RUNNING HEAD: Cooperation among payoff-maximizing agents in sequential games

Order of play matters for cooperation among selfish agents even when moves are unobserved

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Abstract

Theories of cooperation often bear on why people choose to cooperate, but what if there were circumstances where people who are trying to be selfish end up cooperating anyway? We investigate this possibility with real-time, one-shot Public Goods Games where players move sequentially and do not know others' moves. We find that cooperation among players trying to maximize their own payoffs increases with the number of people yet to move after them. Selfish players may be maximizing their payouts on the assumption that everyone moving after them will move as they did. In the absence of other information, it may be that participants feel that their unobserved actions are informative about the behavior of others who are yet to move. A mechanism that induces cooperation among overtly selfish agents is of interest more broadly, with possible applications to policy.

Main

Social cooperation without external monitoring is widely regarded as a fundamental to human culture, sustaining teamwork, mass political participation, and personal sacrifice for family, tribe or nation. People often face opportunities to incur an individual cost in exchange for a collective benefit, and there is a rich literature exploring the whys and wherefores (Rand & Nowak, 2013; Henrich & Muthukrishna, 2021). For example, a pedestrian can choose to throw litter into the gutter, or he can wait until he comes across a trash bin. A CEO might choose to move assets overseas in order to avoid taxes, or she might choose to avoid chicanery, keep assets domestically, and pay more in taxes—in the end, contributing to the public weal. Each choice involves a tradeoff between what is good for the agent and what is good for the group. This tradeoff is widely studied using Public Goods Games (PGGs, Zelmer, 2003). The PGG is used as a model of human cooperation because tension between the benefits accruing to the group via cooperation and the benefits accruing to the individual via defection captures the essence of the types of cooperation problems humans solve on a daily basis.

There may, however, be circumstances in which even selfish players—players for whom there is no tradeoff, who are just trying to maximize their own payouts—end up acting prosocially. We investigate this possibility with a subtle variation on the classic PGG, a sequential game. If players are forced to move one after another, with no knowledge of each others' moves, and we observe an increase in cooperation among players who move earlier in the sequence (an increase borne of the mere knowledge that others will be acting in the same game after you), that is interesting for two reasons. First, knowing how to induce more cooperation is useful—and doubly so in the particular case of people who are trying to do best by themselves and who are indifferent to the costs to others. Second, it gives us a window into how these decisions are being made. It could be the case that selfish players are cooperating because they are calculating an expected payoff on the assumption that everyone moving subsequent to them will make the same move they have, providing valuable insight into possible mechanisms by which this cooperation emerges.

The games used here are "sequential" in that players move one after another, and players' moves are unobserved in that there is no information flow between players: any given player knows nothing about the decisions players who have already moved have made. For example, a five-person PGG is sequential with unobserved moves when the five players move one after another, but each player knows nothing about what the other players have done. Traditional game theory suggests that

the order in which players in the same game are moving is irrelevant as long as they don't know anything about what moves others make, and therefore the distinction between events that have happened and have not happened—even if they are unknown—is lost. Because of this, the formal expression of the simultaneous version of a game is identical to that for a sequential version, where players move one after another.

There are several bodies of work that investigate the effects of agents acting one after another with observability. There is a rich literature investigating team effects, in which individual agents acting as part of a team optimize for the team's success, rather than for their own best interests, under certain conditions ((See Colman & Gold, 2018 for a review) Similarly, there is substantial work investigating leader- and follower- effects in games which have some element of sequential moves (e.g. Gächter et al., 2010), as well as sequence effects in economic games with observed moves, both one-shot and repeated (e.g. Figuières et al., 2012). Critically, the theoretical accounts from these literatures rely on the flow of information about earlier players' moves from early players to later players, and they rely on earlier players knowing that will happen. Evidence for order effects in the absence of any information flow at all may, then, be consequential for these theories.

Relevant to games without information flow, there is a related body of work on the illusion of control: the idea that there are circumstances under which people over-estimate the amount of control they have over a situation. This literature asserts that people are motivated to believe they have more control than they do over a situation, especially when the lack of control should be logical or observable. The feeling of control when there is none may be due to social motivations or to the desire to preserve self-esteem (Stefan & David, 2013 for a review). This provides evidence from other domains for the type of behavior that may lead to effects in sequential games with no information flow.

The literature on order effects in economic games *without* observation, games similar to those investigated here, is modest and inconclusive. Morris et al. (1998) report more cooperation among first-movers (66%) than among second-movers (53%) in a Prisoners' Dilemma, but do not replicate the effect in a subsequent larger experiment. Abele & Erhart (2005) describe two Public Goods Game experiments with undergraduates (N=86 and N=192), and Figuières et al. describe a voluntary contribution game (2012, N=32); both report no order effect for sequential conditions with no information flow. Budescu and Au (2002) describe more defection in earlier movers in a common pool resource game, and Weber et al. (2004) describe order effects in coordination games (but see Li, 2007). Shafir and Tversky (1992) found that informing Prisoner's Dilemma players about their teammate's

move reduced cooperation even if that teammate had chosen to cooperate. The increase in cooperation under uncertainty may reflect a feeling of influence over teammate's unknown action, which would be consistent with some sort of magical thinking. However, their study did not measure projection, nor indicate to participants whether the other player had already moved. Related, Chen and Zhong (2020) report that uncertainty about a dice game results in more moral behavior, which may be relevant to observed behavior in sequential games if uncertainty is fundamentally about how many people have yet to move, vs. the total number of other players. In a sequential game with no information flow there is no change in uncertainty with order in a formal sense. It may, however, be interesting to note that, while any given player knows nothing about his groupmates' moves, those moves (once made) are known in a more general sense. Having been determined, they are at minimum known to others.

In a standard PGG *n* players are each given an endowment *e*, and asked to decide what proportion of the endowment to contribute to the public good, *a*, from nothing to all of it. The total amount from all the players that is contributed to the public good, *c, i*s then multiplied by a multiplier *m* (which must be less than the number of players), and distributed *evenly* among *all* the players—even those who chose to contribute less or nothing. An individual player's payoff function in a standard simultaneous-move PGG is as follows:

$$p = \frac{mc}{n} + e(1–a) \qquad \text{(Equation 1)}$$

Consequently, whenever the multiplier *m* is less than the number of players *n*, the group as a whole does better if everyone contributes their entire endowment (cooperates), but each individual player is better off if he or she contributes nothing (defects). Put another way, the total amount of money in the group is maximized if everyone cooperates, but any individual player always makes more by defecting —independent of anyone else's moves. Because other players do not know your move, they cannot change their own moves in reaction to it. If a group plays the game only once, it is impossible to enact retribution or reward others for their moves.

