Between-group competition enhances cooperation in resource appropriation games

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Abstract

Cooperation in public goods games increases in the presence of between-group competition. In this study, we validate the effect of between-group competition in a different social dilemma, a resource appropriation game. Unlike the voluntary contributions setting, group performance in this game increases with the exercise of a passive choice: not appropriating units in an open-access resource. We conducted an incentivized experiment using 276 undergraduate students in which groups of four subjects played a resource appropriation game. Different groups within a session were ranked in each round according to the group's aggregate payoff. This ranking determined a group performance multiplier, which increased the payoffs in groups ranked above the median and decreased the payoffs in groups below the median. The multipliers were small enough to keep the individual benefits from appropriation larger than the individual benefits from a higher payoff multiplier (derived from an improvement in group ranking by not appropriating the resource unit). We found that implementing this small group performance multiplier decreased the average appropriation by 31%. This efficiency-enhancing device generated a 19-percentage-point increase in overall earnings in a given session.

Keywords: experiments, social comparison, commons dilemmas

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1. Introduction

Between-group competition (BGC) for scarce but shared resources is a two-level problem. At the outer level, the more successful groups obtain, at least probabilistically, larger rewards. At the within-group level, group members need to sacrifice part of their individual rewards to contribute to group success (Sloan Wilson & Wilson, 2007). BGC increases inefficient expenditure in contest games (Abbink et al., 2012; Leibbrandt & Saaksvuori, 2012), but it also increases the likelihood of socially desirable outcomes in within-group coordination (Bornstein et al., 2002; Brandts & Cooper, 2006; Hamman et al., 2007) and cooperation games (Gunnthorsdottir & Rapoport, 2006; Tan & Bolle, 2007; Puurtinen & Mappes, 2009; Burton-Chellew et al., 2010; Reuben & Tyran, 2010; Cárdenas & Mantilla, 2015). The existing experimental evidence shows that BGC increases cooperation in the context of voluntary contributions to public goods (PGs) games, but how BGC inhibits the destruction of a shared resource in an appropriation dilemma remains an open question. This study employs an appropriation game to test whether between-group asymmetries decrease the notion of conflict within the group, increasing cooperation; or, on the contrary, between-group asymmetries have similar negative effects on cooperation to those found in appropriation games with within-group asymmetries (Cox et al., 2013).

In the management of common resources, competition between harvesters is often associated to inefficient outcomes and behaviors. Market competition leads to unsustainable harvest levels (BenDor et al., 2009), to a magnification of the scarcity problem (Gatiso et al., 2015), and to the withholding of information relevant for harvesting decisions (Barnes et al., 2017). We argue that, by studying the management of shared resources as a two-level problem rather than as a single-level problem, competition between "harvesting units" might benefit from the effects of social comparison to yield efficiency-enhancing outcomes. Consider for instance the problem of fisheries. Competition at a higher organizational level, for instance between TURFs or fishermen associations, may induce more cooperative behaviors within the fishermen belonging to each organizational unit.

We call our game an appropriation dilemma, instead of a common-pool resource dilemma, because we focus on the non-excludability of the shared resource. That is, we abstain from exploring the rivalry of the resource, introduced in experimental social dilemmas, by opting for a proportional rather than an egalitarian distribution of the collective rewards (Apesteguia & Maier-Rigaud, 2006). In the study of BGC, the non-excludability property is interesting in itself because it allows us to scale up the notion of asymmetry within groups to the inter-group level. We introduce this dimension by including a multiplier that rewards the best-performing groups and punishes the underperformers without altering the incentives for appropriation of the resource. That is, in our design, the material payoff maximizing Nash equilibrium still predicts full resource appropriation. Based on the above-mentioned literature on group competition, one could expect to reverse the negative effect of asymmetry and promote between-group social comparisons as a means of fostering cooperation and inhibiting the destruction of environmental public goods.

PGs and appropriation dilemmas are not dual problems. They both are social dilemmas, but the incentives associated with provision or appropriation are structurally different (Sandler et al., 2003). Although BCG improves cooperation in provision problems, the study of how competition between groups may induce within group reductions in overexploitation of shared resources has not been explored experimentally.

In the appropriation dilemma, each unit that is taken provides a private benefit at the cost of eliminating the positive externality (e.g., ecosystem services) to the entire group. The social dilemma arises because each resource unit is more valuable to all group members if it remains unappropriated compared with its private value in the case of being appropriated. However, it is difficult to prevent others from extracting resource units beyond socially desirable levels. By contrast, in conventional contribution PG games, the endowment is allocated individually, and the social dilemma lies in the provision, rather than the destruction, of the non-excludable and socially beneficial collective good.

Most of the experimental social dilemmas comparing PG and appropriation games focus on the consequences of the "give-some" versus the "take-some" framing effects (Fleishman, 1988; Andreoni, 1995; van Dijk & Wilke, 1995; Sell & Son, 1997; Khadjavi & Lange, 2015; Gächter et al., 2017). Different mechanisms, supported by experimental data, predict that one should expect higher rates of cooperation with one of these framing effects. On the one hand, two mechanisms support the idea that the "give-some" framing effect should yield higher levels of cooperation than the "take-some" framing effect. First, that the non-pecuniary benefits from contributing to a positive externality (i.e., providing a public good) exceed, in absolute value, the non-pecuniary costs of contributing to a negative externality (i.e., destroying units of the public good) (Andreoni, 1995). Second, that positive reciprocity is more prevalent in the provision of a public good compared to the maintenance or non-appropriation of a public good (Gächter et al., 2017). On the other hand, the "take-some" framing effect should yield higher levels of cooperation than the "give-some" framing effect if exists a bias towards preserving the endowed good (Kahneman & Tversky, 1979; Sell & Son, 1997).

The positive effect of BGC on the provision of a public good in the standard dilemma does not guarantee that BGC decreases the destruction of the shared resource in the appropriation dilemma. More competition in the PG game fosters larger contributions. By contrast, it is not clear whether competition in an appropriation dilemma inhibits the destruction of the shared resource, mostly because the competitive response is to resist appropriation, a passive choice that may be incongruent with competitiveness.

