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Imperfect information facilitates the evolution of reciprocity

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ABSTRACT

The existence of cooperation demands explanation since cooperation is costly to the actor. Reciprocity has long been regarded as a potential explanatory mechanism for the existence of cooperation. Reciprocity is a mechanism wherein a cooperator responds to an opponent's behavior by switching his/her own behavior. Hence, a possible problematic case relevant to the theory of reciprocity evolution arises when the mechanism is such that the information regarding an opponent's behavior is imperfect. Although it has been confirmed also by previous theoretical studies that imperfect information interferes with the evolution of reciprocity, this argument is based on the assumption that there are no mistakes in behavior. And, a previous study presumed that it might be expected that when such mistakes occur, reciprocity can more readily evolve in the case of imperfect information than in the case of perfect information. The reason why the previous study considers so is that in the former case, reciprocators can miss defections incurred by other reciprocators' mistakes due to imperfect information, allowing cooperation to persist when such reciprocators meet. However, contrary to this expectation, the previous study has shown that even when mistakes occur, imperfect information interferes with the evolution of reciprocity. Nevertheless, the previous study assumed that payoffs are linear (i.e., that the effect of behavior is additive and there are no synergetic effects). In this study, we revisited the same problem but removed the assumption that payoffs are linear. We used evolutionarily stable strategy analysis to compare the condition for reciprocity to evolve when mistakes occur and information is imperfect with the condition for reciprocity to evolve when mistakes occur and information is perfect. Our study revealed that when payoffs are not linear, imperfect information can facilitate the evolution of reciprocity when mistakes occur; while when payoffs are linear, imperfect information disturbs the evolution of reciprocity even when mistakes occur. Imperfect information can encourage the evolution of cooperation.

1. Introduction

Cooperation is defined as the social behavior by which the actor decreases fitness while the recipient increases fitness. However, cooperation is abundant in this world. Hence, we can see that the evolution of cooperation, in terms of natural selection, is an issue in evolutionary biology [14,28,38].

The evolution of cooperation can be studied by using the framework which is called prisoner's dilemma [25]. If a cooperator interacts with another cooperator, both receive payoff R. If a cooperator meets a defector, the cooperator receives payoff S, whereas the defector gets the payoff T. Two defectors obtain the payoff P. The game is a prisoner's dilemma if, $T > R, P > S$ and $R > (S+T)/2 > P$. The first and second condition mean that in any interaction, each individual is better off defecting no matter what the other individual does. The third condition means that the average payoff of two individuals increases if one switches from defection to cooperation.

Reciprocity is a key concept to explain the evolution of cooperation between individuals [3,4,38]. It is pointed out that a disturbance mechanism involving imperfect information resulting from cognitive capacity limitations (i.e., people occasionally overlook opponents' behaviors) interferes with the evolution of reciprocity [6]. Reciprocity is a mechanism wherein a cooperator responds to its opponent's behavior by altering its own behavior, thereby encouraging the evolution of cooperation. Therefore, it is expected that when information about the opponent's behavior is somehow blocked, reciprocity does not evolve as readily.

However, this argument about the likelihood of evolution of reciprocity under conditions of perfect and imperfect information is based on the assumption that those who attempt to cooperate always succeed. In reality, all animals, including humans, are prone to error with attempts at cooperation sometimes ending in failure [24]. Let us compare the case in which mistakes occur and information is imperfect with the case in which mistakes occur and information is perfect, in order to examine whether it still holds that

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imperfect information disturbs the evolution of reciprocity even when mistakes occur in the next paragraph.

Kurokawa [19] presumed that when mistakes occur, imperfect information could facilitate the evolution of reciprocity. We explain the logic in a nutshell in the following (see Kurokawa [19] for more detailed explanation). Consider the case in which two reciprocators meet each other. If information is imperfect and each reciprocator sometimes or always attempts to cooperate even when there is no access to information, it is possible that even if one reciprocator accidentally defects, the opponent reciprocator would cooperate because its imperfect information would leave it unaware of the mistake while in the case wherein information is perfect, the opponent reacts to a reciprocator's mistake as if it were a deliberate defection, beginning a chain of defections that stops the current cooperation since defection is not missed. Based on this possibility, it seems plausible that cooperation will persist more often when information is imperfect than when information is perfect, contributing to a positive outcome in the evolution of reciprocity. In this sense, it would seem that when mistakes occur, imperfect information could facilitate the evolution of reciprocity.

Using evolutionarily stable strategy (ESS) analysis, Kurokawa [19] examined whether imperfect information still disturbs the evolution of reciprocity even when mistakes occur, but contrary to the expectation that imperfect information could facilitate the evolution of reciprocity, the result was that imperfect information still interferes with the evolution of reciprocity even when mistakes occur.