We will speak of a focal player, the player of interest in a sequence of players. If all players after the focal player were to make the same move as the focal player, we would expect to see a decline in cooperation with increasing position in the sequence among players trying to maximize their payouts. As the order of the focal player goes up, as the player gets closer to the end of the sequence,

cooperation will go down. Player 1 will tend to cooperate more than Player 2, who will cooperate more than Player 3, etc. A simple model that captures this pattern incorporates *s*, the position of the focal player in the sequence, *c*, the average proportion of the endowment contributed by everyone *before* the focal player, and *d*, a discount applied to all contributions made after the focal player's move, which is simply a proportion by which players after the focal player copy the focal player's move, moving away from a zero contribution. We can express this as follows:

$$p = \frac{m(ce(s-1) + dae(n-s) + ae)}{n} + e(1-a) \qquad \text{(Equation 2)}$$

Solving for *s* where payoffs are equal given *a = 1* or *a = 0* yields:

$$s = \frac{m - n + mnd}{md} \qquad \text{(Equation 3)}$$

This characterizes the point in the sequence where the focal player's payoffs are not sensitive to her contribution. Before this point in the sequence the most profitable move for the focal player is to cooperate, and after this point it makes sense to defect. We would observe a linear decline in contribution on average among selfish players if there is heterogeneity between participants in *d*, the extent to which focal players believe that subsequent selfish players will copy their move (the remaining variables, *m* and *n*, are exogenous). This is because the point in the sequence at which any given player would switch to defect varies with *d*. In a 5-person PGG, at *s* = 1 (the focal player is first to move), most players play cooperate and give their entire endowment to the public good. At *s* = 3 (the focal player is third to move), some players will cooperate and some will defect, depending on *d*, the extent to which they believe subsequent players will make the same move. At *s* = 5 in a 5-person game, most players defect.

In four studies we test whether the temporal order of unobserved moves influences decisions. The first is a three-person Public Goods Game, and the remaining studies use a five-person Public Goods Game. Study 1 asks whether there is an order effect at all, and how that varies with Social Value Orientation (a measure of willingness to give up gains in order to benefit others). Study 2 expands this to five people to better rule out first-mover and last-mover effects. People who arrived at the experiment clearly self-interested are sufficiently rare in the study population that forming five-person

groups in real time proved difficult, so Study 3 asks whether merely instructing respondents to maximize their own payouts is effective. Study 4 deploys the technique from Study 3 and asks whether it is necessary to have people moving after you who are making their own decisions (vs. having their decisions made for them randomly) in order to observe an order effect. In all studies participants contribute three inputs: Comprehension checks, game playing decisions, and predictions of the responses of other players. Apart from game compensation, participants are also paid for correct answers to comprehension checks, and for accurate predictions.

Results

All studies are linear PGGs with a multiplier of two, and share several characteristics. First, before learning what game they are to play, players participate in a chat room with their groupmates in order to serve as a rough and ready Turing test. This also gives the task more psychological reality than might otherwise be felt in an online task with no human interaction. Second, all games are real-time interactions between real players. When players are playing a PGG, they are playing with the groupmates they chatted with in real time. Third, all pre-play attention checks, comprehension questions, gameplay decisions, and predictions are incentivized. Participants are paid more for correct answers. Fourth, all experiments involve simultaneous-play PGG control conditions. Fifth, all players pass familiarization tasks and comprehension checks. Data from players who miss a single comprehension check is excluded from the main analyses. All experiments have the following three up-front comprehension and attention check questions:

Q1: *Do any of the other players **know how much YOU decide to contribute?***
Q2: *Jack and Jill are playing this game together. Jack decided to **TRANSFER** and Jill decided to **KEEP**. Who will make more money, Jack or Jill?*
Q3: *What year is it?*

Participants are given a single chance to get each of these questions right, and a single wrong answer results in that data being excluded. Later studies incorporate more extensive training and comprehension check regimes.

Study 1: 3-Person Sequential Public Goods Game

Participants played one round of a three-person PGG game. Our primary interest was how contribution to the public good varied with order of play. We also expected that correlations between personal contribution and predicted contribution of others will be stronger going forward in time. Along with standard measures, we estimated participants' interpersonal utility tradeoffs using the Social Value Orientation (SVO) scale (Murphy et al., 2011), which divides most participants into two categories, Individualist and Prosocial. Individualists are working to maximize their own outcomes and are indifferent to others' outcomes, while Prosocials try to maximize their own outcomes but do take others' outcomes into account. Order effects should be more pronounced for participants who are primarily interested in their own payoff (Individualists). In contrast, Prosocials should be less sensitive to order of play, as altruistic motivation should not be biased toward future players.

We find good evidence for the preregistered order effect pooling with pilot data, with first-movers contributing more than later players, though we do not resolve a difference between second- and third-movers and therefore do not meet the conditions of the preregistraton. A linear regression of contribution on move order (coded as 1, 2, 3) yields a significant negative slope, $\beta = -0.042$, 95% CI = [-0.081, -0.003], $F(1, 780) = 4.7$, $p = 0.03$. First-movers contribute more than second-movers (p=.013) and more than third-movers (p=.031). The difference between second- and third-movers' contributions is not significant.[1]

We also find support for the preregistered prediction that the order effect is concentrated among participants classified as Individualistic in the SVO task. (Figure 3). Participants classified as Prosocial exhibit no significant differences in contribution levels as function of order, while we do see a difference between the first-mover data and grouped second- and third-mover contributions ($\beta = -0.142$, 95% CI = [-0.248, -0.035], $F(1, 288) = 7.104$, $p = 0.008$).[2] As with the aggregated data, we do not see the hypothesized difference between positions two and three among participants SVO-classified as Individualistic.

[1] See the supplemental online materials for a discussion of the effects variation in times spent waiting within an order

[2] Nearly all participants were SVO classified as Individualistic or Prosocial; two participants were classified as Altruistic, and two as Competitive. These participants' data are excluded from analyses.