A given round of the appropriation dilemma occurs as follows. Each group of four subjects is endowed with 20 units of an open-access resource. Every group member is allowed to appropriate at most five units of the shared resource. Each appropriated unit yields a payoff of 1, solely to the appropriator. Each non-harvested unit yields a payoff of 1.4 that is divided equally among the group members, i.e. each subject receives a payoff of 0.35. These rewards capture the characteristic tension between individual and collective interests in a social dilemma. By creating competition among groups with additional incentives, we aim to decrease this tension.

In the experiment, each session involves sets of three or five groups of four people each, (*3G competition* or *5G competition*, respectively). Subjects interact for 20 rounds, divided into three blocks. Block 1 (rounds 1–5) serves as a baseline without pecuniary incentives for competition. In Block 2 (rounds 6–15), BGC is triggered by introducing a group performance multiplier (GPM) affecting payoffs depending on the ranking of each group. The GPM increases with a group's ranking, which is computed based on the round's aggregate payoffs. This means that more unharvested units will lift the group's ranking. However, the largest GPM is sufficiently low to keep each non-harvested unit less profitable than if the unit were harvested. In Block 3 (rounds 16–20), we study whether partial effects of BGC remain after the GPM is removed. Subjects receive feedback at the end of every round. The information they receive comprises their payoff and their individual and group rankings. Since social comparison *per se* increases within-group cooperation (Burton-Chellew & West, 2012), the provision of such information across treatments allows us to interpret the differences in Block 2 as the effect of the pecuniary incentives for BGC. For a control sample, we apply the same conditions in Block 2 as in Block 1.

We found that introducing the GPM decreased the average appropriation by 31%. This effect translated into a 19-percentage point increase in efficiency, measured as overall earnings in a given session. An exploration of individual behavior revealed that subjects react to their individual and group ranking, and such reaction is larger with the GPM. Below-average individual performance decreased cooperation (i.e., individuals increase appropriation). By contrast, below-average group performance led to more cooperative responses (i.e., individuals reduce appropriation).

2. Experimental paradigm

2.1. The game theoretical setting

We present here the simplified model extending the standard appropriation dilemma to our multi-group approach. See the Supplementary Material for a full description of the theoretical analysis and the characterization of equilibria.

There are 1, 3 or 5 groups of $n = 4$ players. Within the group, the 4 players share a resource with stock size $s = 20$. Subjects decide how many units from the shared resource they want to appropriate, $x_i \in A = \{0, 1, 2, 3, 4, 5\}$. Each player's payoff depends on how many units he or she appropriates and how many units remain unharvested:

$$\pi_i(x_i, x_{-i}) = x_i + 0.35 \left[20 - \left(x_i + \sum_{j \neq i} x_j \right) \right]. \tag{1}$$

With this condition the individual returns from appropriating a unit are larger than the social returns from keeping it unharvested. Since the benefits from appropriating an additional unit are constant, the self-interested choice ($x_i = 5$), i.e. the Nash equilibrium, and the per capita socially efficient appropriation ($x_i = 0$) level lie at the extremes of the action set.

We introduce material incentives for between-group competition throughout a multiplier (μ_g). This multiplier transforms the payoff function in the following manner:

$$\overline{\pi}_i(x_i, x_{-i}) = \mu_g \times \pi_i(x_i, x_{-i}). \tag{2}$$

This multiplier increases the payoff for subjects in groups ranked above the median and decreases the payoff for subjects in groups below the median. For three groups the multiplier takes the values: $1.1, 1.0, 0.9$ correspondingly from the highest earning to the lowest earning group. For five groups the multiplier takes the values: $1.10, 1.05, 1.0, 0.95, 0.90$ correspondingly from the highest earning to the lowest earning group. The tie-breaking rule involves averaging μ_g among the groups involved in the tie. With the inclusion of this multiplier, the game has the following properties: the self-interested optimal choice is $x_i = 5$, the per capita socially efficient appropriation level is $x_i = 0$ and there are no evident asymmetric equilibria.

2.2. Experimental design

The experiment was programmed using oTree (Chen et al., 2016). The code is available in the Supporting Online Material. Subjects played a linear appropriation dilemma for twenty rounds divided in three blocks. In Block 1 (rounds 1–5), BGC was not incentivized. Data from Block 1 served as a between-subjects balancing condition (i.e., to show that there were no differences before introducing the GPM). In Block 2 (rounds 6–15), GPMs were introduced to the *3G competition* and *5G competition* treatments. The *No competition* treatment, without the GPMs, was the baseline condition for comparisons. In Block 3 (rounds 16–20), the GPMs were withdrawn from the *3G competition* and *5G competition* treatments. Data from Block 3 allowed us to test whether the effect of BGC remained, at least partially, after the additional material incentives for BGC were removed. Participants were informed, prior to the beginning of Block 1, that five out of the twenty rounds will be randomly selected for payment, and that these rounds could be selected from different Blocks. Our initial interest to test different numbers of groups competing was initiated by the lack of experimental literature on this regard. However, we found no differences but decided to maintain for full disclosure the results and comparisons of the two settings.

In every block, the feedback received at the end of each round comprised the subject's appropriation level, the unharvested stock, the individual and group rankings in terms of the round's earnings and the individual earnings before and after the GPM was applied (post-multiplier earnings refer only to Block 2 in the *3G competition* and *5G competition* treatments).

Subjects were randomly assigned to groups of four. The group composition remained fixed throughout each block, but participants were rematched between blocks. The identity of the other group members remained unknown. Sessions in the *3G competition* and *No competition* treatments consisted of 12 participants. For the *5G competition* treatment, each session consisted of 20 participants.

Upon arrival at the laboratory, the participants were given a general overview of the game, informed about the money they could earn by participating (between \$5 USD and \$12 USD; the minimum hourly wage in Colombia is \$1.2 USD), and how much time it would take (about 90 minutes, including the time spent on processing their payment). The rules for Block 1 were provided, along with some verification questions to check that the appropriation dilemma was understood. Subjects from all treatments were also told that the rules of the game might change in the subsequent blocks. Before the start of Block 2, the new rules concerning the GPM were explained to participants, who needed to respond to some additional verification questions. The subjects in the *No competition* treatment were informed that there was no change in the rules. Before Block 3, subjects in the *3G competition* and *5G competition* treatments were informed that the GPM was withdrawn, and were then provided with the same instructions as those used in Block 1. In the *No competition* treatment, subjects were again informed that the rules had not changed. At the end of the game, participants completed a brief anonymous survey.

