Managing the Tragedy of the Commons: A Partial Output-Sharing Approach*

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Abstract

Common-pool resources (CPRs) suffer from a social dilemma known as the *'Tragedy of the Commons'*, in which a selfish individual's rational decision leads to over-extraction of the resources and, consequently, leads to depletion of the resources. We can overcome the commons problem by changing the incentive mechanism. Introducing sharing arrangements among resource users induces free-riding behavior, which can offset over-extraction and potentially achieve a socially optimal outcome. One potential method of achieving this is partial output-sharing. Under this process, resource users are pooled into a single group and required to share a proportion of their output evenly with group members. I conduct a laboratory experiment to assess the effectiveness of the partial output-sharing model in CPR environments. The results indicate that partial output-sharing successfully reduces over-extraction and leads to higher collective earnings, suggesting that it can be an effective tool for managing CPRs sustainably.

Keywords: Common Pool Resource, Collective Action, Group Behavior, Experiments
JEL Codes: C71, C92, Q28

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1 Introduction

Common-pool resources (CPRs) are defined to be natural or man-made resources that are non-excludable and rivalrous. Anyone can extract resources and enjoy its benefits since the resources are open to everyone. One's extraction[1] of resources can exclude others from obtaining benefits from it since the resources are finite. Thus, individuals have the incentive to exploit the resources as much as possible before someone else takes them. Such behavior leads to the over-extraction of resources which causes a higher marginal cost since resources become harder to find, lower marginal benefit since the price of resources decreases, and consequently depletion of the resources. Since Hardin's (1968) seminal paper, the phenomenon is called '*Tragedy of the Commons*,' where individuals' rational decisions result in sub-optimal outcomes for the community. The most common examples are fishery, forestry, and groundwater irrigation. However, the '*Tragedy of the Commons*' problems are not limited to replenishable resources, but could also apply to non-replenishable resources such as crude oil, natural gas, and other underground resources. Rapid extraction of such resources could leads to losses while more advanced future technologies could increase extraction efficiency. Thus, avoiding rapid-extraction can increase aggregate outcomes which resemble that of fishery, forestry, and groundwater irrigation. Further, the commons dilemma could also be found in environmental resources such as clean air, since excessive pollution leads to environmental damage, biodiversity loss, and global warming (Barrett, 1994).

In many countries, individual quotas and individual transferable quotas (ITQs) have become popular management regimes in which a government agency announces a total allowable catch and determines how it is distributed among resource users. However, individual quotas and ITQs have several problems. First, they rely on accurate stock estimation which is often difficult in many CPRs. Second, they are susceptible to policymakers' interests. The total allowable catch may be based on election cycles and not on the long-term interest of

[1] In this paper, terms such as "extraction," "harvesting," "exploitation," and "appropriation" are used as equivalent terms for devoting effort to obtaining the product of a CPR.

resource users. Third, they provide incentives to harvest as much as legally possible which could lead to a high-grading problem, where fishermen discard low quality fish (Copes, 1986). However, there are some cases of successful government intervention to sustain CPRs. In the case of Maine lobster fishery and Chile shellfish fishery, territorial user rights for fisheries (TURFs) were established and the distribution of property rights was based on the territory and managed resources sustainably (Steneck et al., 2017). However, TURFs are only effective when the resources are stationary.

Looking at the problems of top-down management regimes, it seems advantageous to have bottom-up management regimes which provide resource users with control and long-term ownership over the resource. Community-based management regimes have the benefit of community members sharing and monitoring information about harvesting activities (Pinkerton, 1994). Ostrom, Gardner, and Walker (1994) summarize various community-based solutions to overcome the CPR problems. In particular, the research using laboratory experiments regarding CPRs provides useful insights on institutional change that could increase cooperation in CPR environments and potentially ameliorate the '*Tragedy of the Commons*' problem. Face-to-face communication (Ostrom and Walker, 1991), communication with sanctions (Ostrom et al., 1992), proposed rules and voting (Walker et al., 2000), and two-stage management where resource users voluntarily participate in preservation after appropriation (Botelho et al., 2015) prove to be effective at reducing the extraction of resources in the laboratory experiments.