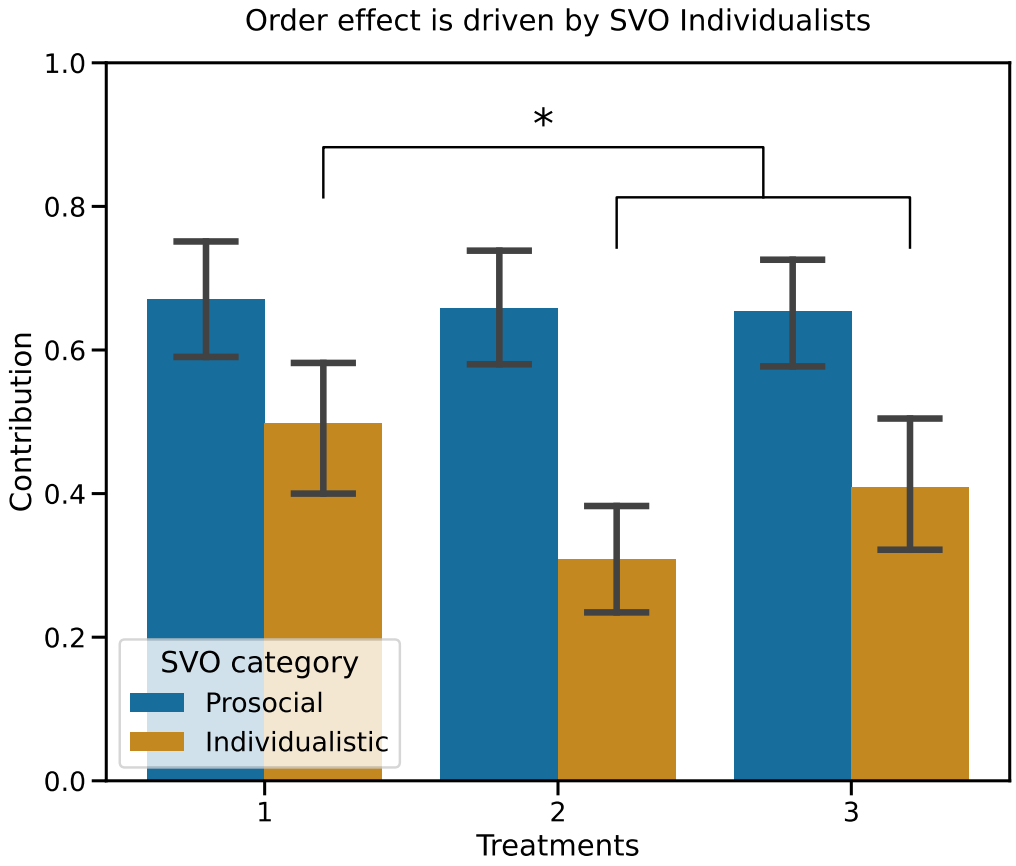

Figure 1: Change in contribution with order is driven by participants SVO-classified as Individualistic. 800 participants who passed comprehension checks (406 Prosocial, 394 Individualistic), excluding batches with errors (1 and 8).

We find some support for the pre-registered hypothesis that the correlation between one's own contribution and prediction of others' contributions is stronger going forward than going backwards. The pre-registered linear model regressing contribution, a present / future dummy variable, and the interaction on prediction does not reach significance ($F(3)=226.114$, $p=0.268$ for the interaction), but is significant ($p=0.006$) when SVO classification is included as a covariate (Regression 2 in Table 1). Table 2 also shows that a model reflecting the preregistered prediction that our effects will be concentrated among SVO- Individualists, confirms a pronounced effect of projection to future players among Individualists (Regression 1c) but no such effect among Prosocials (Regression 1d).

	Dependent variable:predicted_value				
	(1a)	(1b)	(1c)	(1d)	(2)
Intercept	20.208***	22.941***	25.985***	17.763***	25.985***
	(1.948)	(2.074)	(2.539)	(3.503)	(2.595)
Contribution	51.973***	49.612***	42.605***	56.949***	42.605***
	(2.906)	(3.025)	(4.462)	(4.546)	(4.559)
Past or Future[T.1.0]	-3.254	-5.125	-7.090	-2.332	-7.090
	(2.852)	(2.999)	(3.638)	(5.157)	(3.718)
Contribution : Past or Future[T.1.0]	4.618	7.449	17.251**	0.106	17.251**
	(4.170)	(4.325)	(6.148)	(6.650)	(6.282)
SVO Class[T.Prosocial]					-8.222
					(4.305)
Contribution : SVO Class[T.Prosocial]					14.343*
					(6.376)
Past or Future[T.1.0] : SVO Class[T.Prosocial]					4.758
					(6.277)
Contribution : Past or Future[T.1.0] : SVO Class[T.Prosocial]					-17.145
					(9.055)
Observations	1,282	1,198	580	618	1,198
R^2	0.347	0.338	0.337	0.325	0.343
Adjusted R^2	0.345	0.336	0.334	0.322	0.339
Residual Std. Error	32.891 (df=1278)	32.833 (df=1194)	32.070 (df=576)	33.414 (df=614)	32.770 (df=1190)
F Statistic	226.114*** (df=3; 1278)	203.260*** (df=3; 1194)	97.587*** (df=3; 576)	98.503*** (df=3; 614)	88.673*** (df=7; 1190)
Note:					*p<0.05; **p<0.01; ***p<0.001

Table 1: Model 1a is an OLS regression of binary position (1=future, 0=past) and contribution on value predicted for a groupmate's contribution to the community fund. Model 1b is the same, but limiting analysis to participants who completed the SVO battery. Model 1c is participants SVO classified as Individualistic, while Model 1d is those classified as Prosocial. Model 2 adds SVO categorization (Individualistic or Prosocial) to a fully interacted model. The three-way interaction is near significance at p = 0.059

We also observed a strong non-preregistered impact of contribution on predictions of groupmates' behavior relative to the population, with pairwise correlations: +0.190*** for first-movers, +0.135** for second-movers, +0.030 for third movers, and +0.104* for Simultaneous.

Players in the Simultaneous condition are most similar to third-movers in terms of contributions, and correlations of contributions with predictions. This makes it unlikely that waiting time is affecting our results, because in that case their behavior would most resemble the first-movers, who also do not have a waiting period (further analysis of simultaneous conditions can be found in supplementary online materials).

Study 2: 5-Person Sequential Public Goods Game

A five-person PGG allows for more insight into the order effect, especially given the potential for effects due to being either first in a sequence of any length ("leader effects", e.g. Eichenseer, 2019)or last. We report results from a sequential 5-person game where participants were classified based on an SVO task performed up-front. In Study 2 we do not meet our pre-registered threshold to detect an order effect. A programming error meant that time Player 1 and Player 2 had to make a decision was not correct, sometimes being shorter than for other players. We do observe the predicted effect in Players 2-5.

