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Payments or persuasion: norms, subsidies, and efficiency in a common pool resource experiment

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Abstract We study the comparative effectiveness of three policy interventions in a lab experiment that models common pool resources. The interventions we examine are a Pigouvian subsidy, information provision, and an appeal to social norms. The subsidy successfully reduces over-extraction to close to the efficient level on average, but even groups that were not over-extracting are induced to extract less. Because the social optimum is interior, over-compliance reduces efficiency. Moreover, when the subsidy is removed, extraction reaches its least efficient level. Both information provision and normative appeals increase efficiency by reducing over-extraction without exacerbating over-compliance, although the reduction in extraction is much less than that seen with the subsidy. Some of the effect of normative appeals persists even after messages stop being sent. Net of estimates of the marginal cost of raising public funds to pay for a subsidy, the efficiency achieved by the two nonpecuniary treatments is comparable to that achieved by the Pigouvian subsidy.

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1 Introduction

The bad news is that goods once considered non-economic, such as water and air, have begun to suffer from congestion. The good news is that we economists have got congestion licked! Pigou solved it in 1920 (Pigou, 1920): equalize the marginal private cost and marginal social cost at the social optimum, and rational decision-makers will choose the socially optimal level of consumption or resource extraction.

Unfortunately, despite economists' exhortations, Pigou's solution to common pool resource (CPR) congestion has rarely been implemented. Instead, policies have tended to rely on a combination of command-and-control regulation, public information programs, and faith in future technological advances to solve congestion problems. When taxes and subsidies have been used, they have been unlinked to (and likely much smaller than) marginal external costs. Because of this reality, scholars have modeled and studied many non-pecuniary approaches. Economics experiments have been an essential element of this, with much fruitful work on social framing and norms, including the seminal work of Ostrom et al (1994) and more recent work such as Ferraro and Price (2013). However, the literature has yet to provide a measure of the relative effectiveness and efficiency of pecuniary and nonpecuniary policies in reducing congestion in a CPR.

We use a lab experiment to provide a clear comparison of the effectiveness, relative efficiency, and post-intervention persistence of three policies that try to reduce congestion in a CPR game: a Pigouvian subsidy, simple information provision, and information with a normative appeal. We consider average treatment effects and effects across heterogeneous groups, with a focus on the different influences a policy may have on congested, optimally-extracting, and under-used CPRs. Finally, we assess the relative efficiency of the policies, first making a simple direct comparison and then considering reasonable estimates of the marginal cost of public funds that would be needed to pay for a subsidy.

We find, first, that the Pigouvian subsidy achieves its intended effect on average. The subsidy reduces CPR extraction even among groups that had been under-extracting, however, and this under-utilization hurts efficiency. This effect is small enough, however, that the subsidy on net is quite efficient. When the subsidy is removed, over-extraction rebounds to the least-efficient level observed in any treatment. Second, information provision and normative appeals lead to a much smaller reduction in over-extraction, on average, but successfully target over-extractors. Normative messaging also leads to a significant increase in efficiency and, alone among the treatments, has some ability to forestall the decay in cooperation that tends to occur when the treatment is removed. Finally, net of the cost of raising public funds, both information provision and normative appeals lead to efficiency levels comparable to those resulting from the Pigouvian subsidy.

A Pigouvian subsidy is a natural policy to study for several reasons. First, as noted above, Pigouvian instruments have well-known efficiency properties. Second, environmental taxes have proved to be difficult to implement in practice, perhaps because of well-known tax aversion (e.g., Kallbekken et al, 2011; Heres et al, 2013) and loss aversion (Kahneman and Tversky, 1979) phenomena. By contrast, many large environmental subsidy programs exist worldwide (e.g., the United States Conservation Reserve Program). Pigouvian instruments, however, are difficult to implement because social costs are hard to estimate, and the private nature of action makes monitoring and enforcement problematic. Lab experiments allow these issues to be set aside so other elements of policies can be studied. There is a small experimental literature on the use of Pigouvian instruments and the general consensus is that they increase efficiency (Plott, 1983; Cochard et al, 2005). Anderson et al (2007), however, find persistent inefficiency with congestion pricing in an entry and exit game. In contrast, Vossler et al (2006) find that combining communication and fine-based incentives leads to over-compliance.

Because of the limitations of Pigouvian instruments, other management techniques are empirically and theoretically important. Elinor Ostrom's work on CPR institutions indicates that, in practice, many CPRs are successfully and sustainably governed without financial incentives (1992; 2000; 2002).[1] These and other studies have made it clear that Nash equilibrium predictions (assuming purely self-interested actors) have mixed success in predicting subject behavior in CPR games. In their baseline experiment, Ostrom et al. (1994) find that subjects appropriate from a CPR more than is optimal but that subjects' observed choices do not achieve a stable equilibrium. Walker et al (1990) find that the CPR is dissipated by more than the Nash prediction, while Budescu et al (1995) find that subjects over-consume, but by less than the Nash prediction. Suter et al (2012) find that over-consumption declines when the spatial nature of the resource is modeled.

Many factors may account for this non-Nash behavior. Other-regarding preferences such as inequity aversion (Falk et al, 2002) or altruism or even spite (Casari and Plott, 2003) may induce restraint. Strategically irrelevant parameters affect behavior, perhaps because of cognitive limitations (Bru et al, 2003). CPR games are typically nonlinear, and are naturally difficult for subjects to understand. Rodriguez-Sickert et al (2008) find that even a fine that is not implemented affects behavior, perhaps because consideration of the fine establishes a norm. Osés-Eraso and Viladrich-Grau (2011) find that subjects will discriminate in their bestowal of costless rewards to one another after observing appropriation decisions. Cox et al (2009) find that framing a theoretically-equivalent resource as commonly owned (rather than private and shared) increases efficiency, while Janssen et al (2011) posit, referring to results from their asymmetric CPR games, that the context surrounding the establishment of a CPR may affect perceptions of "fairness" and subsequent appropriation decisions.

