An Institutional Mechanism for Assortment in an Ecology of Games

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Abstract

Recent research has revived Long's "ecology of games" model to analyze how policy actors cooperate in the context of multiple policy processes. This paper develops an agent-based model of the ecology of games where agents participate in multiple public goods games. In addition to contribution decisions, the agents can leave and join different games. We show that the payoff for cooperation is greater than for defection when limits to the number of actors per game ("capacity constraints") structure the population in ways that allow cooperators to cluster. The results suggest an important trade-off between the inclusiveness of policy processes and cooperation: fully inclusive policy processes reduce the chances of cooperation.

1 Introduction

Humans are social animals, and we interact in many different social settings. There may often be an overlap of individuals involved in these settings the situations are not mutually exclusive. From a residential standpoint, an individual may be involved in school, work, church, social organizations and governing bodies, all simultaneously. Membership in each institution is not mutually exclusive, and some of the same constellations of individuals may be in a number of institutions. From a policy standpoint, there may be many organizations exercising influence over a particular resource, and interested individuals must divide their own time and resources between institutions wisely [6]. Thus, models that look at single games may not be adequate.

The way in which individuals participate in social interactions is not random, but shaped by social and institutional structures. These structures, however, are not fixed, but are shaped by the involved individuals exerting feedback on the system, a process known as *structuration* [3]. Most models involving multiple games have imposed a fixed spatial or network structure. Even in a recent network model where links were not fixed [12], the number of links in the network was preserved, imposing an artificial exogenous constraint on the system. In a multi-game setting, however, individual choices about leaving and joining games can structure the population in a way similar to networks. The result is an endogenous affiliation network as an aggregate outcome of micro-level choice, without the imposition of a priori network structure.

Though there are many mechanisms by which cooperation may be promoted [9], each involves positive assortment the tendency for individuals to associate at a rate higher than chance. If a population is well-mixed (i.e., interactions are completely random), pure cooperators cannot succeed against pure defectors. However, even in the absence of complex strategies, cooperation can prevail if the population is structured so as to promote positive assortment. This has been demonstrated in a number of models with a highly specified population structure [8, 10, 13]. Most models of multiple games have taken the form of spatial games on lattices or other exogenously determined networks. However, a key point of the structuration hypothesis is that individuals and institutions structure one another in a system of reflexive feedback.

Here we examine an ecology of public goods games, where the games are conceived of as institutions that exist independently of any particular individuals. The games structure the interactions between individuals, but by leaving and joining games, where leaving and joining can occur independently of one another, structure is allowed to further evolve. We show that completely unconstrained multi-game settings reduce to a single public goods game. We then examine two potential constraints that may contribute to structuration, which we call *budget constraints* and *capacity constraints*. Budget constraints refer to limitations on the number of games in which an individual can participate, and may be conceived of as the limitations on a persons available time, capital, or cognitive load. Capacity constraints refer to limitations on the number of individuals that can participate in a single game. Institutions may have formal restrictions on membership numbers, such as a limited number of seats on a board, or restrictions may be informal, such as a maximum number that can effectively communicate in a group. Further, research from animal behavior shows that many species often regulate group size when additional members would lower the groups efficiency [4].

2 The Model

We consider a number of public goods games with production constant r. Individuals have fixed resources to contribute every time step, and each agent either defects by failing to contribute to games, or cooperates by contributing all of its resources, divided evenly among all the games in which the individual is participating. In real-world interactions, not every individual has the same resources, nor would they necessarily contribute equally to all games. Still, it is expected that contributions would vary between individuals, leading positive experiences for some to be interpreted as negative experiences by others. Further, individuals generally do have limited resources, and, and egalitarian attitudes toward sharing are often encouraged in societies that value individual autonomy [1]. The decision to use fixed resources was also motivated theoretically by the finding that they promote the evolution of cooperation in agent-centered public goods games on a fixed heterogeneous network [13].

This model does not explicitly include evolution. Two points should be made about this. First, in classic evolutionary game theory, a mean advantage for cooperators translates into an evolutionary advantage. For medium-small group sizes, cooperators do not have an advantage at high frequencies, resulting in a stable mixed population, or a periodic oscillation around a stable point. Second, this model assumes a large amount of social reorganization happens between generations of reproduction (or imitation). This has been shown in other models to benefit cooperation [12, 14]. We thus follow the tradition of these models and show that social reorganization in a simple ecology of games will lead to positive assortment for cooperators, which in turn leads to a cooperator advantage that would translate to an evolutionary advantage if reproduction comes after social reorganization. It follows, however, that if reproduction/imitation occurs on a faster time scale, our results may not hold.