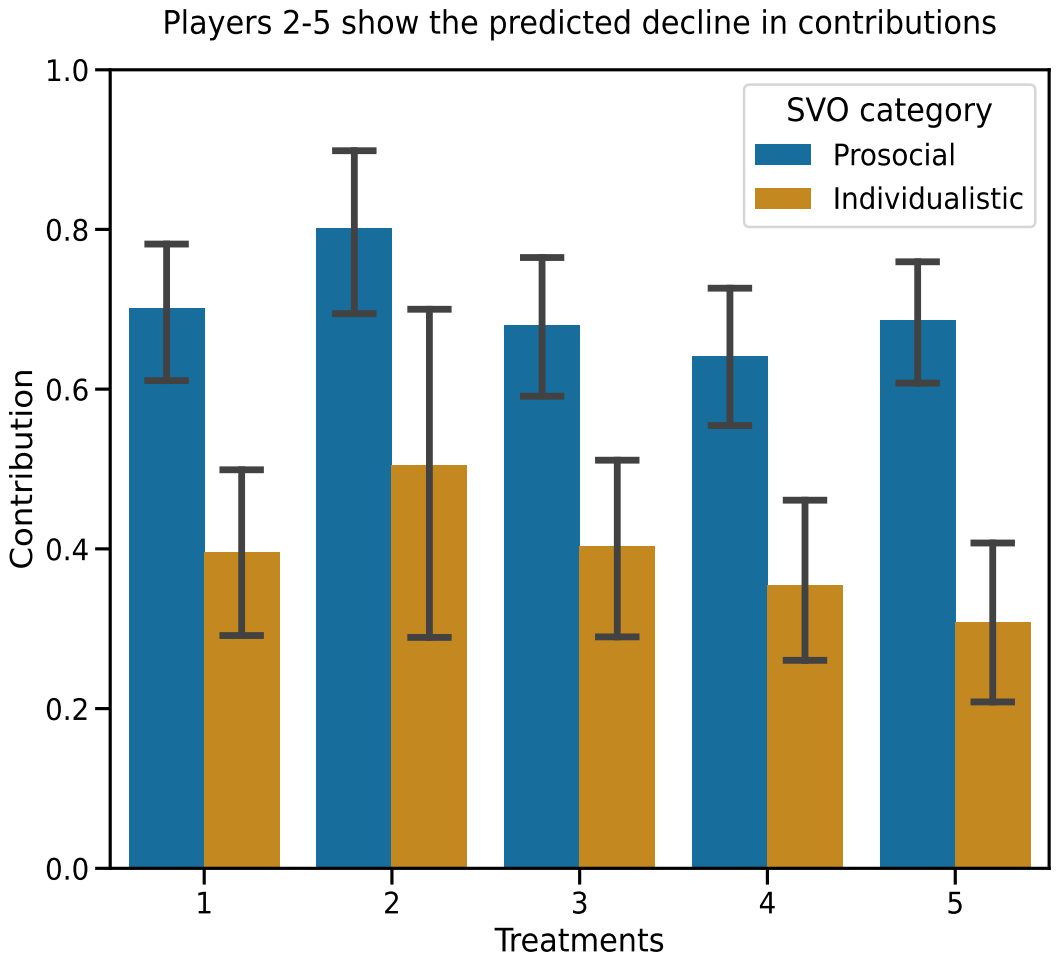

Figure 2: SVO-individualist players show a decline in contribution with increasing order from Player 4, and an anomalous result for Player 1. N=342 Prosocial participants, 257 Individualistic participants.

We noted that the effect became apparent among all positions if analysis is to participants who were close to 0 degrees on the SVO scale, i.e. those who were most clearly maximizing their own returns, as opposed to those who were merely classified as “Individualistic”. If we restrict our analysis to all players whose SVO degree measure was +/- 10 degrees (players who are maximizing their own returns or very close to it), the predicted pattern appears.

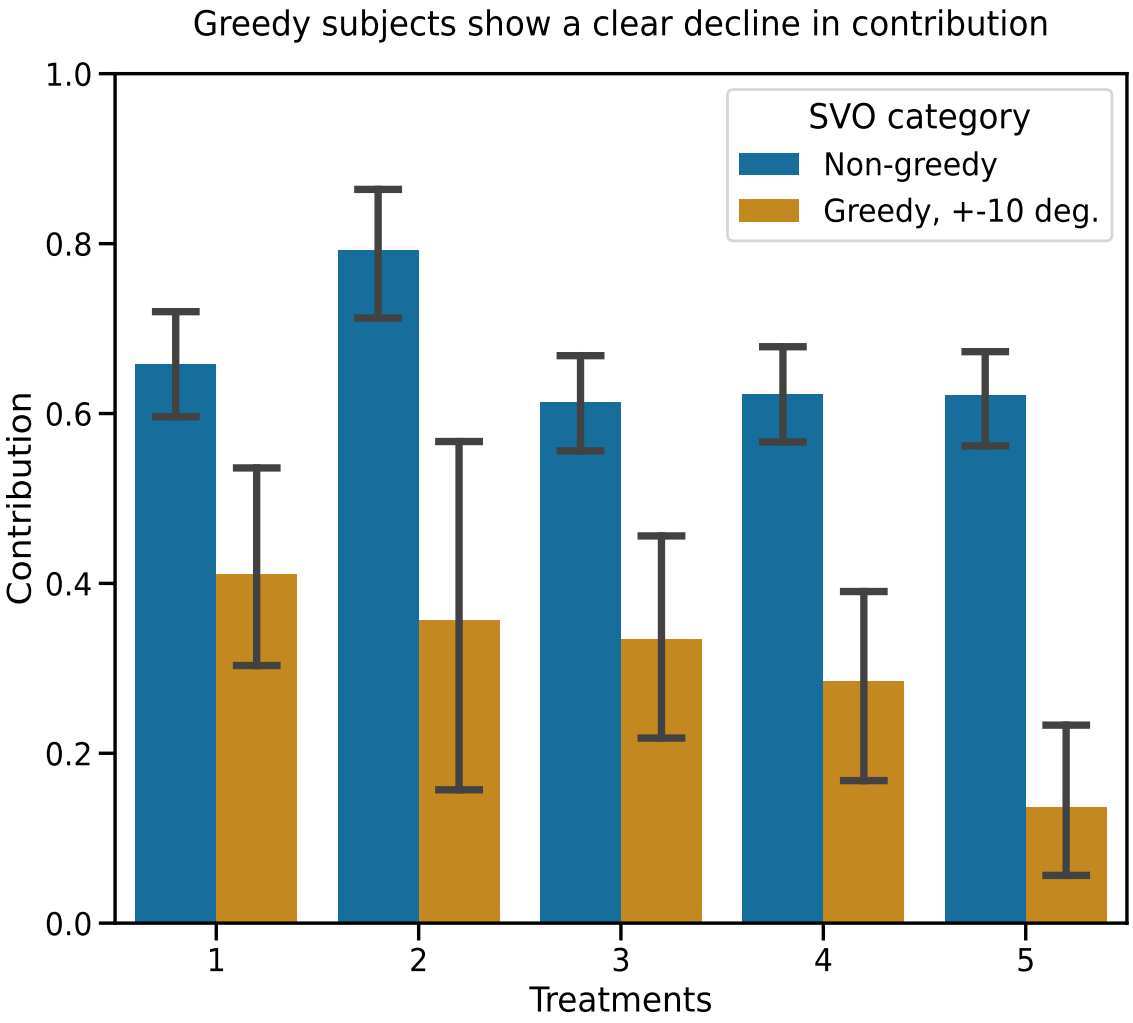

Figure 3: Players whose SVO degree measure is +/-10 degrees show the predicted decline of contribution to the public good with increasing order. N=692 Non-greedy participants, 191 Greedy participants.