These results extend beyond the laboratory. In artefactual field experiments, Velez et al (2009) show that subjects balance self-interest with conformity, while Ferraro and Price (2013) use a large field experiment to show that people reduce resource consumption when treated with normative messages containing social comparisons. Allcott and Rogers (2012) show that a normative intervention has a persistent impact on household energy usage, even after the intervention is discontinued. Thus, social preferences, cognitive limitations, information, and social norms can all influence behavior in CPR settings.[2]

How effective and efficient non-monetary methods are, relative to the first-best solution, remains an unanswered question. We fill this gap by bringing a Pigouvian subsidy, simple information provision, and normative messaging into

[1] Another alternative to Pigouvian instruments in protecting CPRs is decentralized Coasian bargaining (considered experimentally in Harrison et al, 1987).

[2] If people respond to non-monetary incentives, Pigouvian instruments based solely on pecuniary costs and benefits are inefficient. Johansson (1997) discusses how Pigouvian taxes must be modified under altruism, for example.

an otherwise-identical lab setting. This setting is a testbed that lets us compare the three interventions' relative effectiveness and efficiency.

The remainder of the paper proceeds as follows. Section 2 lays out a model of the CPR game of interest, providing a theoretical motivation for each of the policy interventions. Section 3 describes the experiment design. Section 4 explores the results empirically, and Section 5 concludes.

2 Theory

In this paper, we study behavior relating to common pool resources (CPRs). A resource is a CPR if it satisfies two properties. First, a CPR is rival, in that consumption of the good by one agent reduces the stock of the good available to others. Second, a CPR is non-excludable, in that it is costly to prevent any individual from consuming the good. The rivalness of the CPR is generally treated as a negative consumption externality (a congestion externality, as in Brown, 1974). As a result, the privately optimal level of consumption differs from the social optimum, and inefficiency persists in equilibrium.

2.1 A common pool resource appropriation game

A group shares a CPR, and each person in the group must decide how much he or she wants to extract from the resource. Each agent $i \in (1, \ldots, n)$ has an endowment of z_i tokens, from which she can choose to spend $x_i \in (0, \ldots, z_i)$ to extract from the CPR. The total group extraction from the CPR is $\varSigma x_j$. For each token she spends on the CPR, agent i must forgo a constant opportunity cost α. Her return from spending x_i tokens on the CPR depends on her token expenditure and on the total spent on the CPR by all agents: $g(x_i, \varSigma x_j)$. The payoff to agent i is the return from tokens not spent on the CPR plus the return from CPR appropriation.

To introduce a congestion externality, we define the payoff to the common pool resource as $g(x_i, \varSigma x_j) = (\beta - \gamma \sum x_j)x_i$. Agent i's per-token return from the CPR starts at $\beta > 0$ for her first token, but this per-token return decreases by $\gamma > 0$ for each token she or any other group member has spent on the CPR. A rational self-interested agent will choose x_i to maximize her payoff:

$$\pi(x_i, \varSigma x_j) = \alpha(z_i - x_i) + (\beta - \gamma \varSigma x_j)x_i$$

This is mathematically identical to that used in Ostrom et al (1994) and all the underlying incentives are identical, although the framing in our protocol is more like that of the traditional linear voluntary contributions mechanism public goods game (Marwell and Ames, 1979). The nonlinearity of the CPR payoff function generally yields an interior solution $(0 < x_i < z_i)$.

A few features are worth noting. First, there is no dominant strategy. There exists both a symmetrical Nash equilibrium ($x_i^{NE} = \frac{\beta-\alpha}{(n+1)\gamma}$) and a symmetrical social optimum ($x_i^{SO} = \frac{\beta-\alpha}{2n\gamma}$).[3] The socially optimal level of consumption and the

[3] We derive these, the optimal (Pigouvian) subsidy, and the total resource yield at the optimum in the Reviewers' Appendix.

Nash equilibrium level of consumption are only identical for $n = 1$ (in which case we have no externality) or $\beta \leq \alpha$ (in which case even the uncongested CPR is not worth the opportunity cost of consumption). The optimal (Pigouvian) subsidy is $\delta = (\beta - \alpha)\frac{n-1}{2n}$. At the optimum, the total social return from the CPR is $G^{SO} = \sum_{i=1}^{n} g(x_i, \Sigma x_j) = \frac{(\beta^2-\alpha^2)}{4\gamma}$. The efficiency of any level of output level $G(\cdot)$ as a percentage of the social optimum is $\frac{G(\cdot)}{G^{SO}}$.[4]

2.2 The search for efficiency

For interesting groups ($n > 1$, $\beta > \alpha$), we expect private consumption to be above the socially optimal level. How might we solve this problem? Pigou (1920) showed that there exists a subsidy that will induce the socially optimal quantity choice, and that that subsidy amount is the difference between the marginal private cost and the marginal social cost at the optimal quantity. To introduce a subsidy, we can add an additional fixed per-token amount (δ) to the return to the outside option. The transformed payoff function is: $\pi(x_i, \Sigma x_j) = (\alpha + \delta)(z_i - x_i) + (\beta - \gamma\Sigma x_j)x_i$.

The implementation of a Pigouvian subsidy runs into two problems. First, funds must be raised to provide the subsidy. Most revenue-raising taxes create inefficiency—public funds come at some cost. Second, consumers of the CPR must be identified and their consumption monitored. This begs the question presented by common pool resources: one of the key characteristics of a CPR that makes it non-excludable is the possibility of hidden action (Arrow, 1984). Monitoring and enforcement can reduce hidden action, but both are costly and imperfect.

In place of a Pigouvian instrument, a policy that presents information highlighting the problem of congestion and its deleterious effects on the group could reduce congestion of a CPR by engaging naturally existing social preferences, including altruism or efficiency-seeking. Experimental evidence suggests that people respond to not only their own private costs but also the costs borne by others, and that increasing identification with others who bear the costs of our own actions increases this response (Andreoni and Petrie, 2004). In addition, group identity can increase cooperation in social dilemmas (Chen and Li, 2009). Such policies have advantages over a tax or a subsidy: political economy presents fewer problems, monitoring of individual behavior is no longer necessary, and they are less expensive to implement.

