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Sanctions triggered by jealousy help promote the cooperation in spatial prisoner's dilemma games

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ABSTRACT

Human beings have a natural tendency to feel jealous of those who have more than themselves. A previous report found that harmful behavior stemming from jealousy can actually encourage cooperation. The present study considers the efficiency of jealousy-motivated sanctions and the appropriate balance of sanctions and enforcement costs to best encourage cooperation. Through a series of numerical simulations of a spatial prisoner's dilemma game, we find that in the case of a lattice population structure, stronger sanctions and higher sanction efficiency ultimately result in more robust cooperation. In contrast, in the case of a scale-free population structure, higher sanction costs cause the cooperation level to rise.

1. Introduction

In human society, cooperation is crucial for maintaining public welfare [1,2]. Per the Darwinian theory of evolution, the principles of human behavior are governed by competition rather than cooperation. The fact that cooperation is universally observed has therefore resulted in one of the long-running challenges in evolutionary biology and social science and the question of why humans cooperate with unrelated individuals [3,4]. One framework that can be used to justify the promotion of cooperation is costly punishment [5–12]. Costly punishment, in which an agent can pay a cost to impose a fine on defective agents, comes in two forms: individually inspired sanctions through face-to-face interactions (peer punishment [13–17]) and institutional sanctions (pool punishments [18–20]). In both cases, penalizing defectors reduces the likelihood of defection. However, the punishment involves a cost burden for the punishing agents as well as the defector. Consequently, it inevitably diminishes the overall social payoff. Therefore, when considering possible punishment frameworks, not just the evolution of cooperation but also the social efficiency of such frameworks should be discussed [21–24].

In the rich stock of previous studies on this topic, there are various models that include costly punishment. For example, Perc and Szolnoki [25] developed an adaptive punishment mechanism in which the penalty is not constant in time but dynamic. Unlike other models where cost and fine are fixed for an entire episode, their model allows both cost and penalty to be time-variable and to depend on the surrounding situation. It enables an increase in the penalty with a growing number of defectors and a relaxation in the penalty with a decreasing number of defectors. Accordingly, the adaptive punishment scheme provides a rich variety of evolutionary paths and encourages cooperation.

Inspired by the observed fact that human emotion can be a trigger for enforcing punishment, Chen et al. [26] proposed a novel model where a cooperator can decide to enforce a sanction stochastically. Instead of relying on a permanent enforcer, a cooperator plays the role of a temporary enforcer, which can solve the so-called second-order free-rider problem where an enforcer is forced to bear a cost that makes it more advantageous to be merely a cooperator rather than the enforcer. From another perspective, some worthwhile studies concerned with costly punishment have focused on the emotions of individuals [13,27,28]. For example, some studies suggest that punishment is basically motivated by negative feelings such as anger, aversion, and antipathy toward non-cooperators (defectors) [13,27]. Experimental results indicate that dissatisfaction resulting from payoff inequity triggers punishment [28]. In the context of payoff inequity, Ohdaira [29] proposed an alternative framework, "sanction with jealousy," which implies that irrespective of strategy (cooperative or defective), people are willing to devastate the efforts of others through sanctions motivated by jealousy. Consequently, Ohdaira concluded that introducing jealous sanctions helps cooperation by oppressing advantageous defectors without disturbing the growth of mutual cooperation. Although this idea seems novel on the point that cooperators might also be punished in some context, there still remains

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room for a more comprehensive discussion based on a universal model that can highlight how the efficiency of jealous punishment affects emerging cooperation patterns. Although jealous punishment, which allows even a cooperator punishing another cooperator, might be ethically unacceptable, it would be likely happening in real human society. Jealousy, one of human's inherent characteristics, likely triggers, in some cases, such anti-social behavior. This drives us to question how jealous punishment mechanism differs from the conventional costly punishment models where a cooperator never punishes another cooperator. From this background and greatly inspired by Ohdaira's pioneer work, our present study concerns on jealous punishment.

In the present study, we are interested in the balance of costs for the enforcer and the victim of a sanction. One thing to be verified is that in certain situations, the focal player's effort in paying a cost may not effectively reduce his opponent's payoff, but in other cases, it may efficiently drive it down. Therefore, as in Szolnoki's study [20], the present study focuses on how the efficiency of sanctions, specifically penalty over cost, results in different pictures of evolving cooperation assisted by jealous sanctions. We develop a universal model for jealous sanctions and our numerical spatial prisoner's dilemma (SPD) games [30] reveal how the efficiency of jealous sanctions affects emerging cooperation.

2. Model description

We consider a spatial version of the Prisoner's dilemma (PD) games (SPD games). Each agent adopts either a strategy of cooperation (C) or defection (D), and receives a payoff through an interaction. The payoff is determined by the combination of the strategies of both agents and can be defined as punishment (*P*), reward (*R*), sucker (*S*), and temptation (*T*) for respective interactions of D–D, C–C, C–D, and D–C. Following our previous study [31], let us introduce the dilemma parameters, the gamble-intending dilemma $D_g = T\text{-}R$ and the risk-averting dilemma $D_r = P\text{-}S$, presuming $R = 1$ and $P = 0$ without loss of generality. Thus, the payoff matrix can be denoted as

$$\begin{array}{c} \\ C \\ D \end{array}\!\!\begin{array}{c} \begin{matrix} C & D \end{matrix} \\ \begin{pmatrix} R & S \\ T & P \end{pmatrix} \end{array} = \begin{array}{c} \\ C \\ D \end{array}\!\!\begin{array}{c} \begin{matrix} C & \quad D \end{matrix} \\ \begin{pmatrix} 1 & -D_r \\ 1 + D_g & 0 \end{pmatrix} \end{array}, \tag{1}$$

where we limit $D_g > 0$ and $D_r > 0$, resulting in a game that belongs to the PD class. In the following discussion, we impose the additional limits $0 \le D_g \le 1$ and $0 \le D_r \le 1$.