In the Supplementary Material, readers can find a full formal description of the game, the links to access the oTree code used to program the experiment, the data, the Stata code to produce the results here presented and the screen-shoots of the information presented to the participants during the game.

2.3. Participants

We conducted the experiment at Universidad de los Andes (Bogotá, Colombia) between June and August 2016. A total of 276 undergraduate students, 140 men and 136 women, participated in one of the 19 experimental sessions. Participants were, on average, 20.3 ± 2.3 years old and were all over the age of 18. Recruitment was undertaken using an invitation from Universidad de los Andes posted on social media. The invitation included a list of available dates on which participants could take part and the range of potential earnings.

We did not collect any personal information that could be used to link the participants' identity to their choices or responses during the experiment. All participants gave their written informed consent prior to commencing the experiment and were aware of the rules governing their potential earnings. No participants experienced negative earnings. Participants were unaware of the identity of the others in their group. These conditions conform to the ethical guidelines for conducting economic experiments with human subjects. These experimental features, combined with our prior assessment that the intervention would not produce any changes in physiological, biological or psychological subject variables, allow us to classify this study as non-risk research.

3. Results

3.1. Aggregate outcomes

Figure 1 and Table 1 reveal that the introduction of the GPM in Block 2 decreases the appropriation level by about 0.9 units (31%) with respect to the control condition in Block 2 (no GPM). The bottom part of Table 1 reveals that this reduction in appropriation translate into a payoff increase of 1.9 experimental monetary units (EMUs).

This payoff increase is equivalent to an efficiency gain of 19 percentage points. We define efficiency in terms of how many of the 10 additional EMUs, per block of five rounds, were reached on average by each subject. Note that, in a given round, if all 20 units of the resource remain unharvested, the payoff to each group member is $0.35 \times 20 = 7$ EMUs. This payoff is 2 EMUs greater than the payoff for each group member if each one of them harvests (the maximum of) 5 units, yielding $1 \times 5 = 5$ EMUs. Hence, the increase of each player's average payoff of 1.9 EMUs in five rounds is comparable to an increase in efficiency from $(27.4 - 25)/10 \times 100\% = 24\%$ to $(29.3 - 25)/10 \times 100\% = 43\%$, or 19 percentage points.

Table 1 reports pairwise comparisons between treatments within each block using a Mann-Whitney (MW) U test. The unit of observation within each block is defined at the session level [N=19].

In Block 1, which serves as a baseline before the GPM were introduced, we do not observe any systematic differences between treatments if terms of either resource appropriation nor payoffs. This result, in combination with the reshuffling of groups within a session between Blocks, provides a safe baseline start for each block that eliminates any learning of partners' behavior, and reassures our interpretation of the GPM effects described earlier in this Section. Table 2, reported in the next subsection, yields the same results when using a Difference-in-Difference approach.

Our interest in Block 3 dwells in the understanding whether the GPMs would, at least partially, maintain their effect after being removed. Although the rightmost panel in Figure 1 suggest that part of the appropriation differences with respect to the control condition (No competition) remains (about 0.3 units lower), this effect is statistically insignificant.

Despite our findings that small pecuniary incentives for group competition shifted appropriation downwards, we did not find statistically significant differences among the environment in which only 3 groups of 4 subjects each are competing, with respect to an environment in which 5 groups of the same size faced this competition.

We further explore whether the GPM affected the progressive decay in cooperation rates (i.e., an increase in appropriation rates), typically observed in linear social dilemmas (Andreoni, 1988; Ledyard, 1995; Chaudhuri, 2011). Figure 2 compares the average appropriation level per round throughout the game across treatments. The left panel shows the observed behavior aggregated at the treatment $\times$ round level. In both treatments, and in the control condition, is observed the progressive increase of

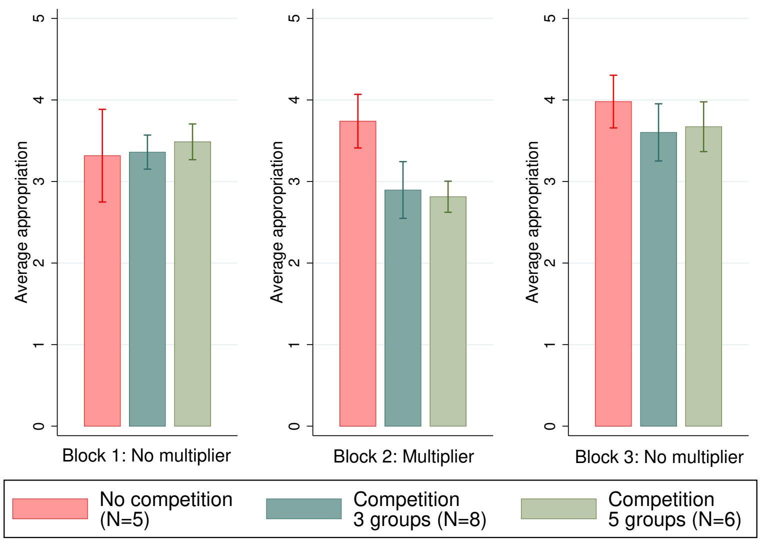

Figure 1: Average appropriation across rounds per block: comparison between treatments. The unit of observation within each block is defined at the session level [N=19]. The number of observations (sessions) per treatment is shown in the legend. Five rounds per block were considered for the averages. This included all rounds from Block 1 and Block 3, and the first half of Block 2 (rounds 6 to 10 were dropped for comparability purposes).

Table 1: **Comparison of appropriation and payoffs per block and between treatments.** Average appropriation/payoffs ± SD are reported at the session level (N=19 within each block) over rounds 1-5 per block (rounds 6-10 in Block 2 are dropped for comparison purposes). The reported p-values in parenthesis correspond to Mann-Whitney U tests between treatments for each block. Within each block, the top-left p-value corresponds to the comparison between 3 Groups Competition and No Competition (Control); the top-right p-value corresponds to the comparison between 5 Groups Competition and No Competition (Control); the bottom p-value corresponds to the comparison between 3 Groups Competition and 5 Groups Competition.

