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Conditional dissociation as a punishment mechanism in the evolution of cooperation

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HIGHLIGHTS

- The effect of conditional dissociation on the evolution of cooperation is investigated.
- Cooperation level is lowered when mixed strategies are allowed.
- Two monomorphic equilibria exist, one is cooperative but intolerant and the other is defective and tolerant.
- Longer lifespan and longer waiting time favor cooperation.

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ABSTRACT

Recent studies show that conditional dissociation, a.k.a. post-interaction partner-refusal, can promote the emergence and stability of cooperation. However, in most of these studies, players' strategies are restricted to pure ones, which is obviously inconsistent with many biological and economic situations. Another concern with line of these studies is that conditional dissociation is often combined with other mechanisms. These mechanisms may favor cooperation *per se*, leaving it unclear whether conditional dissociation is indeed a key factor. In this paper, we study a clean model, pruning all the factors other than conditional dissociation that may favor cooperation. We find that conditional dissociation, which could be viewed as a variant of peer punishment, does promote cooperation, no matter whether mixed strategies are allowed or not. This confirms the previous findings in the literature. In addition, compared with the pure strategy scenario, cooperators are less competitive when mixed strategies are allowed. Our main finding is supported by both the numerical simulations and the theoretical analysis of Neutrally Stable Strategy. We also find that cooperative behavior is favored when waiting time and/or the population's lifespan are longer.

1. Introduction

Evolutionary game theory is the canonical model to study the emergence of cooperation in biological, economic and social systems. It is confusing why the competitive process of natural selection can lead to cooperative behavior, especially when defection has obvious advantages over cooperation. To clarify this issue, many evolutionary mechanisms have been proposed, including kin selection [1], group selection [2,3], direct reciprocity [4], indirect reciprocity [5–7], and graph

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selection [8,9]. Actually, all of these mechanisms increase the probability of a player to play with a same-type player, and this framework is usually termed as positive assortment [10,11].

Recently, theorists find that a new mechanism, post-interaction partner-refusal, can promote the emergence of cooperation too [12–20]. Post-interaction partner-refusal allows a player to break up with her current partner (opponent) and look for a new one if he defects (hereafter, unless otherwise specified, we use "she" to denote a player herself and "he" to denote her opponent). To emphasize the difference with pre-interaction selection of a new partner, post-interaction partner-refusal is also referred to as "conditional dissociation" [19,21–23]. Conditional dissociation requires little cognitive capability. It is a bit like irritability, i.e., to escape an unpleasant environment. This is one of the most basic instincts for almost all organisms.

Most of the previous literature on conditional dissociation investigates only pure strategies [16,18–20], and only a few consider mixed strategies [24,25]. Nevertheless, as argued by Nowak and Sigmund [26,27]:

> *Actual biological situations are fraught with errors and uncertainties. As Ref.* [28] *points out, it is important to* "*take more account of intrinsic stochasticities and of evolutionary stability against representative ensembles of mutant strategies*".

Our first motivation is to investigate the effect of mixed strategies on the conditional dissociation mechanism. Will cooperation still emerge in evolution? If so, is this new factor advantageous or disadvantageous to the emergence of cooperation? Since mainly social optimal and neutrally stable equilibria are concerned, this question is not the focus of Refs. [24,25]. Recall that for the one-shot Prisoner's Dilemma, it is well known that the introduction of mixed strategies has no effect at all: In both scenarios with and without mixed strategies, Defect–Defect is the unique Nash equilibrium. Therefore, this is not a trivial question.

The second major concern with this line of research, as stated by Ref. [19], is that when considering the effect of conditional dissociation, many of the above-mentioned literature usually combines this mechanism with other mechanisms that also favor cooperation, such as spatial or network effects [16,22], segregation in groups [29] and partner pre-selection [14,30–33]. This combination makes it difficult to recognize which mechanism is playing the key role in promoting the emergence and stability of cooperation.

To sort out these issues, we consider a very clean model, pruning all the factors other than conditional dissociation that may favor cooperation, and at the same time mixed strategies are also available to the individuals. Our model, which is described formally in the next section, is analogous to Refs. [19,20] in that players' strategies are restricted, and the population is well mixed, which means that there is no spatial or group structure. Individuals are randomly matched and remain together until one of them decides to break up in the event of the opponent's defection. And a player can choose to leave only if her partner is defected in the previous round.

In our model, the time cost of finding a new partner is taken into consideration. Once a player rejects her partner, both she and her partner have to wait for certain time, called waiting time, to re-enter. This waiting assumption is similar to the moving setting in Ref. [16], where one player may not find another partner immediately after she leaves. We assume that the payoff received during waiting is no more than the least payoff one could get in each round of the game, so breaking up could be viewed as a punishment. In Refs. [19,20], the authors discuss the waiting mechanism too, and find waiting may promote cooperation. Here we explore its effect on the evolution of cooperation and continuation more in-depth.

We have the following four main findings.

First, cooperative behavior does survive, in both the scenarios where only pure strategies are allowed and where mixed strategies are also available. When only pure strategies are allowed and time cost is zero, it has been proved that the game has a partially cooperative polymorphic equilibrium if the populations' lifespan is long enough [18–20]. Compared with Refs. [24,25], where full strategy space and no waiting cost are assumed, we consider the non-zero time cost case with a limited strategy space including mixed strategies, and also derive cooperative results without other mechanisms, say kin selection, graph selection, or reputation, that may favor cooperation *per se*. Actually, since only defections may incur dissociations, the cooperative relationships are more likely to last longer than defective ones. This indicates that conditional dissociation can also be classified as a kind of positive assortment [34,35].

Second, compared with the pure strategy scenario, the cooperation level, which is measured by the probability of ending up with a fully cooperative population, is lowered when players' strategies are more flexible, i.e., when mixed strategies are allowed, unless the lifespan of the population is very short. That is, expanding players' strategy set from pure to mixed is harmful for the cooperation level. This is of some interest, implying that a bigger strategy set may not be a good thing to the society, and sometimes restricting players' strategy set may be beneficial to all individuals. This result might also indicate that cooperation rate in reality may not be so high as former studies, which only consider pure strategies, predict.

Third, in both scenarios, roughly two types of players can dominate the population, namely, either intolerant cooperators or tolerant defectors. Our results depend on a very simple setting, e.g., the one-memory strategy space, which still captures the essence of conditional dissociation. When time cost is ignored, in an unrestricted strategy space, Fujiwara-Greve and Okuno-Fujiwara [18] identify multiple monomorphic and polymorphic equilibria; with a restricted strategy space, Izquierdo et al. [19,20] show that the dynamic evolution of the population eventually enters either a non-cooperative or a partially cooperative regime, depending mainly on the expected lifetime of individuals; and Vesely and Yang [24,25] identify the unique optimal monomorphic equilibrium, which is mixed. Also with a restricted strategy space, our results suggest that