We have looked at how changes in rules could encourage cooperation among resource users and reduce over-extraction. We can also manage the CPRs by changing the incentive mechanism of resource users. One such method is output-sharing (Schott, 2001; Heintzelman et al., 2009). The sharing arrangement induces free-riding behavior that reduces extraction of CPRs. The reduced appropriation could be beneficial in the context of CPRs where resource users are prone to over-harvest. Taking advantage of this feature, Schott (2001) proposed the 'Partnership Solution' that a socially optimum level of harvesting could be induced by dividing the set of resource users into a number of partnerships in such a way that each resource user's tendency to over-extract is exactly offset by the user's tendency to free-ride on the effort of others. Although Cherry et al. (2015) demonstrated that the 'Partnership Solution' is effective in laboratory experiments, its effectiveness in reducing over-extraction in real-world scenarios remains questionable. This uncertainty arises because motivations in field settings may differ from those in laboratory environments. Platteau and Seki (2001) documented the Japanese fishery communities that adopt pooling arrangement. In the interview, the fishermen never mentioned insuring against low catches as one of the motivations for forming output-sharing partnerships. Instead, the desire to avoid the crowding in attractive fishing spots is the motivation for adopting pooling arrangements. From the interview, we notice that the motivation for forming partnerships is to effectively extract more resources rather than to free-ride on the effort of others.

Another approach to utilize the free-riding feature in the context of CPRs is partial output-sharing. Instead of separating resource users into smaller groups and sharing all of the output, pooling all resource users into one large group and sharing only a portion of the output. In this setting, resource users who voluntarily joined the output-sharing group must share a certain proportion of their output to the group, then the shared outputs are distributed equally among group members. The sharing arrangement reduces the marginal benefit of extraction by converting part of the private benefit to the public benefit. The incentive structure is similar to that of a Pigouvian tax on harvest, where the tax revenue is evenly distributed among members.

The sharing arrangement solution offers multiple advantages for managing CPRs, compared to other methods. It directly addresses the commons problem's core issue—economic incentives—by adjusting key parameters to encourage sustainable management, even in non-cooperative scenarios. Additionally, its political acceptability is enhanced since resource rents stay with the users and participation is voluntary, making it preferable to taxes or Individual Transferable Quotas (ITQs).The partial output-sharing model, a variant of the full-output sharing model[2] further benefits from its centralized management structure with one large group in the community. This setup enables organized decision-making that represents all group members, improving information sharing and monitoring of harvesting activities. Unlike the full-output sharing model, where partnerships may frequently change, leading to instability, the partial output-sharing model promises more consistent and stable management over time.

There are many studies on the full output-sharing model including theoretical analysis (Schott, 2001; Heintzelman et al., 2009), and laboratory experiments (Schott et al., 2007; Cherry et al., 2015; Buckley et al., 2018). The key findings are: 1) Increase in group size significantly reduces harvest effort which closely traced Nash predictions, but group assignment makes no significant difference whether it is random or fixed for the period (Schott et al., 2007), 2) Confirmed that right-sized groups reduce harvest effort to the socially optimal level and found systematic deviation toward the socially optimal level due to both altruism and conformity (Cherry et al., 2015), and 3) Local communication within partnerships decreases efficiency because of less free-riding and allowing global communication worsens the efficiency (Buckley et al., 2018).

On the contrary, we know little about the effectiveness of the partial output-sharing model. In particular, there is no research on the behavioral aspect of the partial output-sharing model. To the best of my knowledge, there is one paper by Tilman et al. (2018). They studied the partial output-sharing model[3] using game theoretic analyses and agent-based modeling simulations. They found that output-sharing arrangements can emerge and lead to improvements in resource management under certain conditions[4].

The goal of this study is to examine the effectiveness of the partial output-sharing model in the context of the CPR problem using a laboratory experiment. This will provide behav-

[2]Also known as the partnership solution (Schott, 2001; Schott et al., 2007; Heintzelman et al., 2009; Cherry et al., 2015; Buckley et al., 2018).

[3]Authors called it the revenue-sharing club.

[4]When there is large variability in production and when this variability is uncorrelated across members of the partial output-sharing group.

ioral evidence on the partial output-sharing model. The previous study on the partnership solution has found that the output-sharing reduced appropriation effort and the effect increased with group size (Cherry et al., 2015). We may expect that the partial output-sharing model will reduce appropriation effort, but it is not so clear what percentage of sharing will be most efficient for the community. Although several studies (Schott et al., 2007; Cherry et al., 2015; Buckley et al., 2018) have shown that the appropriation effort coincided with the Nash predictions which assume selfish and rational preferences, we may expect more cooperative behavior in the partial output-sharing model as it unites the community by tying them to a common group, creating a stronger sense of unity. Fischbacher et al. (2001) found that about a third of subjects showed behavior consistent with *homo-economicus* and about half displayed conditional cooperation which further complicates our predictions. Thus, it is essential to study the partial output-sharing model in the laboratory to obtain behavioral evidence.