	Block 1			**Block 2: GPM**			**Block 3**		
	3 Groups	5 Groups	Control	3 Groups	5 Groups	Control	3 Groups	5 Groups	Control
Appropriation	3.36±0.25	3.49±0.21	3.32±0.46	2.90±0.42	2.81±0.18	3.74±0.27	3.60±0.42	3.67±0.29	3.98±0.26
Test wrt Control (p)	(0.659)	(0.234)		(0.005***)	(0.006***)		(0.105)	(0.100)	
Test wrt 5 Groups (p)	(0.175)			(0.439)			(0.698)		
Payoffs (5 rounds)	28.2±0.5	27.9±0.4	28.2±0.9	29.2±0.9	29.4±0.4	27.4±0.5	27.7±0.8	27.5±0.6	26.9±0.5
Test wrt Control (p)	(0.826)	(0.361)		(0.003***)	(0.006***)		(0.105)	(0.143)	
Test wrt 5 Groups (p)	(0.197)			(0.606)			(0.698)		

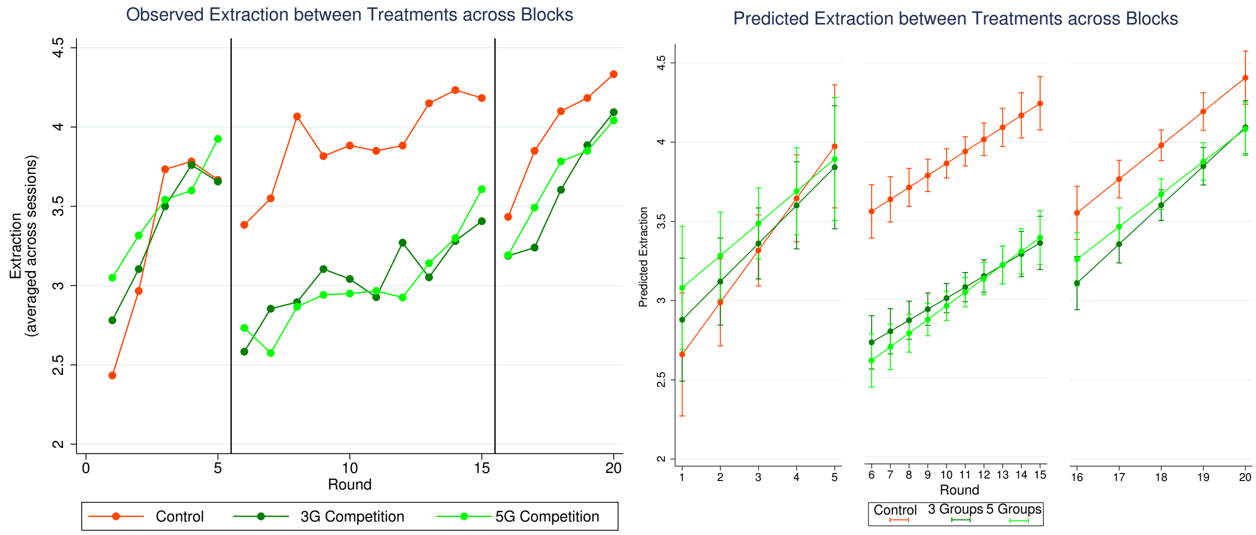

Figure 2: **Dynamics of appropriation.** Left panel: Observed appropriation (averaged across sessions) per round of the game in each treatment. Right panel: predicted appropriation (averaged across sessions) per round of the game in each treatment using a linear regression with the treatment×round as unit of observation (coefficients reported in Table S1 in the Supplementary Material). Colored lines correspond to the treatments 3 Groups Competing (dark green), 5 Groups Competing (light green), and No competition (orange).

appropriation rates within each one of the three blocks. Besides, between blocks, is observed the restart effect that has previously been found in PG experiments (Andreoni, 1988).

The right panel shows the predicted behavior using a regression in which the unit of observation is the treatment × round (see regression coefficients in Table S1 in the Supplementary Material). The appropriation differences in favor of the GPMs in Block 2, from round 6 to 15, are evident in this prediction. On the other hand, predictions in Block 1 show that there are no evident differences between treatments prior to the introduction of the GPMs. In Block 3, once the GPMs are removed, the treatment effect from the GPMs observed in Block 2 is diminished and is only marginally significant. Regression coefficients reported in Table S1 also show that the slope, indicating the increase in appropriation, does not differ across treatments in either of the experimental blocks.

3.2. Individual behavior

In this subsection we validate, using an econometric analysis of individual decisions, the effect of the GPMs. Although groups were rematched between blocks, and five out of the twenty rounds were randomly selected for payment, it might be possible that some subjects' past experience affect their behavior in upcoming blocks. Therefore, we run a mixed model with dummies for each block, for each treatment, and their interactions. This specification is analogous to a difference-in-difference approach. Interactions between Block 2 and each treatment dummy are indeed the effects of between-group competition via the

GPMs. Similarly, the interactions between Block 3 and each treatment dummy will respond whether the efficiency-enhancing effect of the GPMs remained after their removal. We use a mixed model to account for individual differences and group patterns within a block. Hence, the model includes varying intercepts at the participant level and at the group×block level. The same exercise is repeated with a Tobit model to capture the censoring in the appropriation decision.

Furthermore, we explore how feedback on relative performance affect subsequent appropriation decisions. We introduce to the specification described above the lagged individual and group rankings provided to each subject at the end of the rounds. Since the number of subjects and groups differ between experimental conditions, we rescale individual and group rankings to match the *5G competition* condition. That is, individual and group rankings in the *3G competition* and *No competition* conditions were multiplied by 5/3. Therefore, individual rankings range from 1 (top) to 20 (bottom) and group rankings range from 1 (top) to 5 (bottom). Similar results are obtained by comparing the *3G competition* only with the *No competition* condition, treatments that do not need rescaling because both have 12 subjects and 3 groups per session (see Table S2 in the Supplementary Material).

Table 2 shows the coefficients for the mixed model (column 1) and the Tobit model (column 3). Interactions between Block 2 and the *3 Groups Competing* and *5 Groups Competing* treatment dummies validate the effect of the GPMs in appropriation described in Section 3.1. The coefficient for *Block 2 × No Competition* captures the progressive decay of cooperation. Note also that coefficients in column 3 are larger than in column 1, suggesting that the degree of censoring for subjects appropriating either the minimum or the maximum allowed is not negligible.[2]

In Block 1, as one would expect, the treatment effects are not significant since the GPMs have not been introduced yet. Similarly, the mixed model regression shows that the appropriation reduction in treatments *3 Groups Competition* and *5 Groups Competition* is not statistically significant after the removal of the GPMs in Block 3. However, the Tobit model suggests that roughly half of the effect found in Block 2 persists under *5 Groups Competition* in Block 3.