However, the analysis in Kurokawa [19] is limited to the special case in which $R = b - c$, $T = b$, $S = -c$, and $P = 0$ hold true, wherein a cooperator will pay an opponent b at a personal cost of c, and $b > c > 0$ holds true. Kurokawa [19] assumed that the effect of behavior is additive and there are no synergetic effects. In this case, $R + P = S + T$ holds true; this situation is sometimes called "equal gains from switching" [29]. However, in the real world, there exist some examples (e.g., the origin of the eukaryotic cell) wherein there is a synergetic effect [23,35]. Moreover, it is regarded that a cooperator interacting with another cooperator receives an additional fitness boost and there is a positive synergetic effect when $R + P > S + T$ holds true, while it is regarded that a cooperator interacting with another cooperator pays an additional fitness cost and there is a negative synergetic effect when $R + P < S + T$ holds true.

Is the result in Kurokawa [19] robust also in the case wherein there is a synergetic effect? We infer that when removing the assumption that payoff is linear, the result that imperfect information disturbs the evolution of reciprocity even when mistakes in behavior occur might be swayed. This is because it has been pointed out that in general, removing the payoff linearity assumption allows for the possible emergence of richer scenarios (e.g., [1,2,31,37]). Moreover, in this topic, in particular, when imperfect information makes a reciprocator miss the defection by the opponent reciprocator, and hence, the interaction wherein both reciprocators cooperate lasts long, if there is a positive synergetic effect (or R is large), there is a possibility that imperfect information facilitates the evolution of reciprocity. Similarly, when imperfect information makes a reciprocator miss the defection by the opponent reciprocator, and hence, the interaction wherein a reciprocator cooperates and the other reciprocator defects lasts long, if there is a negative synergetic effect (or S is large), there is a possibility that imperfect information facilitates the evolution of reciprocity.

In this paper, we examine if removing the assumption that payoffs are linear can alter the outcome that imperfect information interferes with the evolution of reciprocity even when mistakes occur. By extending the model to cover the situation in which payoffs are not linear, we discuss the accuracy of our previous statement in Kurokawa [19] that the evolution of reciprocity is interfered with by imperfect information even when mistakes occur.

The remainder of this paper is organized as follows. In Section 2, we propose the model. In Section 3, we briefly review our previous paper [19], which considers the case in which payoffs are linear. In Section 4, we extend the model in Section 3 [19] to general payoffs and investigate whether payoff nonlinearity alters the result that even when mistakes occur, imperfect information interferes with the evolution of reciprocity. In Section 5, we describe the results and discuss the relationship between this work and studies about generosity. Additionally, we suggest future studies to be undertaken.

2. Model

Consider the iterated prisoner's dilemma game in which individuals either cooperate or defect in each round. We assume that individuals are paired at random. The probability that the individuals interact more than t times in a given pair is w^t, where w is a constant discounting factor between 0 and 1. This assumption means that the expected number of interactions is $1/(1-w)$. We can see that the number of interactions per pair increases as w increases.

Here, we consider the case wherein information is imperfect and mistakes in behavior, such as an individual intending to cooperate sometimes failing to do so, occur. Let e, $0 \leq e \leq 1$, be the probability that information is somehow blocked, i.e., that an actor cannot obtain access to information regarding an opponent's behavior. Similarly, let μ, $0 \leq \mu \leq 1$, be the probability that mistakes in behavior occur, and that an individual who intends to cooperate fails to and defects. When $\mu = 1$, players never cooperate, and the case is not worth investigating. Hence, we assume that $\mu < 1$.

Following earlier studies [4, 19], we consider two strategies: always defect (ALLD) and tit-for-tat (TFT). In the ALLD strategy, the player defects no matter what the opponent does, while in the first round, an actor following the TFT strategy attempts to cooperate with probability 1, but fails to cooperate successfully with probability μ, and in the following rounds, the TFT player attempts to cooperate with probability 1, but fails to do so with probability μ if access to information regarding the opponent's behavior is available *and* the opponent cooperated in the previous round; if access to information is available but the opponent defected in the previous round, then the TFT player defects. In contrast, if access to information regarding the opponent's behavior in the previous round is *not* available, then the TFT player attempts to cooperate with probability 1 but fails to do so with probability μ. In other words, we assume that reciprocators are optimistic.

3. Previous studies [19]

We consider the case wherein payoffs are linear. Let us briefly review the results of our previous analysis under the payoff linearity assumption. Kurokawa [19] considered the case wherein payoffs are linear and derived the condition under which a TFT strategy is an ESS against the encroachment of an ALLD strategy:

$$\frac{c}{b} < w(1-e)(1-\mu) \tag{1}$$

This condition implies that even when mistakes occur, imperfect information can still interfere with the evolution of reciprocity. In the next section, we remove the assumption that payoffs are linear and examine whether the result is robust.