The experiment was not sufficiently powered to detect an effect among the most selfish +/-10 degrees SVO population who passed comprehension checks, but a linear regression of contribution on order interacted with a binary greedy / not greedy variable using data from all participants does detect the effect ($F(3)=45.66$, $p=0.043$ for the interaction).

Study 3: 5-Person Sequential PGG with induced self-interest

The observation from Study 2 that the most self-interested participants were those exhibiting the largest order effect led to the design of Study 3. Filling real-time 5-person games with enough selfish

participants proved impractical due to the rarity of participants who score +/- 10 degrees on the SVO battery, so Study 3 was meant to efficiently examine if a mere prompt to act in one's own interests would allow us to replicate the pattern observed in participants who arrived at earlier studies already selfish. The task is similar to Study 2, but has significant improvements. The main difference is that participants did not perform the SVO filtering task. Instead, participants were randomized to a condition with no prompt, or to a condition with the prompt:

> *Please try to play this game however you think will make you the most money. We understand that sometimes you want to help other people, but for the purposes of this experiment we want you to try to make as much money as possible.*

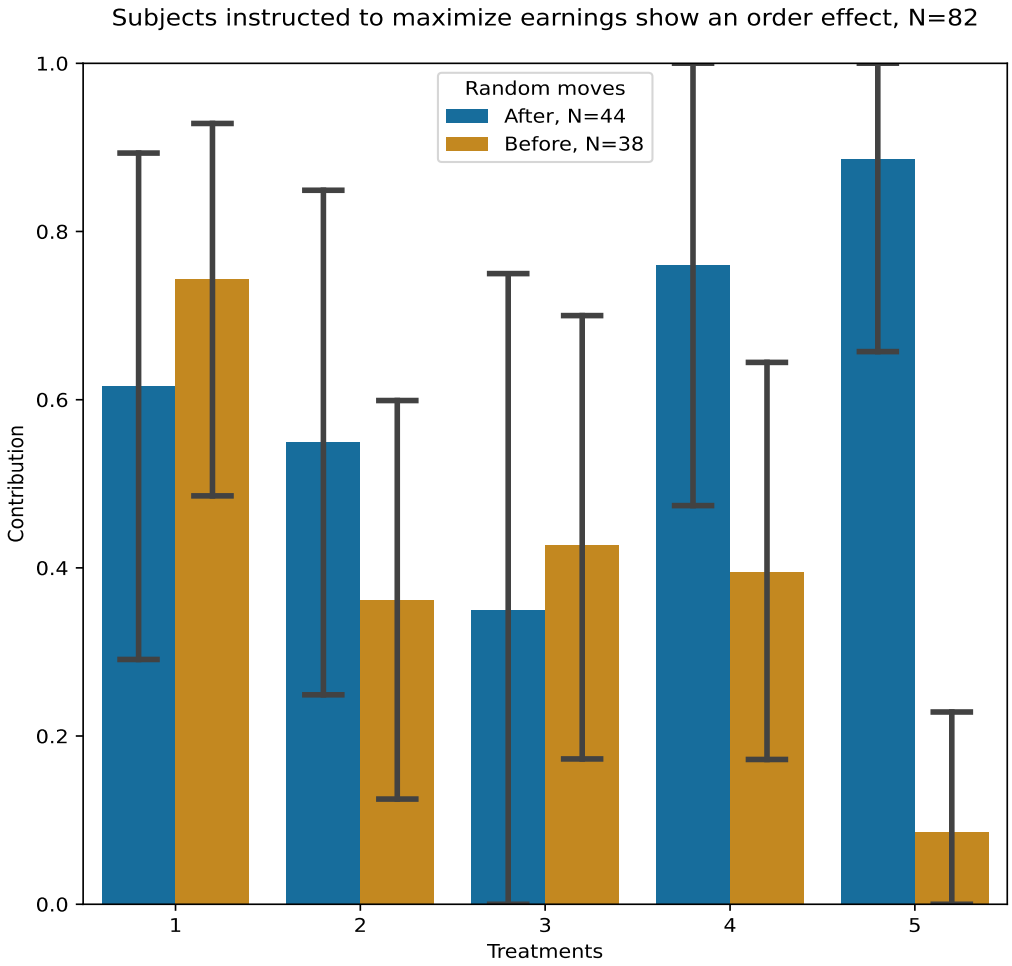

Figure 4: Study 3 shows the hypothesized decline with order among those who were instructed to be greedy. N=44 participants instructed to be greedy, 38 participants given no instruction.

In addition to the prompt, Study 3 incorporates three additional substantive improvements. First, Study 3 incorporates an additional simultaneous-play control condition that incorporates a delay of 80 seconds. These participants will wait about as long as sequential-condition players who are moving last (order = 5). This condition was incorporated in order to control for the possibility of wait time effects. While waiting, participants are shown the task's standard wait screen which incorporates the option to play a simple game to keep participants engaged with the task. Second, Study 3 incorporates an interactive practice game after the instructions and comprehension questions. This practice game asks participants to calculate the correct answers to questions about payoffs for hypothetical players in a PGG. Subjects are paid for correct answers, and they can make multiple attempts at any given question,

limited only by time. Third, participants in Study 3 move in lock-step with one another. Each page in the study takes an allotted amount of time no matter the subject's behavior. This is to ensure that information cannot leak via response times. For instance, Player 2 might notice that Player 1 moved rather quickly if Player 1 is allowed to advance from the Contribution page as quickly as she likes.

We observe the order effect in this non-preregistered study. A linear regression of contribution on order interacted with a binary instructed to be greedy / not instructed to be greedy variable plus wealth using data from participants who pass comprehension checks detects the interaction effect (β = -0.189, 95% CI = [-0.294, -0.074], $F(3, 78) = 5.038$, $p = 0.006$ for the interaction). Subjects receiving the prompt show a decline in contribution with increasing order. We do not observe a difference between the two simultaneous-play control conditions.

Study 4: 5-Person Sequential Public Goods Game with random moves

Having collected some evidence that a prompt to maximize one's own payouts works as well as arriving at the experiment already wanting to, Study 4 extends Study 3 by applying the instruction to act to maximize one's own payouts to all participants and at larger scale, but with two additional conditions: all participants are either told that every player before them has his or her contribution determined randomly ("Random Before"), or that every player moving after them has his or her contribution determined randomly ("Random After"). This allows some insight into whether the order effect is somehow driven by the fact that other people, specifically, will be moving after the focal player—even though he cannot see their moves. Players are presented with a page that explains the setup, and are presented with symbols that make which players' moves were randomly decided clear. For instance, if the focal player is in position 3, players see graphical representations similar to that shown in *Figure 5* on all pages from the point at which the concept of random moves is introduced until the end of the game. Subjects in Study 4 continue to move in lock-step, preventing the flow of information to other players via response times.