We now focus on columns 2 and 4 to explore the effects of feedback on past group and individual ranking. In Block 2, lowering positions in the group ranking increases subsequent appropriation, whereas lowering positions in the individual ranking decreases subsequent appropriation. Since the dependent variable is measured in levels and not changes, the coefficients for past performance reveal persistent behavior, i.e., low-ranked subjects maintain lower appropriation levels (and hence contribute to hold their group ranking in high positions).

In Blocks 1 and 3, the results obtained with the mixed (uncensored) and the Tobit (censored) model

[2]In fact, 8% of the appropriation choices correspond to the lower bound ($x = 0$), and 33% correspond to the upper bound ($x = 5$).

Table 2: **Econometric analysis of extraction decisions including the role of feedback on relative position.** The mixed model includes random coefficients at the player level and at the group×block level. Standard errors are clustered at the group×block level in the Tobit model. Models (1) and (3) include only the dummies for blocks and treatments, and treatment effects are obtained from the interactions between them.

Dependent variable:	Mixed model				Tobit			
Appropriation	(1)		(2)		(3)		(4)	
Block 1: Baseline								
Block 1 x 3 Groups Competing	0.044	(0.216)	-0.024	(0.217)	0.035	(0.258)	-0.136	(0.253)
Block 1 x 5 Groups Competing	0.170	(0.207)	0.0620	(0.208)	0.298	(0.252)	0.063	(0.255)
Block 1 x Individual rank (lag)			-0.009	(0.007)			-0.091***	(0.021)
Block 1 x Group rank (lag)			-0.018	(0.031)			0.254***	(0.068)
Block 2: Group Performance Multipliers								
Block 2 x 3 Groups Competing	-0.902***	(0.298)	-0.827***	(0.296)	-1.518***	(0.442)	-1.332***	(0.364)
Block 2 x 5 Groups Competing	-1.069***	(0.287)	-0.956***	(0.285)	-1.790***	(0.428)	-1.544***	(0.358)
Block 2 x No Competition	0.583**	(0.234)	0.180	(0.259)	0.994***	(0.340)	0.062	(0.401)
Block 2 x Individual rank (lag)			-0.022***	(0.005)			-0.126***	(0.017)
Block 2 x Group rank (lag)			0.088***	(0.020)			0.563***	(0.064)
Block 3: Removed Multipliers								
Block 3 x 3 Groups Competing	-0.422	(0.305)	-0.352	(0.303)	-0.787	(0.483)	-0.668	(0.408)
Block 3 x 5 Groups Competing	-0.478	(0.293)	-0.372	(0.291)	-0.916**	(0.433)	-0.784**	(0.369)
Block 3 x No Competition	0.663***	(0.239)	0.401	(0.270)	1.264***	(0.327)	0.631	(0.436)
Block 3 x Individual rank (lag)			-0.023***	(0.007)			-0.131***	(0.020)
Block 3 x Group rank (lag)			0.043	(0.028)			0.506***	(0.090)
Constant	3.317***	(0.168)	3.679***	(0.196)	3.741***	(0.191)	4.299***	(0.292)
sd (Group × block level)	0.180***	(0.043)	0.199***	(0.043)	2.478***	(0.0701)	2.316***	(0.064)
sd (Player level)	0.669***	(0.093)	0.561***	(0.053)				
Observations	5,520		5,244		5,520		5,244	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

are quite different. In the mixed model the effects of rankings in absence of the GPMs are small and in most of the cases statistically non-significant. By contrast, in the Tobit model the coefficient for lagged individual ranking is negative and significant, and the coefficient for lagged group ranking is positive and significant, in Blocks 1 and 3.

The significance of individual and group ranking in Block 1 suggests that relative comparisons affect decisions even in absence of additional pecuniary incentives (Tan & Bolle, 2007; Puurtinen & Mappes, 2009). The role of the GPMs is to increase the magnitude of the response to relative performance.

What we cannot disentangle from Table 2 is the differential effect of lagged individual and group rankings in each treatment. In order to capture these differences we would need a third-degree interaction, between block, treatment and the respective ranking. Moreover, to get rid of the persistent behavior and the censoring problem we will substitute the dependent variable from levels to differences. The ΔAppropriation variable corresponds to the change in individual appropriation between two consecutive rounds.

Since the model with triple interactions is not straightforward to interpret we opted for computing the marginal effects of individual and group rankings for ΔAppropriation (the full list of coefficients is reported in Table S3). Figure 3.2 reports the predicted marginal effects of individual (bottom panels) and group (top panels) ranking. In each panel are reported the marginal effects in a given block for all the three treatments.

It can be easily noticed that, within each block, the effect of the lagged individual ranking does not differ between treatments. Subjects being low-ranked tend to increase their appropriation with respect to the previous round. The effect of lagged group ranking is also very similar between treatments within blocks: subjects in low-ranked groups tend to decrease their appropriation with respect to the previous round. The main difference is that in Block 2, in presence of the GPMs, subjects in grups ranked below the median decrease their appropriation more than in the control condition (no GPMs, same block).

What remains unexplained is why the group ranking does not have an effect among subjects in high-ranked groups in the presence of the GPMs. The reason is that a considerable proportion of subjects in top ranked groups were already not appropriating the resource, or appropriating a very small value. Figure 4 reports the fractions of subjects that were a) increasing, b) not changing, and c) decreasing their appropriation, as a function of the group ranking and the treatment (*3 Groups Competition* versus *No competition*, since only in these treatments the number of groups is equal). We observe that 58% and 25% of decisions showed either no change or a decrease in appropriation, respectively, in the *3 Groups Competition* treatment compared with 43% and 33%, respectively, in the *No competition* treatment. This suggests that, with the GPMs, the majority of subjects from top-performing groups reach and maintain the socially desirable per capita appropriation level, even if the multiplier is not large enough to sustain this outcome as an equilibrium involving self-interested players.

