various mutant (not limited to ALLD mutant) invades the population and examine the stability by using evolutionarily stable strategy (ESS) analysis. In Section 4.3, we consider the three strategies game, and observe dynamics. In Section 5, we summarize the result obtained in this paper, and discuss why the results are obtained.

## 2. Model

As seen in Introduction section, in the absence of information, the decision making is easy since people cannot behave retaliatory. On the other hand, in the presence of information, decision making is difficult since people can behave retaliatory, and retaliation and persistence are not mutually exclusive decisions. Hence, this paper focuses on the case where information about the opponent is always present.

It may be that the players do not always succeed in regarding cooperation by the opponent as cooperation. Our previous work (Section 3) considered the case where errors in perception never occur. In this paper (Section 4), we introduce a type of mistake in the iterated prisoner's dilemma game: the error in perception [2]. Reactive cooperators mistakenly regard cooperation by the opponent as defection when errors in perception occur. We use  $e$ , where  $0 \leq e < 1$ , to denote the probability that such an error occurs. We can say that Section 3 considers the special case in which  $e = 0$  holds true. On the other hand, regarding their “own” behaviors, we assume that reactive cooperators always succeed in perception for their “own” behaviors throughout this paper.

We consider the following strategy. The space of strategies for a game for the current case would be a vector of five probabilities:  $f$ ,  $P_{CC}$ ,  $P_{CD}$ ,  $P_{DC}$ , and  $P_{DD}$ .  $f$  represents the probability of trying to cooperate in the first round.  $P_{ij}$  represents the probability of trying to cooperate when the focal player did  $i$  and the focal player

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