Direct appeals to social norms may be even more effective than simple information provision. Normative appeals have proved successful in some field experiments (Ayres et al, 2012; Ferraro and Price, 2013). Evidence suggests that the most successful normative appeals combine positive descriptive normative messages ("many do choose socially desirable behavior") with negative injunctive normative messages ("do not engage in socially undesirable behavior") (Schultz et al. 2007). These messages engage the same preferences to which information presentation appeals, but also bring to bear social comparisons (Festinger, 1954).

[4] This is gross (or resource) efficiency. Another potential definition of efficiency is net efficiency, in which returns to the outside option are included. Gross efficiency, which does consider the relative price of the outside option, is more appropriate in this context because net efficiency is sensitive to the size of the CPR relative to the size of the economy—if the CPR is relatively small, it can have little effect on overall efficiency. A CPR's relative size in a lab setting does not simulate that of CPRs outside the lab.

3 Experiment

In the experiment, subjects interact in three-person groups ($n = 3$) for a number of periods. The composition of the groups is fixed for the entire session (there is no rematching). In each period, each subject gets an endowment of tokens and must decide how to allocate those tokens between two accounts. The RED investment represents the outside option and pays a fixed per-token amount. Each token invested in the BLUE investment, which represents the CPR, pays a per-token amount that depends upon the total number of tokens invested in BLUE by the group.

Subjects play with their groups for 21 rounds. Each subject's payment for the session is the sum of the payoff she earns in each round. The session consists of three seven-round phases: a first baseline, a treatment phase, and a second baseline. Subjects know that the game will last for 21 rounds and are alerted when a change in payoffs is about to occur, but they are not otherwise told when a treatment will begin or end. The second baseline lets us observe, and perhaps account for, trends in behavior such as learning or the decay in cooperation that has been widely documented in public goods games (e.g., Isaac and Walker, 1988). It also lets us consider persistence after an intervention has been removed.

There are three treatments, described in detail below: subsidy, information, and normative messaging. The design is across-subject: each subject participates in just one of these treatments for all seven periods of the treatment phase.

In all treatments, the per-token baseline RED payoff is $\alpha = \$0.00$, the per-token starting BLUE payoff is $\beta = \$0.36$, the per-token BLUE congestion parameter is $\gamma = \$0.01$, and the per-period token endowment is $z = 10$ for all subjects. In the baseline phases, these parameters give a self-interested symmetric Nash solution of $x_i = 9$ tokens, while the social optimum is for each subject to choose $x_i = 6$. The social optimum and self-interested Nash decisions are far enough from each other to allow for statistical inference. The differences are economically significant: with the socially optimal outcome, subjects would earn \$26.88 while the per-subject payment with the Nash equilibrium outcome is \$22.26.

3.1 Subsidy treatment

In the subsidy treatment, the return to the outside option is augmented with a per-token RED subsidy of $\delta = \$0.12$. This is the Pigouvian subsidy: it is the distance between the private and social marginal costs at the social optimum. With this subsidy, the symmetric self-interested Nash equilibrium outcome is $x_i = 6$, which yields the socially optimal outcome. Subject earnings for the experiment can range from \$4.20 to \$54.60 in subsidy sessions.

3.2 Information treatment

In the information treatment, subjects receive one of three messages, depending on the group level of CPR appropriation in the previous period. If over-consumption occurred, subjects receive the message:

`During the last period, your group earned a total of [`$\Sigma\pi_{j,t-1}$`]. The maximum your group could have earned was $3.24. Your group earned LESS than it could have in that period. To increase your group's total payoff, your group should REDUCE its investment in the BLUE investment.`

If under-appropriation occurred, the word `REDUCE` is replaced by the word `INCREASE`. Following optimal consumption of the CPR, subjects receive the message:

`Your group earned as much as it could have in that period. Your group is investing in the BLUE investment at the right level to maximize your group payoff.`

Subject earnings for the experiment can range from \$0.00 to \$54.60 in information treatment sessions.

3.3 Normative messaging treatment

In the normative messaging treatment, groups that were over-appropriating in the previous round receive the following message:

`Your group earned LESS than it could have in last period! :( In previous experiments, many groups contributed LESS to BLUE than your group did, and the members of those groups earned more as a result. To boost your group's earnings, DO NOT put so much in BLUE!`

Groups that were appropriating less than the social optimum receive a similar message with `RED` replacing `BLUE`, and groups with optimal consumption receive the message:

`Your group earned as much as it could have last period! :) To maintain your group's earnings, do not change the total number of tokens in the BLUE investment!`

Subject earnings for the experiment can range from \$0.00 to \$54.60 in normative treatment sessions.

3.4 Experiment execution

Subjects are recruited to a session. Upon arrival, they are signed into the laboratory. The experiment is computerized, so subjects are seated at computers and receive instructions on the task. Subjects are given a walk-through tutorial of the computer interface. They are then asked to practice using the software for as long as they like with a computer playing deterministically as the "rest of the group" (the computer selects 0 tokens in the BLUE investment in the first round, 1 in the second round, continuing up through 20, then restarting at 0 tokens).

Subjects are then randomly assigned into three-person groups, which they remain in throughout the experiment. They make the series of twenty-one "investment" decisions as described above: seven rounds of baseline, seven rounds of a treatment (either subsidy, information, or normative messaging), and seven rounds of a second baseline. The sessions are run with a double-anonymous protocol to reduce experimenter influence (see, for example, Cox and Deck, 2005). A subject learns what decisions her group members made but never knows which other people in the room were in her group, and the experimenter can never link this subject's decisions to her identity. After all decisions, subjects complete a questionnaire and then receive payment alone and anonymously.

4 Results

The experiment was conducted in six sessions at Georgia State University's Experimental Economics Center (ExCEN) in April 2009 and July 2011. In each session there were 21–27 subjects. Each session lasted about an hour and a half. Individual earnings, including a $5 show-up payment, ranged from $17.98 to $40.60. Subjects engaged heavily in practice with the interface, playing between 0 and 42 practice rounds.