In the rest of the paper, I describe the experimental design to study the effectiveness of the partial output-sharing model using CPR games in the laboratory and discuss the potential analyses, policy implications, and future works. The paper proceeds as follows: section 2 outlines CPR model in detail. section 3 describes the experimental design, including the treatments, parameter choices, Social Value Orientation task, survey, and experimental procedures. In section 4, I will discuss future analyses. Section 5 discusses the implication of the research and future works. Subject instructions are included in the appendix.

2 The common-pool resource model

The early model in CPR game is based on the public good game. Andreoni (1995) introduced negatively framed public good games that are different from positively framed typical public good games. In a typical public good game, each person in a group is endowed with some money first, then each person decides how much to contribute to public goods for the group. The amount of contribution will be multiplied by M and then divided evenly to people. Here, $M > 1$ captures the positive externality from the contribution. On the other hand, in a negatively framed public good game, the endowment is a group resource first, and then each person in the group decides how much to appropriate from the group resource.

$$u_i(x) = x_i + \frac{M}{N}(E - \sum_{j=1}^{N} x_j) \tag{1}$$

In this game, the pooled endowment $E = \sum_{j=1}^{N} e_j$ is given, and each person decides how much to appropriate, x_i. The payoff of each person, $u_i(x)$, is decided by how much they appropriate from the group resource, x_i, and how much is left after the group's total, which is multiplied by M and then divided equally among group members. This is called an appropriation game. Later, Ostrom et al. (1994) introduced CPR game that added more features of common resources to Andreoni's appropriation game.

In the CPR games, there are n appropriators with access to the CPR. Each appropriator i has an endowment of e which can be invested either in the CPR or a safe, outside activity. The marginal payoff of the outside activity is equal to w. The payoff to an individual appropriator from investing in the CPR depends on the aggregate group investment in the CPR and on the appropriator investment as a percentage of the aggregate. Let x_i denote appropriator i's investment in the CPR, where $0 \leq x_i \leq e$. The group return to investment in CPR is given by the production function $F(\sum x_i)$, where F is a concave function, with $F(0) = 0$, $F'(0) > w$, and $F'(ne) < 0$. Initially, investment in the CPR pays better than the opportunity cost of the forgone safe investment $[F'(0) > w]$; but if the appropriators invest all resources in the CPR, the outcome is counterproductive $[F'(ne) < 0]$. Thus, the yield from the CPR reaches a maximum net level when individuals invest some, but not all, of their endowments in the CPR (See figure 1).

$$\begin{aligned} u_i(x) &= we \text{ if } x_i = 0 \\ &= w(e - x_i) + (x_i / \sum x_i) F(\sum x_i) \text{ if } x_i > 0 \end{aligned} \tag{2}$$

Let the payoff in the equation 2 be the payoff functions in a symmetric, non-cooperative game. There is a symmetric Nash equilibrium, with each player investing x_i^* in the CPR, where

$$-w + (1/n)F'(nx_i^*) + F(nx_i^*)[(n-1)/x_i^* n^2] = 0 \tag{3}$$

For the optimal solution to the group, summing across individual payoffs $u_i(x)$ for all appropriators i, we have group payoff function

$$u(x) = nwe - w \sum x_i + F(\sum x_i),$$

which is to be maximized subject to the constraints $0 \leq \sum x_i \leq ne$. Given, the production function F, the group maximization problem has a unique solution characterized by the condition:

$$-w + F'(\sum x_i) = 0 \tag{4}$$

According to equation 4, the marginal return from a CPR should equal the opportunity cost of the outside alternative for the last unit invested in the CPR. Note that neither Nash equilibrium investment nor the optimum group investment depend on the endowment e, as long as e is sufficiently large. However, out of equilibrium, larger e means players are capable of making larger negative yields when appropriating too much from CPR.

In experiments that use CPR games, the CPR scenario is modeled using quadratic pro-

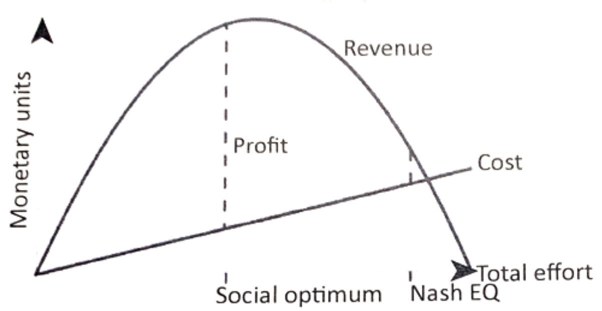


Figure 1: Production function for CPRs

duction functions denoted as $F(\sum x_i)$, where $F(\sum x_i) = a\sum x_i - b(\sum x_i)^2$ with conditions that $F'(0) = a > w$ and $F'(ne) = a - 2bne < 0$. This quadratic specification leads to a payoff function where the investment level at symmetric Nash equilibrium $x_i = (a-w)/(n+1)b$ falls between the maximal net yield (the group optimum) condition $x_i = (a-w)/2nb$ and the zero net yield condition $x_i = (a-w)/nb$.