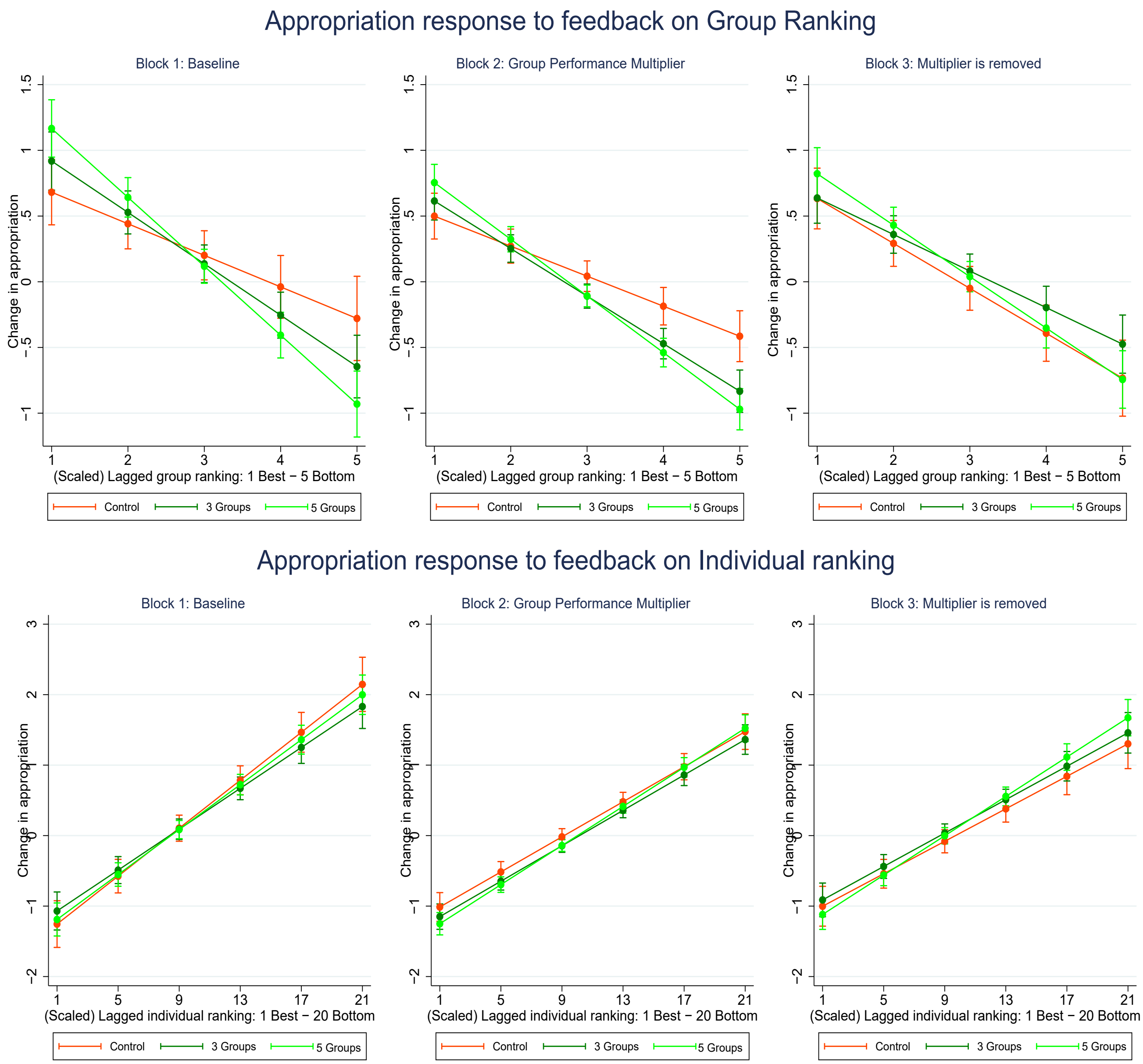

Figure 3: **Marginal effects predicting appropriation responses to lagged group ranking (top panels) and lagged individual ranking (bottom panels).** Coefficients from mixed model reported in Table S3 (see Supplementary Material). Colored lines correspond to the treatments 3 Groups Competing (dark green), 5 Groups Competing (light green), and No competition (orange).

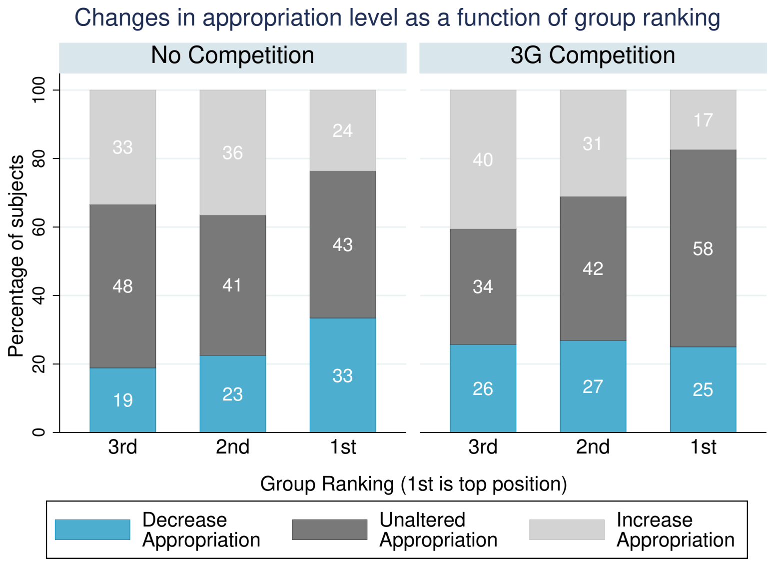

Figure 4: Appropriation responses to group ranking throughout Block 2 (with GPM). Appropriation responses are coded as a decrease ($x_t < x_{t-1}$, bright blue), unaltered ($x_t = x_{t-1}$, dark grey) and an increase ($x_t > x_{t-1}$, light grey).

4. Discussion

Our experimental design introduces a cooperation game in which individual actions mimic the problem of extracting a shared resource, while maintaining the properties of typical social dilemmas. Our appropriation game relates to other classical 2x2 games in some particular ways. With respect to the Prisoners Dilemma, it shares that all players, if seeking to maximize their own material payoffs and assume that other players behave likewise, should extract as much possible from the shared resource. In both cases the Nash equilibrium is a sub-optimal one, and Pareto inefficient. In our experimental environment we explore the case of appropriation which is less frequent in the literature, and even more so for the case of testing the potential of group competition as a way for enhancing cooperation.

