



# Promote or hinder? The role of punishment in the emergence of cooperation



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## HIGHLIGHTS

- Evolution of cooperation is not always hindered by anti-social punishment.
- Whether and how punishment promotes cooperation depend on the pattern of punishment.
- Costly centralized punishment is much better in facilitating cooperation.
- Cooperation fails if pro- and anti-social punishments are in the same pattern.
- Cooperation evolves in the case of pool pro-social and peer anti-social punishments.

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## ABSTRACT

Investigation of anti-social punishment has shaken the positive role of punishment in the evolution of cooperation. However, punishment is ubiquitous in nature, and the centralized, apposed to decentralized, punishment is more favored by certain modern societies in particular. To explore the underlying principle of such phenomenon, we study the evolution of cooperation in the context of pro- and anti-social punishments subject to two distinct patterns: costly centralized and decentralized punishments. The results suggest that the pattern of punishment has a great effect on the role of punishment in the evolution of cooperation. In the absence of anti-social punishment, the costly centralized punishment is more effective in promoting the emergence of cooperation. Anti-social punishment can subvert the positive role of punishment when anti- and pro-social punishments are in the same pattern. However, driven by centralized pro-social punishment, cooperation can be more advantageous than defection even in the presence of decentralized anti-social punishment.

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## 1. Introduction

Cooperation is widespread in nature, while it seems in conflict with the philosophy of “survival of the fittest” as it is always beneficial to others at a cost to the performers. Explaining this conundrum is of great interest across the biological and social sciences (Wu et al., 2009a; Cong et al., 2012; Rand and Nowak, 2013; Zhang et al., 2013; Matsuo et al., 2014; Du et al., 2014a). So far, several mechanisms have been discussed, such as kin selection (Salter, 2008; Nowak et al., 2010), multi-level selection (Traulsen and Nowak, 2006; García and van den Bergh, 2011), spatial selection (Traulsen and Claussen, 2004; Perc and Szolnoki, 2008;

Hauert and Imhof, 2012), reputation (Fu et al., 2008; Wu et al., 2009a; Chen et al., 2012; Li et al., 2013), aspiration (Perc and Wang, 2010; Liu et al., 2011; Wu et al., 2012; Du et al., 2014b), direct (Rand et al., 2009; Martinez-Vaquero et al., 2012) and indirect reciprocity (Nowak and Sigmund, 2005; Uchida and Sigmund, 2010; Yoeli et al., 2013). In addition, costly punishment, which has been considered as an effective solution for explaining the evolution of cooperation, has attracted much attention (Sigmund et al., 2001; Henrich et al., 2006; Gächter et al., 2008). Costly punishment can be succinctly depicted as: punishers impose a fine on the punished at a cost. In general, the fine is usually greater than the cost. Costly punishment has been deemed as an altruistic behavior (Boyd et al., 2003; Fowler, 2005) due to the fact that it is costly to the performers in the absence of an immediate gain as others benefiting indirectly. Meanwhile, on account of the ability to punish the potential invaders, it has also been illustrated as a

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self-interested behavior (Rand and Nowak, 2011). Under the regulation of costly punishment mechanism, the individuals who do not punish others act as the “second-order free riders”. Then a “second-order social dilemma” is raised (Hauert et al., 2007).

Generally, punishment can be classified as follows. According to the pattern of punishment, it can be basically divided into decentralized and centralized punishments. In human society, the centralized punishment is more favored by some modern societies (Guala, 2012). Decentralized punishment occurs at individual level while centralized punishment is always conducted by an authority (e.g., state, government, institution, or the experimenters) (Balliet et al., 2011). Peer punishment (Falk et al., 2005; Henrich et al., 2006; Rand et al., 2009; de Melo and Piaggio, 2012) where punishers impose a fine on the punished at a cost personally is a typical decentralized punishment. Compared with peer punishment, pool punishment (Sigmund et al., 2010; Hilbe et al., 2014; Schoenmakers et al., 2014) is more centralized. In pool punishment, the costly punishment can be described as a collective behavior. Punishers contribute a cost to the “punishment pool” for punishing wrong-doers in advance of the game, and the punishment is executed after the game by an outsourcing institution. The fine of each punished is identical and proportional to the number of punishers. According to the social aim of the costly punishment, it can be mainly sorted into pro- and anti-social punishments. Pro-social punishment is usually defined as the punishment of wrong-doers (Fehr and Fischbacher, 2004; Jensen, 2010; Przepiorka and Diekmann, 2013; Chen et al., 2014). Obviously, the punishment of defectors coming from cooperators is a kind of pro-social punishment in evolutionary games. As the employment of pro-social punishment, cooperation is remarkably promoted in consequence of punishment to protect cooperators from being invaded by defectors (Shinada and Yamagishi, 2007; Hauert et al., 2008; Boyd et al., 2010; Perc and Szolnoki, 2012). Anti-social punishment demonstrates the phenomena where the wrong-doers frequently react to the well-doers (Cinyabuguma et al., 2006; Gächter and Herrmann, 2009; Janssen et al., 2010). In evolutionary games, the punishment of cooperators by defectors is a representative anti-social punishment.