N agents play pure strategies of cooperate or defect, with frequency of cooperators f_C, and are initially distributed among M public goods games. An agent i plays m_i games, and a game j involves n_j players. **Budget constraints** may enforce a maximum number of games per player, m^*. Similarly, **capacity constraints** may impose a maximum number of players per game, n^*. Agents are initially placed in $\min(m^*, \gamma M)$ games, where $0 < \gamma \leq 1$ is a constant that determines the rate of agent "social mobility." Placement ends if and when all games reach n^* players.

Each time step, all public goods are played. The per-agent payout for each game j is

$$\pi_j = \frac{r}{n_j} \sum_{i=1}^{n_j} \frac{s_i}{m_i},$$

where r is the game production and $s_i = 1$ if i is a cooperator and zero if i is a defector. Each agent then has the opportunity to try and join a new game, with probability γ. They are restricted to games being played by a current co-player, which is consistent with the fact that that individuals often have an "in" when joining groups. The agent considers all games with positive payouts and atempts to join one with probability proportional to its relative payout. Agents then attempt to leave a game, again with probability γ. The agent considers all its current games, excluding one just joined, and leaves the one with the lowest payout if $\pi_j - s_i \leq 0$. The process is continued until an equilibrium is reached. Unless otherwise stated, we used values of $r = 2.5$, $N = 100$, $M = 100$, and $\gamma = 0.1$. We confirmed our results for populations up to $N = 500$.

3 Results

The unconstrained model resolves to a state equivalent to a single public goods game, in which cooperators are heavily exploited by defectors. Severe budget constraints allow cooperators to do slightly better than in the unconstrained model, but they still do far worse than defectors. Only capacity constraints allow cooperators to outperform defectors. Figure 1 shows the relative cooperator payoff at equilibrium, which is $\left(\frac{1}{f_c N}\sum_{i\in C}P_i\right)/\left(\frac{1}{(1-f_C)N}\sum_{i\in D}P_i\right)$, where P_i is the total net payoff across all games for agent i.

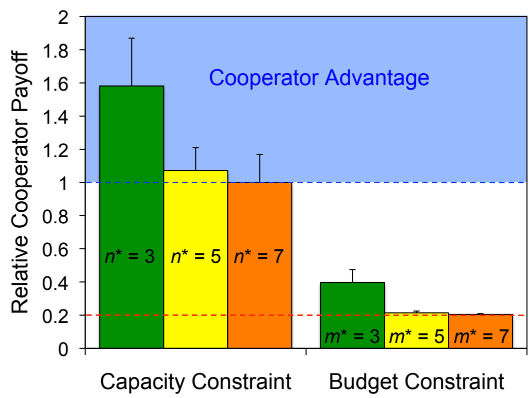

Figure 1: Mean relative cooperator payoff at equilibrium for sample values of n* and m*, 50% cooperators. Only capacity constraints allow cooperators to outperform defectors. The red line indicates the single game attractor for the unconstrained model. Means are taken from 100 runs, error bars are standard deviations.

3.1 Cooperator Frequency and Excess Assortment

The influence of the global cooperator frequency is not monotonic under capacity constraints: cooperators do best when in the minority, at frequencies close to 0.4 (Figure 2A). This can be explained by considering the model dynamics. Cooperators flee games in which defectors have too strong a presence. If there are enough such games, cooperators will only be found in games where they have a majority presence. Note that in such games, any defectors will still be able to exploit the cooperators. Thus, cooperators only win out in the end if the games in which they are exploited are outweighed by the effects of the cooperator-only games and the defector-only games.