We found that the introduction of the GPM decreases resource appropriation by an average of 31%, even though the rewarding multipliers are low enough not to distort the incentives in the within-group social dilemma. Previous studies rewarding BGC without altering the equilibrium predictions in a PG game have shown similar effects (Tan & Bolle, 2007; Puurtinen & Mappes, 2009). We have created an incentive setting that brings a dynamic asymmetry in which any group can move up or down the rankings and alter its payoff based on its own performance. Building on the work of Cox *et al.* (2013), we extend this problem of destruction *versus* provision of the public good to a multiple-group environment in which asymmetries become efficiency-enhancing. In the same manner in which Reuben and Tyran (Reuben & Tyran, 2010) show how BGC increases the provision of public goods through the payoff multipliers at the group level, we show a similar effect from BGC in the case of appropriation games.

We did not find a significant difference across treatments (at the 5% level) once the GPM was withdrawn. Since other-regarding preferences could transform a social dilemma into a coordination game (Rabin, 1993; Fehr & Schmidt, 1999), and BGC has been shown to improve outcomes in coordination games (Bornstein et al., 2002; Brandts & Cooper, 2006; Hamman et al., 2007), we hypothesized that a partial effect of the GPM could remain after these monetary incentives were withdrawn. Although we did not find definitive statistical support in the experimental data, the observed pattern supports the coordination hypothesis, and thus further research to pinpoint this effect in social dilemmas is recommended.

Similarly, we did not find any significant effect based on the number of groups in the competition. The effects of the GPM in the *3G competition* and *5G competition* treatments were indistinguishable. Subjects responded to relative rankings (i.e., being "last"), regardless of the treatment. We offer two conjectures for this lack of effect. First, the non-excludability of the common good was defined within the group, but the appropriation of the good was perfectly excludable between groups. Second, the largest reward for the best group, and the largest penalty for the worst-ranked group, both embedded in the GPM, were the same regardless of the number of groups in the competition. A third potential explanation for the null effect of the number of groups in the competition is that the payment thresholds faced by the groups drive the effect of competition (Jordan et al., 2017). We argue that, given that our design does not alter the Nash equilibrium of maximum appropriation when competition is involved, this is a less plausible explanation in our experimental setting.

4.1. An evolutionary interpretation of between-group competition in resource appropriation

The evolutionary approach can be particularly useful to assess policy measures affecting motivations or preferences from individuals in an environmental context (Safarzyńska, 2013). According to the evolutionary perspective subjects might adjust their behavior over time in response to their own (and others') success. As a consequence, one would expect that strategies with higher payoffs would increase in frequency over time (Crawford, 1991; Weibull, 1997). In a cooperation dilemma, such as the appropriation game employed in this study, defection (i.e., maximum appropriation) yields a higher payoff and therefore makes cooperation (i.e., minimum appropriation) implausible to evolve. However, defection can be unstable under certain combinations between number of actions and the distribution of played strategies (Sethi, 2000; Tanimoto & Sagara, 2007), or when additional mechanisms such as reciprocity (either direct, indirect or in networks), kin selection or group selection (Nowak, 2006) are at play. The latter mechanism, group selection, is the focus of this Section.

Group selection accounts for the advantages that groups of cooperators will have over groups of defectors. These advantages arise naturally as long as the number of groups (m) is large and the number of subjects per group (n) is small, allowing for a positive sorting within the population (Traulsen &

Nowak, 2006). The specific condition,[3] with respect to the benefit-cost ratio of cooperation is given by (for small m):

$$\frac{b}{c} > 1 + \frac{n}{m-2}$$

For our game parameterization, the benefit b to each group member is 0.35, and the cost is the difference between the payoff for not cooperating minus the benefit to himself if cooperates, divided by the number of other group members. Hence $c =$ (1-0.35)/3=0.217, and $b/c = 1.615$. The latter value is lower than $1 + n/m$ in our two treatment configurations (equal to 5.0 when $n/(m-2) = 4/1$, and equal to 2.3 when $n/(m-2) = 4/3$).[4] Therefore, our results are not purely driven by a population structure favoring small groups that, by chance, benefit from the positive assortment of cooperators.

Having said this, we conjecture that group selection plays a role in explaining our findings, but from a longer-term perspective. Following Burton-Chellew & West (2012), we argue that social-comparison, even with null or small pecuniary incentives, is a powerful driver of cooperativeness toward the in-group. This concern for social-comparison might be the result of a long-term group selection process that "wired" us to react to competition. This is an explanation for the responses to individual and group rankings found in this study, and similar to those previously reported in a PG contributions game (Cárdenas & Mantilla, 2015). A low individual ranking triggers an increase in resource appropriation, an expected imitation response to the fact that other group members are extracting more, and hence profiting more, than the oneself. By contrast, a low group ranking triggers a reduction in resource appropriation, i.e., a more cooperative and efficiency-enhancing response suggesting that poor collective performance leads to group-minded decisions with small pecuniary incentives for competition.

Institutional differences might yield the same group-selection through different mechanisms including norm following, conformism and prestige-based transmission (Richerson & Boyd, 2005; Van den Bergh & Gowdy, 2009). Think for instance on arrangements that are individually costly but beneficial to the group such as food sharing among non-kin (Bowles, 2006) and costly peer sanctioning (Fehr & Gächter, 2002). The latter, when studied in the context of common resource management, have shown to provide advantage to groups with large proportions of cooperators and punishers, able to deter entry from defectors (Noailly et al., 2009; Sethi & Somanathan, 1996). In fact, evidence from an experimental social dilemma shows that subjects, when are allowed to migrate from a sanction-free to a sanctioning environment, opt for the group with sanctioning rules and increase their cooperativeness (Gürerk et al., 2006).

[3] We derive another condition for group-selection based on our specific multipliers, yielding the same results. See Section S4 in the Supplementary Material.

[4] This might be an additional reason for the lack of a difference based on the number of groups in competition.

The GPMs in our experimental setting mimic, explicitly, the advantages that groups of cooperators will have over groups of defectors. Payoff increasing multipliers for "winner" groups, combined with payoff decreasing multipliers for "loser" groups, represent a mild version of intergroup conflict (i.e., losers are not eliminated but rather taxed). To understand how gains from winning the conflict affect resource management it is necessary to know whether groups in conflict exploited a shared global common resource, or each group separately exploited a local common resource. Our experimental setting is based on the latter scenario, but the following discussion might motivate future experimental work in this direction.