Because subjects within a group may influence each other, and because one of our primary research questions involves the efficiency of total CPR consumption, the analysis we perform is at the group, rather than individual, level. Total group appropriation from the CPR (contribution to the BLUE investment) is our main variable of interest.[5]

Figure 1 shows group appropriation decisions for the three treatments as the rounds of the experiment progress. Recall that rounds 1–7 are the first baseline, 8–14 are the treatment, and 15–21 are the second baseline. Since the endowment $z = 10$, the maximum appropriation in a round is 30. Horizontal lines on the plots in Figure 1 show the social optimum (18 tokens) and the self-centered Nash equilibrium (27 tokens). Panels a, b, and c show the distribution of group appropriation in each period for each treatment, while panel d plots the period averages of group appropriation decisions for all three treatments together. Over-appropriation is clearly a problem in these lab CPRs, but it is important to note that (at least in the first two phases of the experiment) we observe a substantial number of groups that under-appropriate as well. For each treatment, a treatment effect is visible, and it is strongest for the subsidy treatment. In each case, cooperation also seems to decay as the rounds progress, as all lines slope upward.

4.1 Descriptive results and comparisons

Table 1 summarizes group-level appropriation levels, averaged across all rounds of each phase of each session type.

First, we note the evidence of a decay of cooperation across the treatments. In the first baseline, average group appropriation across all three treatments is 23.283

[5] While the concept of efficiency does not pertain to individual choices because efficiency is a function only of total group appropriation, our appropriation results are qualitatively robust to individual-level analysis.

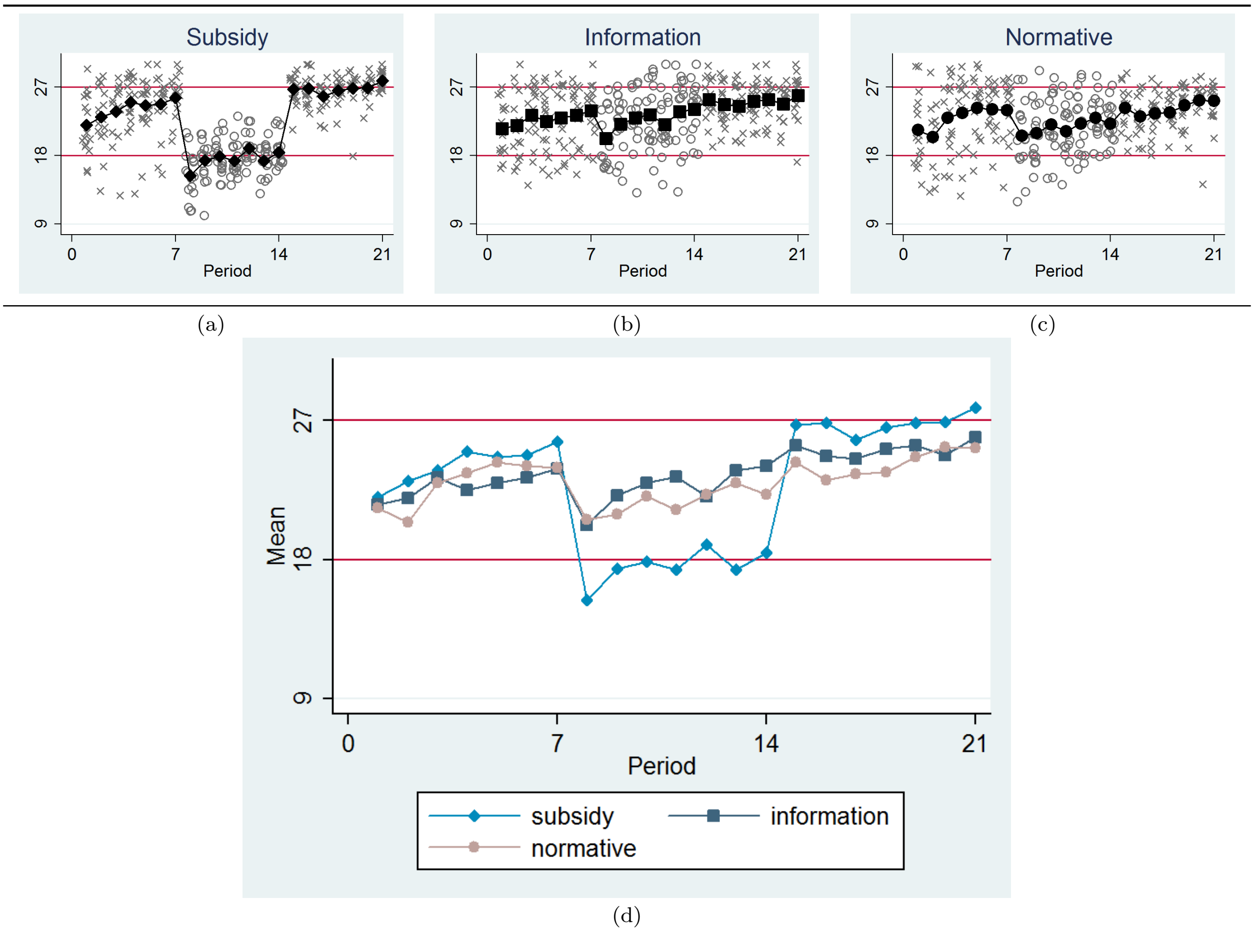

Fig. 1 Group appropriation levels by round. (a), (b), and (c) present group appropriation levels and mean group appropriation levels for the subsidy, information, and normative message treatments respectively, while (d) presents mean group appropriation levels for all three treatments together.

tokens. This drops during the treatment periods and then rises back to a mean of 25.389 tokens during the second baseline. This decay is statistically significant for the pooled treatments and for all treatments (although it is only marginally significant for the normative messaging treatment).