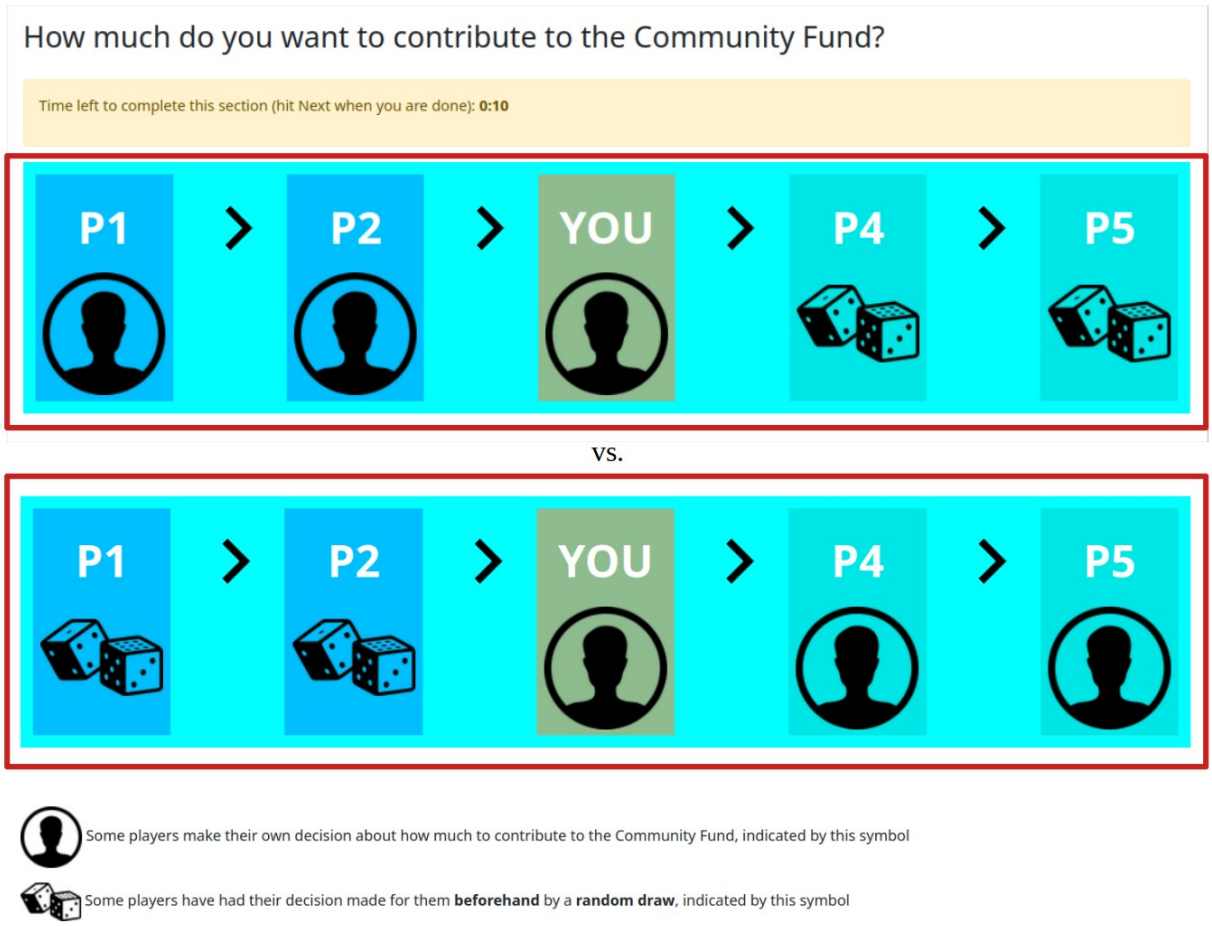

Figure 5: The graphical representation given to Player 3 on the Contribution page is shown in two conditions, in red boxes: Random After and Random Before. Players see a graphical representation of their position relative to other players that clearly conveys which players are having their moves made by a random process. This is in addition to a previous screen that explains how some players are having their moves made for them by random processes.