As the discovery of anti-social punishment in experiments, much attention has been paid to exploring the effect of anti-social punishment on the evolution of cooperation (Herrmann et al., 2008; Nikiforakis, 2008; Dreber and Rand, 2012; García and Traulsen, 2012; Sasaki et al., 2012). Several studies have shown that the evolution of cooperation is no longer facilitated by punishment when anti-social punishment is possible (Rand et al., 2010; Rand and Nowak, 2011; Hauser et al., 2014). These results raise the query regarding the wide application of costly punishment in nature. Furthermore, why the centralized punishment is so preferred by certain modern societies is still unclear. Underlying the principle of this phenomenon is worth efforts.

In this study, we show that the role of punishment in the evolution of cooperation critically depends on the pattern of punishment. Particularly, there are scenarios where cooperation can be facilitated by punishment when anti-social punishment is possible. In existing studies, pro- and anti-social punishments are always in the same pattern, and most of which have focused on peer punishment. Actually, in human society, the centralized punishment, compared with the decentralized punishment, is more advocated. Several organizations (such as schools or companies) are more or less beneficial from the centralized punishment. Institutional punishment, a centralized punishment system, is always well-organized and conducted as the punishment of wrong-doers by some outsourcing institutions. For instance, some law enforcements (e.g., police and court), which are funded in the

form of tax payment, are instituted to protect the law-abiding citizens and fight against criminals. And yet, personal punishment which occurs between punishers and the punished directly is decentralized and often adopted as a form of most anti-social punishment, such as the reaction of some violators to law-abiding citizens. From the evolutionary perspective, the pattern of institutional and personal punishments can be ideally sketched into pool and peer punishments separately. Then it will be a reasonable assumption that the pro- and anti-social punishments are in different patterns.

To investigate the effects of punishment patterns on the role of punishment in the evolution of cooperation, especially in the presence of anti-social punishment, we model the pro- and anti-social punishments more realistically subject to two distinct patterns: peer punishment and pool punishment. The model in this study is appealing for the reason that pro- and anti-social punishments are not restricted in the same pattern. When anti-social punishment is absent, we make a comparison between peer and pool punishments on promoting the emergence of cooperation. When anti-social punishment is possible, we analyze the effects of punishment patterns on the evolution of cooperation in the situations where pro- and anti-social punishments are either in the same pattern or in different patterns. Anti-social punishment does not always hinder the evolution of cooperation. When anti-social punishment is possible, whether cooperation is promoted by punishment or not critically depends on which pattern of punishment is adopted. Particularly, punishment can facilitate the emergence of cooperation as long as the pro-social punishment is centralized in the presence of decentralized anti-social punishment.

## 2. Model

Consider a well-mixed population of  $N$  individuals playing the prisoner's dilemma game with strategies cooperation and defection. In a detailed way, two players each receive  $b - c$  upon mutual cooperation and 0 upon mutual defection. Whenever a cooperator interacts with a defector, the former gets the payoff  $-c$  while the later  $b$ . As is common we set  $b > c > 0$ . Generally, cooperation is never favored over defection by natural selection without any mechanism in well-mixed populations (Rand and Nowak, 2013). Costly punishment is introduced in this evolutionary process, and the individuals can choose to be a punisher or not. The total payoff of each individual is the sum of payoff from prisoner's dilemma game and punishment game.

Here, pro-social punishment is defined as the punishment targeted at defectors from cooperators, and anti-social punishment is the punishment of cooperators from defectors. Peer punishment and pool punishment are two distinct patterns of punishment. Peer punishment occurs between punishers and punished directly after the prisoner's dilemma game. Each peer punisher costs  $\alpha$  to impose a fine  $\beta$  ( $\beta > \alpha$ ) on the objective partner personally. For instance, a pro-social punisher will impose a fine  $\beta$  on a defective partner at a cost  $\alpha$ . The payoff of a defector in the punishment game is either 0 or  $\beta$  depending on the partner's strategy. Compared with peer punishment, pool punishment is more centralized. Pool punishers have to contribute a cost  $\alpha$  to punishment pool in advance of the prisoner's dilemma game, and pool punishment is uniformly conducted after the prisoner's dilemma game. The punished in the population are equally fined, and the fine belongs to  $[\beta/(N-1), (N-1)\beta]$ . For example, in a population of  $i$  pro-social punishers and  $N-i$  defectors, defectors are always punished regardless of the strategies of their partners.

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