Next, we examine treatment effects. To do this, we observe first that CPR appropriation levels in the first baseline are statistically identical across all three treatments, as one would expect. We then note that in all three treatments, if we pool the first and second baselines together, baseline phase appropriation is significantly greater than appropriation in the treatment phase ($p < 0.02$ in all cases). While first baseline behavior is significantly different from the self-centered Nash prediction, average appropriation drops when a treatment is imposed. It drops by much more in the subsidy treatment than in the information or normative messaging treatments, and these differences are significant, while appropriation levels

Table 1 Group appropriation levels and nonparametric tests

	Average Group Appropriation				Across-treatment tests (Wilcoxon rank-sum p-values)		
	Pooled	Subsidy (S)	Information (I)	Normative (N)	S = I	S = N	I = N
Baseline appropriation (baseline 1)	23.283	24.116	22.777	22.933	0.117	0.185	0.906
	(2.887)	(2.933)	(2.779)	(2.946)			
Treatment appropriation	20.611	17.518	22.652	21.733	0.000	0.000	0.286
	(3.289)	(1.404)	(3.044)	(2.543)			
Baseline appropriation (baseline 2)	25.389	26.759	25.098	24.238	0.01	0.000	0.277
	(2.059)	(1.030)	(2.099)	(2.111)			
Baseline shift (baseline 2 − baseline 1)	2.106	2.643	2.321	1.305	0.985	0.440	0.553
	(2.374)	(2.491)	(1.527)	(2.882)			
N (groups)	47	16	16	15			
Within-treatment tests (Wilcoxon signed-rank p-values)							
baseline 1 = treatment	0.000	0.001	1	0.094			
treatment = baseline 2	0.000	0.000	0.001	0.002			
baseline 1 = baseline 2	0.000	0.001	0.001	0.094			
Nash: baseline 1 = 27	0.000	0.001	0.000	0.001			
Nash: treatment = 18 for subsidy, 27 for others		0.088	0.000	0.001			
Nash: baseline 2 = 27	0.000	0.363	0.003	0.001			

Standard deviations in parentheses. Values in tokens (0 to 30).

in the information and normative messaging treatments are statistically indistinguishable from each other. In fact, the subsidy induced a level of appropriation that was even lower than the social optimum, though the significance is marginal ($p = 0.088$).

The data also suggest that post-treatment decay of cooperation is more of a problem for the subsidy treatment and less of a problem for the normative messaging treatment; seen another way, the normative messaging treatment seems to have better persistence properties while the subsidy seems to have much worse. The subsidy treatment leads to full decay to the Nash equilibrium level of CPR appropriation in the second baseline, significantly worse than the second baseline of either of the other treatments. However, these results are merely suggestive; the difference between first and second baseline mean group appropriation (the "baseline shift") is not significantly different across treatments.

Examing average appropriation levels ignores two key points. First, in the normative and information treatments, different subjects within the treatment receive different actual treatments—some get a message about over-extraction, and others about optimal extraction, and still others about under-extraction. In addition, since this game (like most CPR games) has a nonlinear congestion cost function, an improvement in average extraction may not imply an increase in efficiency. We address these concerns in two ways. First, we break groups into over- and under-extractors and look at the effects each treatment has on the target groups separately. Second, we directly consider efficiency, which accounts for the nonlinear damages. This also allows us to consider the cost of public funds used to pay for a subsidy.

4.2 Extracting more or less

Groups make choices in each round that place them in one of three categories for that round: over-extractors (those groups that appropriated more than the social optimum), under-extractors (those that appropriated less than the social optimum), and groups extracting at a socially optimal level. There are some cases in which all groups are treated identically (the baseline phase and the subsidy treatment) and some cases in which they are treated differently (the information and normative treatments). The normative messaging and information treatments each contain three sub-treatments that depend on what the group has done in the previous round. Under-extractors are informed that an increase in their level of CPR extraction would increase the payoff to the group. Socially optimal extractors are informed that their current level of extraction was optimal. Over-extractors are informed that a reduction in extraction would increase the group payoff. If information has an effect, offsetting behavior by these different types could diminish the average treatment effect, measured in appropriation levels, while nonetheless increasing efficiency.[6]

How these different group types react to treatment matters for efficiency. Even if mean extraction is too high, when some groups are optimal extractors or under-extractors and the congestion function is nonlinear, an across-the-board reduction in extraction can be anti-social on net. This is because the efficiency costs imposed on under-extractors who further under-utilize the resource may be worse, if they are further from the social optimum, than the benefits that come from moderation on the part of over-extractors. The efficiency of the policies, therefore, is not simply a matter of the average appropriation level but also the different effects the policies have on groups in these different categories.

In the information treatment sessions, of the 112 (= 7 rounds $\times$ 16 groups) group messages transmitted in the treatment, 92 informed subjects that a decrease in appropriation would improve group payoff, 14 that an increase would improve group payoff, and 6 that they were at the maximum group payoff. Consequently, 17.9% of the messages sent to subjects would not be expected to induce a reduction in CPR appropriation. Similarly, of the 105 (= 7 rounds $\times$ 15 groups) group messages transmitted in the normative messaging treatment, 81 encouraged a decrease in appropriation, 13 encouraged an increase, and 11 informed subjects they were at an optimum. In this case, 22.9% of messages would not be expected to induce a reduction in CPR appropriation.

An over-extracting group can see one of four changes in a following period: nothing (baseline), a subsidy on the outside option (subsidy), information on the socially optimal course of action (information), or a normative appeal to decrease

[6] In this setting, efficiency is determined by aggregate group appropriation levels, so the same efficiency is achieved by a group with total extraction level $\tilde{G}$ regardless of whether that occurs with symmetric or varying individual extraction choices within the group. However, the same average extraction level across groups can yield vastly different efficiency outcomes: if average extraction is optimal, efficiency is perfect if all groups extract optimally but can be quite bad if some groups greatly over-extract while others greatly under-extract.

appropriation (normative). To estimate the effect of a normative message in reducing group over-extraction, we must compare the later behavior of an over-extracting group that gets a normative message to the later behavior of this group when it receives no message and no other treatment. The treatment effect we would like to identify for such groups is:

$E(\Sigma x_j|\text{over-extractor, normative}) - E(\Sigma x_j|\text{over-extractor})$