Cooperators tend to do best when there are enough defectors in the population to force the defectors into many defector only games, where defectors receive zero payoff. Maximizing both cooperator-only and defector-only games is akin to maximizing the degree of positive assortment in the population. A useful measure [11] is the *excess assortment*, α_E, which is defined as the average observed assortment,

$$\alpha_O = \frac{1}{N}\sum_i\left(\frac{1}{m_i}\sum_j\frac{n_j^{(\text{same})}}{n_j}\right),$$

minus the expected assortment,

$$\langle\alpha\rangle = f_C^2 + (1-f_C)^2.$$

Figure 2 shows that the excess assortment is maximal when cooperators represent slightly less than half the population, and that excess assortment corresponds quite well to the relative cooperator payoff. Further analysis shows strong correlations between excess assortment and relative cooperator payoff on either side of the maximum assortment. We ran linear regressions on the aggregate results from $n^* = \{3,5,7,9,10\}$. We found $R^2 = 0.756$ ($p < .0001$) for $f_C \leq 0.4$ and $R^2 = 0.671$ ($p < .0001$) for $f_C \geq 0.4$. These results also indicates that in an evolutionary version of this model, the cooperator frequency would stabilize around 0.4.

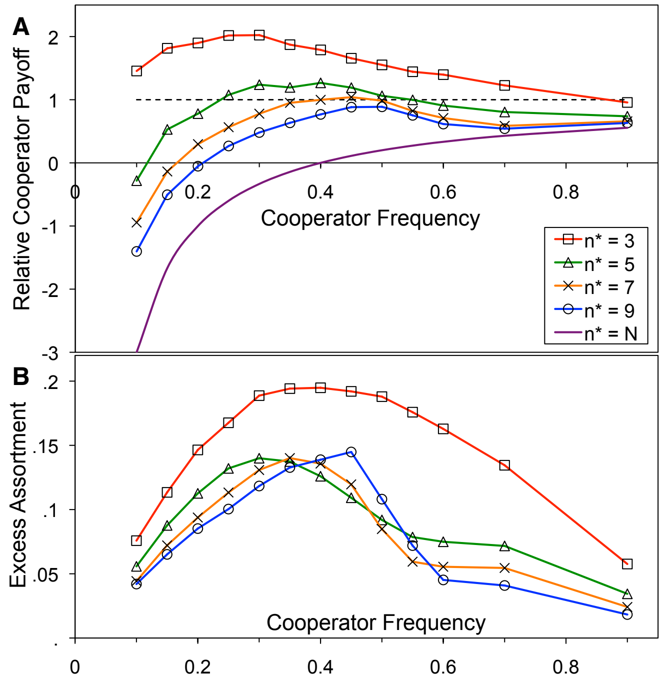

Figure 2: Average relative cooperator payoff (A) and excess assortment (B) at equilibrium as a function of the global cooperator frequency, f_C. Cooperator success is highly correlated with the ability of cooperators to assort at a level beyond that predicted by chance.

3.2 Number of Initial Games

Having more initial games relative to population size also promoted cooperation, due to more chances for cooperator-heavy games. Likewise, too few initial games reduced the cooperator advantage. For example, with $f_C = 0.5$, the mean relative cooperator payoff for $n^* = 5$ dropped below unity around M/N = 0.82, though cooperations retained the advantage for all values of M when $n^* = 3$.

4 Discussion

We have begun to formulate a framework for studying an ecology of games. Budget constraints on games per individual are not sufficient to promote cooperation, as there is no mechanism for cooperator assortment. When leaving and joining are dynamic, capacity constraints on actors per game can allow cooperators to flourish by allowing defector-heavy games to vanish, and preventing defectors from joining games already full of cooperators. As a consequence, fully inclusive policy processes may reduce the chances of cooperation.

Positive assortment is a necessary condition for the evolution of cooperation [7]. Limitations on group size can produce positive assortment of cooperators by eliminating groups where there are too many defectors. A previous model [11] has also found that positive assortment may be generated when both types of actors flee defector-heavy groups, and that limitations on group sizes promotes positive assortment. We show this to be the case in the context of an ecology of public goods games, and that these mechanisms may be used to promote cooperation. As a broader generalization, network and institutional structures that endogenously produce positive assortment will promote cooperation.

Our model requires many initial games, which may appear unrealistic. However, we do not explicitly provide a mechanism for the founding of new games. New games are likely to be founded by small groups with cooperator majorities. Even if new games are formed with random cooperator frequencies, our model predicts that, with enough games being formed, cooperation will eventually prevail. The addition of more complex behavior can also promote cooperation, including reputation [2], punishment [5] and reinforcement of beneficial social ties [14]. Modeling an ecology of games with more complex agents will be an important area for future study.

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