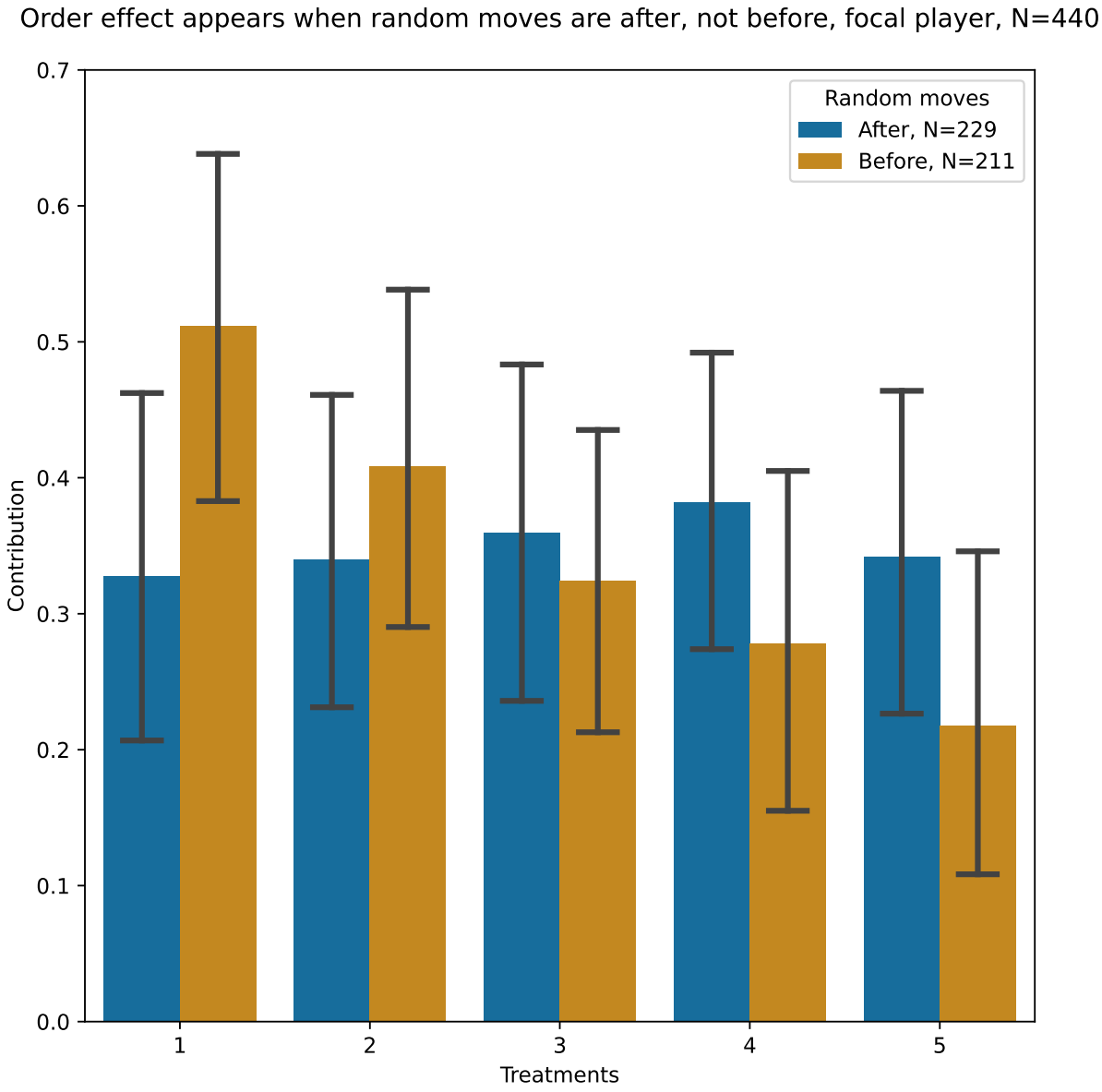

Figure 6: Study 4 shows a decline in contribution to the public good among players who are told that all other players moving after them are making their own moves, and all players moving before them are having their moves made randomly. No effect is observed among players who are told that everyone moving after them has a move selected at random.

In Study 4 we observe a decline in contribution with order only among those players who are told that everyone moving *before* them has his move determined randomly, while everyone moving *after* them is deciding on what move to make as usual . The preregistered linear regression contribution ~

order*random_before + wealth, differing from previous analyses in that it controls for a measure of wealth, finds the effect. A significant regression equation was found, $\beta = -0.078$, 95% CI = [-0.131, -0.024], $F(4, 482) = 3.642$, $p = 0.006$ for the interaction. Among players told the opposite, that everyone moving after them has their move made randomly, we observe no order effect. 75% of players in this experiment contribute either 100% or 0% of their endowment, and the effect size and direction are preserved in this subset, $\beta = -0.096$, 95% CI = [-0.163, -0.028], $F(4, 354) = 3.849$, $p = 0.006$ for the interaction, lending credence to the idea that heterogeneity in the point at which the optimal move switches from cooperate to defect is driving the order effect.

Discussion

Reward-maximizing players in sequential PGGs cooperate more when they believe there are people moving after them. Four experiments support this view: participants understand the game (and effect sizes increase when using ex post comprehension checks), participants are trying to maximize their own rewards (and in some cases are instructed to), so it appears they believe contributing more at the beginning of a sequence of agential players will, in fact, maximize their own payouts. That this effect is not present when subsequent players have their moves made randomly suggests implicit causal thinking at play: It is not just *that* I cooperate that suggests others will cooperate, but *if* I cooperate, others will cooperate. This makes it clear that the distinction between events that have happened and those that have not is important for behavior. We speculate that a simple model may capture something of the process generating this behavior specifically in selfish agents: these agents understand the rules of the game and are trying to maximize their payouts—they just act as if their move is informative about all subsequent players' moves in a sequential game, and make the move that maximizes payouts if everyone who has not yet moved were to make the same move.

It may be that there is a source of information about what others might do in a standard PGG. In the total absence of other information, it is possible that players look to their own behavior in an attempt to learn about what others will do via social projection (Dawes, 1989; Hoch, 1987). If a focal player assumes some similarity between himself and the other players, it may seem reasonable to look to his own behavior as a source of information. If this is the case, there may be mechanisms by which people who are selfish—who are trying to maximize their own payoffs independent of what is good for others—end up cooperating anyway. Projection from personal decisions to collective behavior can be consistent with Bayes' rule.

Self-signaling is another mechanism that may explain cooperation by selfish agents. In a self-signaling account, individuals regard their own decisions as informative about their unknown "deep" characteristics, such as morality, affection, dedication or willpower. Self-signaling implies that individuals will favor decisions that generate good news (a positive self-signal) about these characteristics, and that the effect is conditional on (a) the signal being costly, (since signals that are too easy to generate are not informative) and (b) some prior uncertainty about the characteristics (since being quite sure about these types means self-signals are uninformative in comparison to what is already known) (Bernheim & Thomadsen, 2005; Bodner & Prelec, 2003; Dhar & Wertenbroch, 2012; Mijovic-Prelec & Prelec, 2010). Agents who are self-signaling are motivated to produce signals that give them good news. In the case of a PGG, selfish players are motivated to learn from their own behavior that others will also contribute, thereby raising their estimate of their profits—and their level

of cooperation. Crucially, from the standpoint of both theory and empirical evidence, self-signaling does not require a perceived causal link between decisions and the underlying characteristic of interest; it can influence decisions even when their causal irrelevance is made obvious by experimental design (Quattrone & Tversky, 1984). Projection from personal decisions to collective behavior, as in social projection, is consistent with Bayes' rule. With decisions, however, there is a causal component to projection. By freely choosing an action the individual also chooses the signal about collective behavior that the action delivers. Causal power over one's expectations about others' prosocial behavior may be motivationally, if not logically, equivalent to a feeling of power over their actual behavior. It also may be the case that some participants are acting as if they have control even though they know they do not. These behaviors reflect what might be called magical thinking, where agents act as if they have control over events they know they cannot influence (Daley & Sadowski, 2017 for an overview). This account, in contrast to the preceding two, is more clearly irrational at some psychological level. All three of these potential mechanisms could be present in the same subject population.

Literature investigating the effects of order of agents' actions on behavior, such as that on teams, first- and last-mover effects, and that on sequential games with information flow may need to be revisited. Interpreted in the light of the results we report here, it may be the case that many of the findings in these bodies of literature are a function of sequence alone.

Finally, whatever the mechanism, a means by which selfish actors might decide to contribute to the public good is relevant to many practical policy questions. For example, using this sort of magical thinking an agent might say to herself: if I vote then it is more likely that other people will vote; if I conserve energy, then others will conserve as well; if I contribute to a public good, so will others—and my payoffs will be maximized. This could explain why even a purely self-interested individual might feel that their investment of time or effort for a public cause will pay off, provided there are several others deciding to contribute—or not—at a later time.

Methods

Ethics: All studies reported here were approved by MIT's Committee on the Use of Humans as Experimental Subjects (COUHES) and comply with all relevant ethical regulations. We obtained electronic consent from all participants.