If this difference in group-level appropriation is negative, then the normative message was effective. In the analogous construction for under-extractors, efficiency would increase with a positive treatment effect. We do not observe the same decision for the same group in both conditions in a given round. However, treatment type (subsidy, information, or normative messaging) is exogenously varied by the experimenter, and every group is observed both with the treatment and without (in the baseline rounds). We can therefore estimate treatment effects using the model:

$\Sigma x_j = \beta_0 + \beta_1(overex) + \beta_2(overex \times normative) + \Gamma X + \epsilon$

Here, *overex* is an indicator for over-extractor, X is a collection of group- and period-specific covariates, and Γ is the vector of coefficients for those covariates. The average treatment effect on the treated—the effect of the treatment on this type of group—is then β_2. By constructing indicator variables for over-extractors, under-extractors, and socially-optimal extractors, as well as for each of the three treatments, and including full interactions with each treatment, we extend the simple model above to isolate treatment effects for each of the treatments.

Table 2 presents panel OLS estimates of treatment effects. To examine the possibility of omitted variable bias, we include fixed- and random-effects models and two models of differing parsimony. The two fixed-effects specifications reported include one with no additional controls and one with two lags of group appropriation as well as a time trend in the model. Specification I uses fixed effects and therefore can be interpreted as giving the average of within-group effects of each treatment on the total appropriation. Specification II demonstrates that results do not change when random effects are used, in which case the treatment effect includes between-group comparisons. A Hausman test indicates that the fixed-effects model is more appropriate than the random-effects model. Specification III therefore uses fixed effects and establishes that results are qualitatively robust to inclusion of other controls.[7]

In the absence of any policy intervention, over-extractors tend to congest the CPR further. This could be caused by a persistent individual tendency of these people to over-extract or by conditional cooperation. All of the policies significantly reduced over-extraction relative to the baseline. However, the subsidy was by far the most effective policy for reducing extraction by over-extractors. The subsidy was significantly more effective than either information or normative messaging ($p < 0.001$), and those treatments did not differ significantly from each other ($p = 0.164$). The treatment effect of the subsidy (8.916 tokens) is quite close to the difference between the self-centered Nash equilibrium without (27 tokens) and with (18 tokens) the subsidy. These results strongly favor a subsidy as a tool to reduce over-extraction if the cost of providing the subsidy is low.

[7] These results are robust to other combinations of control variables, and to the use of a Tobit model that accounts for potential censoring above at full contribution to the group fund.

Table 2 Panel OLS regressions of group-level appropriation on period-level covariates

	Specification	I	II	III
Over-extractors	Over-extracting group in previous period	2.700***	2.942***	0.393
		(0.515)	(0.403)	(0.885)
	interacted with			
	subsidy	-8.892***	-8.242***	-8.863***
		(0.435)	(0.473)	(0.539)
	information	-1.513***	-1.567***	-1.461***
		(0.449)	(0.361)	(0.434)
	normative	-2.254***	-2.550***	-2.250***
		(0.449)	(0.380)	(0.469)
Optimal extractors	Socially optimal group in previous period	(omitted)	(omitted)	(omitted)
	interacted with			
	subsidy	-5.592***	-4.848***	-8.066***
		(0.685)	(0.844)	(0.923)
	information	0.529	-0.305	-1.356
		(1.032)	(1.309)	(1.310)
	normative	0.483	-0.355	-1.518
		(1.033)	(1.005)	(1.324)
Under-extractors	Under-extracting group in previous period	-0.795	-1.311**	-2.205**
		(0.822)	(0.600)	(1.085)
	interacted with			
	subsidy	-4.465***	-3.387***	-5.200***
		(1.022)	(0.649)	(1.066)
	information	0.242	-0.465	-0.076
		(1.389)	(0.965)	(1.420)
	normative	0.229	0.097	-0.267
		(1.016)	(0.972)	1.014
	Constant	22.133	21.966	23.115
		(0.470)	(0.398)	(1.374)
	Specification and controls	FE	RE	FE, 2 lags, time trend
	Observations ($n \times t$)	987	987	893
	Overall R^2	0.357	0.377	0.406
	Number of groups	47	47	47

Dependent variable is group-level extraction in tokens (out of 30). "baseline" is the omitted category. Standard errors (clustered on group) in parentheses. The time trend in Specification II is a linear time trend. ***: $p < 0.01$, **: $p < 0.05$, *: $p < 0.1$

The subsidy had a less desirable outcome among the other types of groups. Providing the subsidy to optimal-extraction groups led to subsequent under-extraction and it exacerbated existing under-extraction. It should be unsurprising that a greater incentive to select the outside option increases the use of that outside option regardless of the initial level of consumption. Group-level heterogeneity in ex ante CPR extraction means that the subsidy can, in a significant minority of cases, have anti-social consequences.

The effects of the information and normative treatments were significantly different from the effect of the subsidy when applied to optimally-extracting groups or under-extracting groups ($p < 0.001$ in all cases). In neither case were the information and normative treatments significantly different from one another. They do not appear to have had a statistically significant effect on appropriation by under- or optimally-extracting groups, which means that while they did not cure under-extraction, unlike the subsidy, they did no harm.

A subsidy unambiguously and broadly reduces extraction. In cases of over-extraction, this is efficiency-enhancing, but in cases of under-extraction, it exacerbates existing anti-social behavior. Information and normative messaging, on the other hand, have a weaker ability to reduce over-extraction, but this efficiency enhancement is not offset by efficiency losses among under-extracting groups.

4.3 Achieving and maintaining economic efficiency

The subsidy is much more effective than the information or normative messaging treatments in fighting over-extraction; on the other hand, the subsidy's increased efficiency from this feature is offset by efficiency losses from reduced extraction by optimal extractors under-extractors, which does not occur with the other treatments. On net, then, how does efficiency compare across treatments?

