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Shared rewarding overcomes defection traps in generalized volunteer's dilemmas

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HIGHLIGHTS

- Shared rewarding is a powerful mechanism for promoting voluntary contributions to a common good.
- Even small rewards suffice to destabilize full defection, resulting in fractions of volunteers as high as 50%.
- First increasing and then again decreasing group size can dramatically boost volunteering.

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ABSTRACT

For societies to produce or safeguard public goods, costly voluntary contributions are often required. From the perspective of each individual, however, it is advantageous not to volunteer such contributions, in the hope that other individuals will carry the associated costs. This conflict can be modeled as a volunteer's dilemma. To encourage rational individuals to make voluntary contributions, a government or other social organizations can offer rewards, to be shared among the volunteers. Here we apply such shared rewarding to the generalized N-person volunteer's dilemma, in which a threshold number of volunteers is required for producing the public good. By means of theoretical and numerical analyses, we show that without shared rewarding only two evolutionary outcomes are possible: full defection or coexistence of volunteers and non-volunteers. We show that already small rewards destabilize full defection, stabilizing small fractions of volunteers instead. Furthermore, at these intermediate reward levels, we find a hysteresis effect such that increasing or decreasing group sizes can trigger different social outcomes. In particular, when group size is increased, the fraction of volunteers first increases gradually before jumping up abruptly; when group size is then decreased again, the fraction of volunteers not only remains high, but even continues to increase. As the shared reward is increased beyond a critical level, the bistablitity underlying this hysteresis effect vanishes altogether, and only a single social outcome remains, corresponding to considerable fractions of volunteers. We find that this critical level of shared rewarding is relatively small compared to the total cost of contributing to the public good. These results show that the introduction of shared rewarding is remarkably effective in overcoming defection traps in the generalized volunteer's dilemma.

1. Introduction

Understanding the emergence and stability of cooperation among rational individuals is a central challenge in evolutionary biology, as well as in the social sciences. Evolutionary game theory provides a common mathematical framework for interpreting the evolution of cooperation. In particular, the prisoner's dilemma game and its N-person variant are the most commonly employed games for studying this challenge (Axelrod and Hamilton, 1981; Maynard Smith, 1982; Hauert et al., 2002; Doebeli and Hauert, 2005; Nowak, 2006; Hauert et al., 2007; Szabó and Fáth, 2007; Santos et al., 2008; Traulsen et al., 2009; Sigmund et al., 2010; Perc et al., 2013). However, there are some social dilemmas concerning altruistic behavior for which different games offer more appropriate models. In particular, the volunteer's dilemma game has been proposed as another important paradigm (Diekmann, 1985).

The volunteer's dilemma is defined as follows (Diekmann, 1985): members of a group can volunteer to pay a small cost (Volunteer, a cooperative strategy) or avoid to pay the cost (Ignore, a defective strategy) towards the production or maintenance of a public good. If at least one individual chooses to volunteer, the

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public good is produced and benefits all individuals in the group, irrespective of their contributions. In contrast, if nobody volunteers, the public good is not produced, and all group members pay a cost that is higher than that of volunteering. Clearly, a volunteer benefits from his or her action if nobody else volunteers, whereas such a voluntary investment is wasted if another group member volunteers as well (Archetti, 2009b). This volunteer's dilemma game has been extended to the more general case in which more than one volunteer is required for producing the public good; the resultant game is also known as a threshold public good game (Myatt and Wallace, 2008; Archetti, 2009a; Boza and Számadó, 2010).

The volunteer's dilemma and its generalization can be applied to many situations studied in the social sciences (Diekmann, 1985, 1993), such as volunteering work in charitable organizations, cleaning shared accommodation, or getting up at night to placate a crying baby (Bilodeau and Slivinski, 1996; Otsubo and Rapoport, 2008). Moreover, the volunteer's dilemma is relevant also in the context of evolutionary biology (Goeree and Holt, 2005; Archetti, 2009a, 2009b; Archetti and Scheuring, 2011; Archetti, 2011): a typical example from the biological context is a population of social animals using alarm calls to warn others of predators. In such a situation, the individual raising the alarm promotes the collective security of its population from predation, but individually incurs non-negligible costs, because raising an alarm often increases the risk of being targeted by a predator.