Code availability: All statistical analysis was done in python. Satistical analysis scripts are available as part of the supplementary information and on osf.io.

Data availability: Anonymized data sets are available as part of the supplementary information and on osf.io.

A convenience sample provided by Amazon Mechanical Turk was selected for all experiments because it is a reasonable approximation of American adults for our purposes. Studies 3 and 4 used a panel filtered by Cloud Research. This work makes the point that these effects exist in human populations, and it is left for future work to examine how they vary across ages, sexes, SES, cultures, and other covariates of interest. All experiments also involved extensive training and comprehension checks. Data from participants who failed one or more pre-play comprehension check questions was excluded. All experiments are real-time online group tasks, where participants interact via text chat before learning the rules of the game in order to establish some sense that they are completing the task with actual people in real time. All studies except for Study 3 were preregistered on osf.io.

Study 1

Participants. 1668 U.S.-based participants from Amazon Mechanical Turk completed the study. Median total pay per subject (including bonuses for accurate predictions) is $3.16 (*SD* = 0.90), yielding an hourly rate o $18.46 per hour at 10 minutes' duration (SD = 8.38). Of 1668 participants, 69% (1151) passed all of the comprehension check questions. Data from batches 1 and 8 were excluded due to technical problems resulting in server crashes during the experiment. Analysis is limited to 1002 responses which passed comprehension checks and were not in batches 1 or 8. To estimate the sample size required, we performed a power analysis via simulation using pilot data.

Materials and procedure. Study 1 is a one-shot sequential PGG with a multiplier of two. Three players can transfer any part of their individual $1 endowment. The total transfer amount from all participants is then doubled and distributed evenly among the players, irrespective of individual transfers. Order of play is determined randomly, with no communication among players. The only

difference in information among the players is knowledge of their position in the sequence. Each participant was assigned to one of four conditions: orders 1-3 and a simultaneous-move condition. Players arrive at the experiment web page, are consented, and then engage in a real effort task transcribing nonsense sentences. After this, they are placed in a chat room for 30 seconds after all players in their group have arrived to ensure participants believe the experiment is, in fact, a real game in real time with real people. After the chat, participants are provided with an explanation of the rules of the game (which appear on every subsequent page for reference). The Public Goods Game is framed as a question of how much to contribute to a "Community Fund". A player can "transfer" some or all of her endowment to the Community Fund, and she may "keep" some amount. Instructions include if-then statements about the consequences of certain moves to aid understanding.

Subjects are then asked three comprehension and attention check questions: (1) Do any of the other players know how much you decide to contribute? (2) No matter what the other players do, what earns you the most money? TRANSFERRING to the community fund or KEEPING your endowment? and (3) What year is it? As with the PD, responses to the comprehension questions are only relevant to data analysis: players continue on whether or not they have answered correctly. Since players do not interact after the initial chat, players who fail the comprehension checks can have no further influence on those that pass.

After having completed the comprehension questions, players make their move. The contribution page includes a graphic at the top highlighting their place in the sequence of moves in red (see supplemental online materials). Players in the simultaneous condition do not see any indication of sequence since they are moving simultaneously. Subjects then complete prediction questions, and then a Social Value Orientation (SVO) slider battery (Murphy et al. 2011, code based on Bakker 2019)[3]. The SVO battery measures preferences for how to allocate resources between oneself and others. Respondents are often categorized into Individualistic (concerned only with what is best for self), Competitive (maximize own outcomes as with Individualistic, but also minimize the outcomes for others), Prosocial (maximize outcomes for both self and other), and Altruistic (eager to give up own gains to help others). Players then exit the experiment and are paid.

[3] SVO is measured post-treatment, but we do not observe an effect of treatment on SVO. See supplementary online materials for a discussion of the effect of the treatment on SVO.

Study 2

Participants. 1089 U.S.-based participants from Amazon Mechanical Turk completed the study. Median total pay per subject (including bonuses for accurate predictions) is $3.40 (*SD* = 0.53), yielding an hourly rate of $11.18 per hour at 18 minutes' duration (SD = 3.83). Of 1089 participants, 66% (720) passed all of the up-front comprehension check questions. Time on the decision-making page for players 1 and 2 was variable due to a programming error. Amazon Mechanical Turk was selected because it is a reasonable approximation of a representative sample of American adults for our purposes. To estimate the sample size required, we performed a power analysis via simulation using pilot data.

Materials and procedure. Study 2 is a one-shot sequential public goods game identical to Study 1, with the exception that there are five players rather than three, that the up-front chat was 90 instead of 30 seconds, and that participants complete the SVO slider battery before the PGG.

Study 3

Participants. 86 U.S.-based participants from Amazon Mechanical Turk completed the study via Cloud Research. Median total pay per subject (including bonuses for accurate predictions) is $3.99 (*SD* = 1.25), yielding an hourly rate of $15.99 per hour at 15.2 minutes duration (SD = 4.39). Of the 86 participants who completed the task, 82 (95.0%) passed all of the up-front comprehension check questions. To estimate the sample size required, we performed a power analysis via simulation using pilot data.

Materials and procedure. Study 3 adds some features to the basic design from Study 2. In Study 3, SVO is not measured. Instead, players are randomized to a "Selfish" and a "Non-Selfish" condition. In the Selfish condition, players see a prompt:

> *Please try to play this game however you think will make you the most money. We understand that sometimes you want to help other people, but for the purposes of this experiment we want you to try to make as much money as possible.*

Players are also randomized to a delayed simultaneous condition in addition to the simultaneous condition from previous studies, to control for effects that arrive merely from waiting. Subjects randomized to the delayed simultaneous condition wait for 80s on the standard wait page for the task (which contains a simple game they may play if they wish). In addition, players in Study 3 move in lock-step throughout the task. Instead of being able to advance on certain pages when they feel they are ready, participants have and that players move in lock-step with a certain

number of second allotted for each page (so players cannot infer anything from how quickly those previous to them have moved).

Study 4

Participants. 539 U.S.-based participants from Amazon Mechanical Turk via Cloud Research completed the study. Median total pay per subject (including bonuses for accurate predictions) is $4.24 (*SD* = 1.19), yielding an hourly rate of $16.13 per hour at 16.0 minutes duration (SD = 3.97). Of 539 participants, 440 (82%) passed all of the up-front comprehension check questions. To estimate the sample size required, we performed a power analysis via simulation using pilot data.

Materials and procedure. Study 4 is a one-shot sequential public goods game identical to Study 3, with the exception that players are randomized between two conditions, fully crossed with orders 1-5: players are told that everyone before them in the sequence has their decision about how much to contribute to the public good made by a random process ("Random Before"), players are told that everyone after them has their decision made by a random process ("Random After"). In addition, as in Study 3, there are two simultaneous control conditions: one with a delay, and one without.

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