Earlier we defined efficiency as the actual return from the CPR divided by the return from the CPR at the social optimum. Table 3 presents comparisons of efficiency across treatments and against the baseline periods. The subsidy achieved the highest level of efficiency at 98.0%, with normative messaging reaching 91.4% efficiency and information reaching 88.4%.[8] With this measure of efficiency, we find that the subsidy was, indeed, more efficient than either the normative or the information treatment. However, because deadweight loss increases with the square of the distance from the social optimum, the efficiency gains from even the small reductions in over-extraction in the normative treatment were quite large.

A few results are worth noting. First, we see no statistically significant differences in efficiency in the first baseline across treatments. Second, the subsidy treatment and the normative treatment significantly increase efficiency. Third, removal of the subsidy leads to a drastic reduction in efficiency, with post-subsidy extraction at its least efficient level in the whole experiment. This is consistent with other work showing that extrinsic motivation frames social dilemmas as essentially transactional, undermining intrinsic social motivation and causing motivational crowding out (e.g., Gneezy and Rustichini, 2000; Frey and Jegen, 2001).

As with the subsidy, the cessation of treatment with information or normative messaging also caused efficiency losses. The normative messaging treatment, however, exhibited no significant difference in efficiency across the two baselines, indicating that, alone among the treatments, the normative messaging treatment was effective in preventing, or at least slowing, the decay in cooperation often observed in social dilemma games. The importance of the differential effects on sub-groups is apparent here. Recall that we observed no significant differences in baseline shifts across the treatments when considering appropriation levels. Here we see that, even so, there are some significant differences in baseline shifts across treatments when considering efficiency. The efficiency fall-off in the subsidy treatment is significantly larger than in the normative treatment ($p = 0.013$), while the

[8] The efficiency of the subsidy is higher than the 93% efficiency observed with a Pigouvian tax in Plott (1983), but Plott notes that his tax and license treatments (which came in at 98.3% efficiency) are likely not statistically significantly different. If there is a difference, it may be due to tax aversion in Plott (see, e.g., Kallbekken et al, 2011 and Heres et al, 2013).

Table 3 Efficiency levels by treatment

	Average Group Efficiency				Across-treatment tests (Wilcoxon rank-sum p-values)		
	Pooled	Subsidy (S)	Information (I)	Normative (N)	S = I	S = N	I = N
Baseline efficiency (baseline 1)	0.862 (0.076)	0.839 (0.070)	0.883 (0.076)	0.863 (0.082)	0.127	0.363	0.693
Treatment efficiency	0.926 (0.072)	0.980 (0.014)	0.884 (0.074)	0.914 (0.072)	0.000	0.000	0.260
Baseline efficiency (baseline 2)	0.809 (0.080)	0.753 (0.050)	0.822 (0.084)	0.856 (0.068)	0.008	0.000	0.236
Baseline efficiency shift (baseline 2 − baseline 1)	-0.052 (0.074)	-0.087 (0.073)	-0.061 (0.051)	-0.006 (0.076)	0.283	0.013	0.069
N (groups)	47	16	16	15			
Within-treatment tests (Wilcoxon signed-rank p-values)							
baseline 1 = treatment	0.000	0.001	1.000	0.023			
treatment = baseline 2	0.000	0.000	0.001	0.003			
baseline 1 = baseline 2	0.000	0.002	0.001	0.570			

Standard deviations in parentheses. Values in proportions of total surplus reaped from CPR (0 to 1).

difference between information and normative treatments was marginally significant ($p = 0.069$).

The subsidy appears more efficient than the non-pecuniary treatments, but we must remember that the government must raise revenues to pay a subsidy. When we consider the inefficiency caused by revenue-raising (e.g., the dead weight loss from general taxation), is the subsidy still better than normative messaging or information provision? This depends on the marginal cost of funds (MCF) used to pay for the subsidy.[9]

We therefore estimate the cutoff MCF such that if public funds are more expensive to raise than this MCF, the net gains of the normative messaging treatment (for example) are higher, and if public funds are less expensive to raise than this, the net gains of the subsidy treatment are higher. We define G^N as the return from the CPR under the normative treatment, G^I as the return under the information treatment, G^S as the return under the subsidy, and Δ as the total subsidy expenditure. Thus $MCF * \Delta$ is the social cost of raising the necessary revenue to provide the subsidy. The cutoff MCF occurs when the net returns are equal: $G^N = G^S - MCF * \Delta$. The cutoff MCF is then: $MCF = \frac{G^N - G^S}{\Delta}$. A similar cutoff MCF can be calculated for the information treatment: $MCF = \frac{G^I - G^S}{\Delta}$.

We do not observe both G^N (or G^I) and G^S for any group, but we can use Monte Carlo methods to come up with a cutoff estimate. Drawing from our observed group decisions (7 groups × 16 rounds = 112 for the subsidy treatment and 7 groups × 15 rounds = 105 for the normative treatment) in 80,000 trials, the 95%

[9] We assume for simplicity that the administrative costs of information and normative policies are no greater than the administrative costs of a subsidy.

interval estimate break-even MCF between the normative and subsidy treatments is $(-0.154, -0.151)$. The estimated break-even MCF between the information and subsidy treatments is $(-0.220, -0.216)$.[10] In other words, the MCF must be less than 15 cents per dollar for the subsidy to be more efficient than normative messaging, and it must be less than 22 cents per dollar for the subsidy to be more efficient than simple information provision. Both of these are within ranges that have been estimated for the marginal cost of public funds. Ballard et al (1985) find that each additional dollar of revenue comes at a welfare cost of 17 to 56 cents, and Allgood and Snow (1998) estimate the cost to be 13 to 28 cents. Therefore, considering the efficiency cost of raising revenue, in our results, normative messaging and information provision achieved net efficiency gains similar to those of a Pigouvian subsidy.