The total number of agents is set to $N = 10^4$. We adopt two spatial population structures: a square lattice with a Moore neighborhood (degree of $k = 8$) and a scale-free network following the Barabási–Albert model (hereafter BA-SF [32]) with $\langle k \rangle = 8$.

For each simulation episode, equal numbers of Cs and Ds are randomly distributed on an underlying network as an initial condition. Each agent plays games with his/her neighbors in a network and accumulates a payoff at each time step. An agent decides whether to introduce a jealous sanction based on an evaluation of the payoff situation between himself and each of his neighbors. If his opponent's payoff, π_j, is slightly larger than his personal payoff, π_i, and within twice his ($\pi_i < \pi_j < 2\pi_i$), the focal agent enforces a sanction with a payoff-based probability $(\pi_i - \pi_j)/\pi_i$. In this case, the agent pays a sanction cost that is some fraction of his own accumulated payoff, c_s, so as to introduce a sanction ($p\pi_i$) on his opponent in order to reduce the opponent's payoff. Assuming there is an upper limit on the jealous sanction might be justified since one tends to feel less jealousy directed toward people who are far richer. To discuss the efficiency of the sanction described above, let us introduce two parameters, a cost coefficient c_s and a penalty

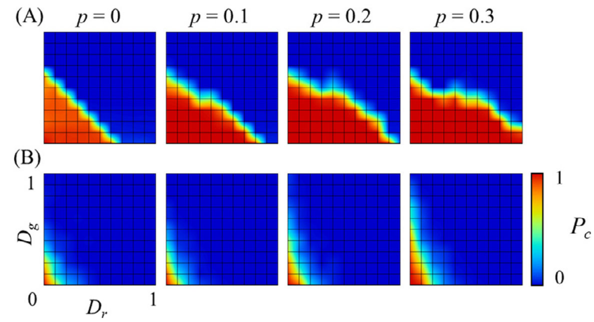

Fig. 1. Ensemble-averaged cooperation fraction, P_c, while varying the penalty ratio *p* with constant efficiency $\beta = 1$. The assumed spatial structures are (A) a lattice and (B) BA-SF.

coefficient *p*, as follows:

$$\begin{aligned} \pi'_i &= (1 - c_s)\pi_i \\ \pi'_j &= \pi_j - p\pi_i \end{aligned}. \tag{2}$$

Here, we define the efficiency of a sanction via a cost-penalty ratio, $\beta = p/c_s$. Eq. (2) implies that even if a sanction enforcer reduces their own payoff, they intend to impose β times the penalty on their opponent. After all games, an agent synchronously refreshes his strategy by referring to their own payoff and their neighbors' payoffs. In this study, we adopt the imitation max (IM) update rule. This means that the focal player *i* imitates the strategy that has the maximum accumulated payoff of all strategies used by the player and their immediate neighbors; strategy updating occurs simultaneously. By iterating the gaming and updating strategies, the global cooperation fraction, P_c, which is the ratio of agents adopting C to the total number of agents (*N*), is updated at each time step. This process is repeated until the global cooperation fraction attains equilibrium. For statistical reasons, we evaluate an ensemble average of 100 independent trials for each parameter set.

3. Results and discussion

Fig. 1 shows the cooperation fraction, P_c, the averaged cooperation fraction, over 100 independent trials for different *p* values with fixed β (=1). The case of $p = 0$ represents the default case in which no jealous punishment is imposed. The general tendency in both panels A and B implies that cooperation is enhanced with increasing *p*. Since the cost-penalty ratio is kept at 1, greater damage caused by a jealous sanction, which although entails a larger cost, results in a positive effect that ultimately enhances cooperation. Note that in other cases that implement a different update rule to IM, such as pairwise-fermi or a random underlying network topology, no significant enhancement can be observed.

In the case of the lattice (panel A), more significant enhancement than that in the default case ($p = 0$) is observed when increasing the number of stag-hunt (SH)-type dilemmas (D_r) and decreasing the number of chicken-type dilemmas (D_g). In contrast to this, games with only chicken-type dilemmas ($D_r = 0$) show only a slight improvement in terms of cooperation over the default case. This fact suggests that the enhancement caused by the jealous punishment mechanism depends on the dilemma structure. Fig. 2 indicates one of the representative time series showing who (A: the punisher) punishes whom (B: the victim) as A→B for each of the representative game structures with only chicken-type or only SH-type dilemma games. In the former case, at the beginning of the episode, C to D is the most frequent occurrence. This is because large D_g but low D_r gives a huge incentive to defectors exploiting cooperators. Additionally, cooperators punishing defectors must pay a punishing cost, which gives them a significant disadvantage.