Previous studies have examined different factors affecting cooperation in volunteer's dilemmas, such as group size (Franzen, 1995; Weesie and Franzen, 1998; Archetti, 2009b; Brännström et al., 2011), individual vigilance (Archetti, 2011), and nonlinear benefits (Do et al., 2009; Archetti and Scheuring, 2011). Specifically, it was found that the fraction of volunteers decreases with group size, so that larger groups tend to under-produce the public good (Franzen, 1995; Weesie and Franzen, 1998; Archetti, 2009b; Brännström et al., 2011). Above a certain group size, reducing an individual's vigilance can induce other players to volunteer more often (Archetti, 2011). Moreover, incorporating nonlinear returns on investments allows cooperation to be sustained, so that cooperators and free-riders are expected to coexist in a stable mixed equilibrium (Archetti and Scheuring, 2011).

In this study, we incorporate a rewarding mechanism into the volunteer's dilemma. Our motivation for this extension stems from the observation that in many real-world situations voluntary contributions are maintained by a reward system providing incentives for volunteering. For example, companies or enterprises reward groups of employees for good performance in teamwork, and volunteers at events such as Olympic Games receive favorable public recognition. Furthermore, governments or other social organizations involved with public security enact regulations that reward and protect citizens who voluntarily strengthen the fight against crime (Marin and Harder, 1994). These volunteers can thus become role models for other people, which further stimulates voluntary behavior.

In this study, we assume that volunteers in a group receive a certain reward from an external pool of resources that is shared among them. We study how the introduction of such shared rewarding influences the equilibrium fraction of volunteers in large well-mixed populations, and what level of rewarding is needed to overcome defection traps in these systems. We find that the introduction of shared rewarding has two interesting consequences. First, shared rewarding leads to a hysteresis effect under which the highest level of volunteering is reached by first increasing and then decreasing group size. Second, even small total rewards suffice to stabilize the coexistence of volunteers and non-volunteers, and are thus surprisingly efficient in robustly overcoming defection traps.

2. Methods

2.1. Volunteer's dilemma

We consider the generalized N-person volunteer's dilemma, describing the interaction of individuals in groups of N ($N \geq 2$) players. In each round of the game, an interaction group is assembled by randomly drawing N individuals from a large (infinite) well-mixed population (Hauert et al., 2002, 2006). Each player can choose between the strategies Volunteer or Ignore. The public good is produced if at least k ($1 \leq k < N$) individuals choose to volunteer. The cost of volunteering is c, relative to a baseline payoff of 1; volunteers incur this cost irrespective of whether or not the public good is produced. A failure of producing the public good imposes a cost $a > c$ on each player in the group. As a result, the payoffs of the strategies Volunteer and Ignore are given by

$$P_V(M) = \begin{cases} 1-c & \text{if } M \geq k, \\ 1-a-c & \text{if } M < k, \end{cases} \tag{1a}$$

and

$$P_I(M) = \begin{cases} 1 & \text{if } M \geq k, \\ 1-a & \text{if } M < k, \end{cases} \tag{1b}$$

respectively, where M is the number of volunteers in the group. For $c > 0$, $P_I(M)$ thus always exceeds $P_V(M)$.

It is worth pointing out that payoffs in the volunteer's dilemma can alternatively be described by assuming a cost resulting from the public good's absence (as above) or a benefit resulting from its presence (Archetti, 2011). The evolutionary dynamics reported below are unaffected by this alternative parameterization.

2.2. Shared rewarding

We extend the N-person volunteer's dilemma specified above by introducing shared rewarding. For this we assume that the volunteers in an interaction group in each round share a total reward δ ($0 < \delta < Nc$). Whether δ is provided from an external pool of resources or through compulsory contributions made by all players has no bearing on the evolutionary dynamics reported below.

For this generalized volunteer's dilemma with shared rewarding, the average payoffs of the strategies Volunteer and Ignore are given by

$$\begin{aligned} P_{\mathrm{V}} &= \sum_{M=0}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} \cdot \left[P_{\mathrm{V}}(M+1) + \frac{\delta}{M+1} \right] \\ &= \sum_{M=k-1}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} \cdot (1-c) \\ &\quad + \left[1 - \sum_{M=k-1}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} \right] \cdot (1-a-c) \\ &\quad + \sum_{M=0}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} \cdot \frac{\delta}{M+1} \end{aligned} \tag{2a}$$

and

$$\begin{aligned} P_{\mathrm{I}} &= \sum_{M=0}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} P_{\mathrm{I}}(M) \\ &= \sum_{M=k}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M} \cdot 1 \\ &\quad + [1 - \sum_{M=k}^{N-1} \binom{N-1}{M} x^M (1-x)^{N-1-M}] \cdot (1-a), \end{aligned} \tag{2b}$$

where x is the current fraction of volunteers in the population.