5 Conclusion

As the global population grows, congestion externalities in important common pool resources are being felt more and more acutely. The optimal policy response to these externalities depends greatly on how people behave. Pioneering work by Walker et al (1990) broke ground in using experiments to study how people do behave in these scenarios, but common pool resources still have not received the experimental attention that private and pure public goods have received. Existing literature has discussed promising tools to fight common pool resource congestion: Pigouvian taxes and subsidies are theoretically powerful but politically and practically difficult; information provision and normative messaging seem weaker in that they don't directly modify incentives, but they are cheaper to implement and likely more politically palatable. These tools have been tried in actual policies: hybrid vehicle tax credits simulate elements of a Pigouvian subsidy; certification and labeling programs such as Energy Star provide simple information; and anti-forest fire campaigns add a normative message to information. We bring Pigouvian subsidies, information provision, and normative messaging into the lab to compare the performance of these three instruments on a simple testbed.

We find that a Pigouvian subsidy effectively decreases over-extraction in a CPR, but that it reduces extraction even in a CPR where the group is extracting optimally or under-extracting, and this is inefficient. Even so, the net effect is a large efficiency increase: our groups achieve a 98% level of efficiency under the subsidy treatment. This is similar to that observed in previous experiments (Plott, 1983).

Removal of the subsidy leads to the highest observed levels of over-extraction, however. The introduction of an additional monetary incentive may crowd out social motivations and induce self-centered Nash behavior more quickly. Evidence from the Irish plastic bags tax indicates that combining Pigouvian instruments with information provision may create more persistent benefits (Convery et al, 2007). Future research should examine the effectiveness of a Pigouvian instrument used as part of a broader policy approach—one that may include information

[10] If the means of G^S, G^N, G^I, and Δ are used instead of Monte Carlo trials, the cutoff MCF for the normative treatment is 0.143 and the cutoff MCF for the information treatment is 0.207.

provision and normative messages. If such a policy leads to the formation of new norms, a smaller subsidy should be able to achieve higher levels of efficiency.

We also show that information provision and normative appeals can reduce over-extraction, although not by as much as a Pigouvian subsidy. If under-extraction is a concern, for example due to poor information flows or heterogeneity in non-monetary preferences, information provision and normative messaging work better than a subsidy. Outside the lab, some common pool resources—such as local public parks—are localized resources shared among small groups of people. If people sort according to preferences, some groups may be over-utilizers while other groups are under-utilizers even when facing the same kind of resource. In these cases, attempts to fight over-utilization with policies that treat all groups identically may drive people who had not been overusing the resource in the past toward inefficient resource under-use.

In all treatments, when the policy intervention stops, there is an increase in appropriation. In the information and subsidy treatments, we observe a decay in efficiency from the first baseline to the second baseline. We infer that treatment effects from these policies are unlikely to persist without other institutional changes. In practice, many policies aimed at reducing CPR congestion are recommendations or inducements to purchase durable goods or make long-term investments that will reduce a person's future incentive to appropriate. Allcott and Rogers (2012) find that Opower customers who received normative messages over a long period and then abruptly ceased to receive them did show persistent energy conservation, and attribute this to formation of some kind of "capital stock." They do not find meaningful evidence of increased investment in energy-conserving products and suggest that more effective conservation habits may have been formed. Future lab and field experiments allowing subjects to make long-term investments or choices to commit to a fixed future stream of extraction could provide more insight into the use of these policies to establish long-term congestion reductions.

Because deadweight loss increases with the square of the distance from the social optimum, the gains achieved in our experimental setting through information provision and normative messaging are disproportionately large, with information provision achieving 88.4% efficiency and normative messaging achieving 91.4% efficiency. If we also consider reasonable estimates of the cost of raising public funds, the policies are comparable to the Pigouvian subsidy in terms of efficiency. Net of monitoring and enforcement costs, these communication- and norm-based approaches may be preferable to pecuniary approaches. While they may lack the elegance of Pigou's solution, perhaps the reason that strong verbal encouragements have persisted as a policy tool for thousands of years is that, on net, they are cheap and effective.

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6 Reviewers' Appendix

In this Appendix, we derive the self-centered Nash solution and the social optimum for the common pool resource game presented in this paper, we find the optimal (Pigouvian) subsidy to correct the externality, and we derive the total return from the resource at the social optimum.

A self-centered agent will choose the number of tokens x_i to allocate to the common pool resource in any round to maximize her payoff:

$\max_{x_i} \pi(x_i, \Sigma x_j) = (\alpha + \delta)(z_i - x_i) + (\beta - \gamma \Sigma x_j)x_i$

This gives the first order condition:

$-(\alpha + \delta) + \beta - 2\gamma x_i - \gamma \Sigma_{j \neq i} x_j = 0$

If all agents are identical, a symmetric Nash equilibrium can be expected, so that $x = x_i = x_j$ for all i, j. Therefore, the first order condition solves to:

$x = \frac{\beta - \alpha - \delta}{(n+1)\gamma}$

The social optimum occurs if we maximize total profits, again assuming symmetry:

$\max_x n\pi(x) = n[\alpha(z - x) + (\beta - \gamma \Sigma x)x]$

The first order condition is:

$n(\beta - \alpha) - 2\gamma n^2 x = 0$

The social optimum therefore solves to:

$x = \frac{\beta - \alpha}{2n\gamma}$

The optimal Pigouvian subsidy δ that aligns the private incentive with the social optimum is found by setting these equal and solving for δ. This subsidy is $\delta = (\beta - \alpha)\frac{n-1}{2n}$.

At the optimum, the total yield from the CPR is:

$G = \Sigma g(x_i, \Sigma x_j) = \Sigma(\beta - \gamma \Sigma x_j)x_i$

Noting that $x = x_i = x_j$ for all i, j, we have:

$G = \Sigma(\beta - \gamma \Sigma x)x = n\beta x - n^2 \gamma x^2$

If we plug in the social optimum $x = \frac{\beta - \alpha}{2n\gamma}$, this is:

$G = n\beta \frac{\beta - \alpha}{2n\gamma} - n^2 \gamma (\frac{\beta - \alpha}{2n\gamma})^2$

This rearranges to:

$G = \frac{\beta^2 - \alpha\beta}{2\gamma} - \frac{(\beta - \alpha)^2}{4\gamma}$

Which simplifies to:

$G = \frac{\beta^2 - \alpha^2}{4\gamma}$

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