

## Cooperation maintained by defect and collapsed by reward in a generalized metanorms game

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We propose a generalized metanorms game (GMG) that integrates both punishment and reward in order to analyze the evolution of cooperation in public goods games. Axelrod (1986) developed a meta-punishment game in which players can punish those who do not punish non-cooperators as well as those who do not cooperate. We have expanded this original game to include a meta-rewarding part whereby players can reward those who reward cooperators as well as those who cooperate. The meta-punishment part of the GMG is suitable for modeling order formations in groups to formalize typical public goods games, while the meta-rewarding part is suitable for public goods games in which punishments have no efficacy. For example, it is almost impossible for participants who do not provide information to be punished in knowledge-sharing communities on the Internet, and thus, a framework that includes reward is needed for analyzing the evolution of cooperation.

We performed simulations to clarify the conditions needed to dominate cooperation using GMG. In the meta-punishment part, there is an equilibrium point in which cooperation dominates, but it is unstable, and cooperation eventually collapses in the long term. In the meta-rewarding part, on the other hand, cooperation dominates robustly. We install Social Indicator (SI) in order to promote cooperation in the game. SI is an agent with a fixed and controlled strategy and exists slightly in a group. We tested four types of SIs in the meta-punishment part: (1) always cooperate but never punish the others, (2) always cooperate and always punish the others, (3) always defect and never punish, and (4) always defect and always punish the others. Surprisingly, the SIs that always defect (types 3 and 4) are needed for keeping the cooperation robust. The existence of these SIs enables players to recognize the necessity of punishment for defectors, and thus, free riders for punishment cannot invade. We also use four types of SIs in the meta-rewarding part: (1) always cooperate but never reward the others, (2) always cooperate and always reward the others, (3) always defect and never reward, and (4) always defect and always reward the others. SIs that rewarded only (type 4) have a negative effect on cooperation. We find that specific SIs do not contribute directly for cooperation, but contribute indirectly by preparing environment which lets players recognize the necessity of punishment or reward.

[1] Axelrod, R.M., An Evolutionary Approach to Norms, *American Political Science Review*, 80 (4), 1095-1111, 1986.