In the case of a global common resource, winners can impose exploitation restrictions to losers that will increase overall efficiency (i.e., cooperators imposing cooperation). In the case of local common resources spatially disconnected, winners do not benefit directly from imposing exploitation restrictions to losers. In this scenario, the notion of power, which explains the adoption of sanctioning institutions in a group-selection approach (Safarzyńska & van den Bergh, 2010), can be extended to devise a system of cross-subsidies rewarding the winning (more cooperative) group like the one proposed in our experiment.

4.2. Policy relevance of between-group competition facing resource management

A policy challenge to introduce incentives for BGC to the management of common resources is the definition of the in-group/out-group notion. In other between-group conflicts involving a within-group social dilemma such as warfare (Bowles, 2006; Choi & Bowles, 2007), resource allocation within a firm (Marino & Zabojnik, 2004; Friebel & Raith, 2010) and team sporting competitions (Turchin, 2015), this notion is well established. For common-access resources, the in-group/out-group definition is more convoluted. In fact, the first of Ostrom's eight principles for managing a commons is to "define clear group boundaries" (Ostrom, 1990). In other words, a transparent definition of in-group/out-group would have helped to partially solve the commons dilemma, but part of the problem lies in the difficulty in establishing such limits.

An example involving fisheries is helpful in providing understanding. Two types of policy instruments define property rights to mitigate the commons problem. They either allocate space-based property rights via territorial-use rights for fisheries (TURFs), or species-based property rights via individually transferable quotas (ITQs) (Grafton, 1996; Wilen et al., 2012). We focus on TURFs because they allow a wider and more tangible definition of the in-group/out-group notion compared with ITQs (Cancino et al., 2007).

The coexistence of successful and unsuccessful TURFs[5] suggests that there is room for improvement in the allocation of space-based property rights, and incentives for group performance can be part of this

[5]The international experience with TURFs is mixed. In Japan, TURFs allocated in coastal areas have functioned adequately since their legal establishment in 1948 (Uchida & Makino, 2008). By contrast, in Chile, the allocation of TURFs since the 1990s has yielded more heterogeneous results (Gonzalez, 1996; San Martín et al., 2010).

improvement. For instance, priority in terms of technical support or differential taxation based on the TURF's relative performance might trigger cooperative behavior within the groups. To avoid fishermen perceiving this policy as unfair (through favouring historically successful TURFs), the assessment of a TURFs' performance should be undertaken using a multiple-tier system.

Further, interactions between competition and cooperation in common-pool resources are a very likely force playing a role here. A recent study with coastal fisheries (Basurto et al., 2016), explore how pro-social and anti-social traits seem to be more present, and not conflicting with each other, inside Marine Protected Areas than outside. Integration to markets and the need for enhancing inter-group competition seem to go hand in hand with cooperation within fishers groups. That is, avoiding the over appropriation of the commons just in the same line of our experimental results.

An alternative interpretation of the GPM dwells in its use as an allocation mechanism for shared resources. BenDor et al. (2009) proposes an allocation of effort quotas proportional to the harvest efficiency as a way to improve resource sustainability with respect to market competition. The incentive structure of our GPM mimics the proportional shares rewarding harvest efficiency by assigning greater multipliers to more efficient groups.

One last point in terms of policy relevance. Our incentives design show that, in equilibrium, BGC is budget balanced, requiring no external resources for its implementation. Furthermore, out of equilibrium, the losses from reducing the payoffs of under performing competitors almost fully pay for the extra bonuses required to compensate the top performers. Consider one single individual in a group deviates from the dominant strategy of maximizing appropriation. The GPM will reward the entire group a multiplier greater than one, and will impose to other groups a multiplier strictly smaller than one, despite the small efficiency gains from the minimum deviation triggering unequal group multipliers. Although this is the most pessimistic scenario in terms of efficiency gains from the GPM, under our parametrization it creates a small budgetary deficit (with respect to the social surplus under the Nash equilibrium) of 0.7% with three and of 0.4% with five groups in competition.

Our experimental results reveal that efficiency gains exceeded the additional resources needed to cover the budgetary deficit induced by the GPM. Remember from Table 1 that the efficiency gains from the GPM are on average 1.9 EMU per participant over five rounds, or 19 percentage points with respect to the baseline efficiency without the GPM. By contrast, the budgetary deficit created by the GPM, are on average 0.14 EMU per participant over the five rounds[6], or 7% of the efficiency gains from the GPM. Notice that in the theoretical case (last paragraph) the comparison was against the Nash Prediction

[6]The deficit is computed by taking each round and for each participant getting the difference between its income after applying the GPM and its income before it, then summing among all participants within a session and getting the overall budget balance. Then getting the average for each participant among the five session to make it comparable to our measure of average efficiency gains

(everyone extract the higher amount possible) and in our experimental results, even in the absence of GPM, participants did not, in average, played the Nash Prediction.

5. Conclusions and further research

Our experiments show that individuals are more likely to reduce their appropriation of a shared resource when their groups are immersed in a context of between group competition, even if the material incentives foster full extraction of the resource. In the same spirit of results from standard public goods under group competition, we show that non-material incentives such as social comparisons can help solve social dilemmas in the case of appropriation problems, not studied before in experimental settings. Further, we have no evidence of policies designed to promote group competition among shared natural resources. Our experiment offers a novel policy setting to promote resource sustainable use, at least for the case of linear externalities. For instance, these results suggest that TURFs could explore the use of BGC incentives to align individual and collective incentives and expect efficiency gains from lower resource appropriation within and across groups.

Further research involving within-group appropriation dilemmas (and common-pool resource dilemmas) in BGC should tackle two questions. First, to understand if the efficiency-enhancing effect of competition can be also found in non-linear resource dilemmas experiments, resembling closely the biological properties of the resource (Ostrom et al., 1994). The non-linearity makes self-interested deviations more profitable when other group members are closer to the socially desirable appropriation level. Therefore, it is possible that weak incentives for between-group competition are not sufficiently salient to prevent such deviations. The second, and more challenging, question concerns the effect of BGC when the definition of in-group/out-group does not guarantee the resource's excludability between groups. This environment would require a redefinition of the benefits of within-group cooperation (e.g., better extractive or monitoring technologies) because the ability to maintain a well-managed resource becomes an advantage to outsiders when they cannot be excluded from its appropriation.

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