$$\begin{aligned} u_i(x) &= we \text{ if } x_i = 0 \\ &= w(e - x_i) + \big(\frac{x_i}{\sum x_i}\big)\big(a\sum x_i - b(\sum x_i)^2\big) \text{ if } x_i > 0 \end{aligned} \tag{5}$$

2.1 CPR games and partial output-sharing treatments

I use the CPR game as the baseline game, following the seminal work of Ostrom et al. (1992). In CPR games, subjects are randomly assigned into the group size of N. After the group assignment, subjects are given an endowment e by the experimenter, and they must allocate this endowment between two possible investments. One option is to invest in a safe, outside activity which gives a fixed return, w on each invested endowment. The other option is to invest in the CPR which gives variable returns depending on the aggregate group investment in the CPR, X. As the aggregated group investment in the CPR increases, the returns from investment in the CPR decreases. The individual payoff for CPR games in each round is expressed in equation 6.

$$\pi_i = w(e - x_i) + x_i(a - bX) \tag{6}$$

For the partial output-sharing treatments, two components are added from the baseline CPR games to operationalize the partial sharing among group members. One component is the percentage of sharing arrangement, $\lambda \in [0, 1]$, and the other component is the additional income source from the equal distribution of the shared output from the group. In the partial output-sharing treatments, similar to the CPR games, subjects are randomly assigned into the group size of N. Then, they are given an endowment e to allocate between two possible investments. However, they must share λ percentage of their output from the investment into the CPR. The shared output will be distributed equally to the group members. The λ is the key parameter of the partial output-sharing model since it controls the individual's final payoff, and thus it governs the individual's behavior. As the sharing arrangement λ increases, the benefit of appropriation from CPR decreases, while the benefit from the shared income increases, which results in reduced appropriation of CPR. For example, if an individual decides not to appropriate CPR and stays home, the individual earns $w * e$ plus the amount shared from the group. An individual who decides to appropriate x_i, earns $w * (e - x_i)$ plus their own portion of the output from the appropriation of CPR plus the amount shared from the group (See equation 7).

$$\pi_i = w(e - x_i) + x_i(1 - \lambda)(a - bX) + \frac{\lambda}{N}(aX - bX^2) \tag{7}$$

We can set the percentage of sharing arrangement, λ to satisfy the investment level at symmetric Nash equilibrium in equation 8 to meet the group optimum condition $x_i =$

$(a - w)/2nb$.

$$x_i = \frac{(1 - \lambda + \lambda/n)a - w}{\big((n+1) - \lambda(n-1)\big)b} \tag{8}$$

2.2 Parameter choices

Table 1: Parameters for a Given Decision Round

	Notations	Parameters
Number of subjects	N	8
Individual effort endowment	e	25
Production function	$aX - bX^2$	$20X - 0.1171X^2$
Activity A return/ unit of output	w	E$ 5
Nash equilibrium allocation in Activity B		14
Group optimal allocation in Activity B		8
Earnings/ subject at group maximum		E$ 185
Earnings/ subject at Nash equilibrium		E$ 151
Earnings difference: Nash vs Group max (%)		22%
Optimum sharing arrangement	λ^*	0.60

I focus on experiments utilizing the parameters shown in table 1. Parameters for the number of subjects and the individual token endowment are chosen based on the experiments from Ostrom et al. (1992), Walker and Gardner (1992), and Ostrom et al. (1994). Other parameters, such as the production function for investing in CPR, and a fixed return from other activities, are selected to ensure that both the Nash equilibrium and the group maximum investment in CPR are close to integer values. The parameters are chosen to guarantee that the difference in individual earnings between the Nash equilibrium and the group maximum is 22%. The optimum sharing arrangement in the main parameters, denoted by λ, is 0.6. This implies that self-interested subjects under a partial output-sharing treatment with $\lambda = 0.6$ will choose to appropriate in CPR at the socially optimal level. Figure 2 depicts the theoretical predictions of an individual appropriation in CPR when varying the sharing arrangement level, λ, for the chosen parameters.

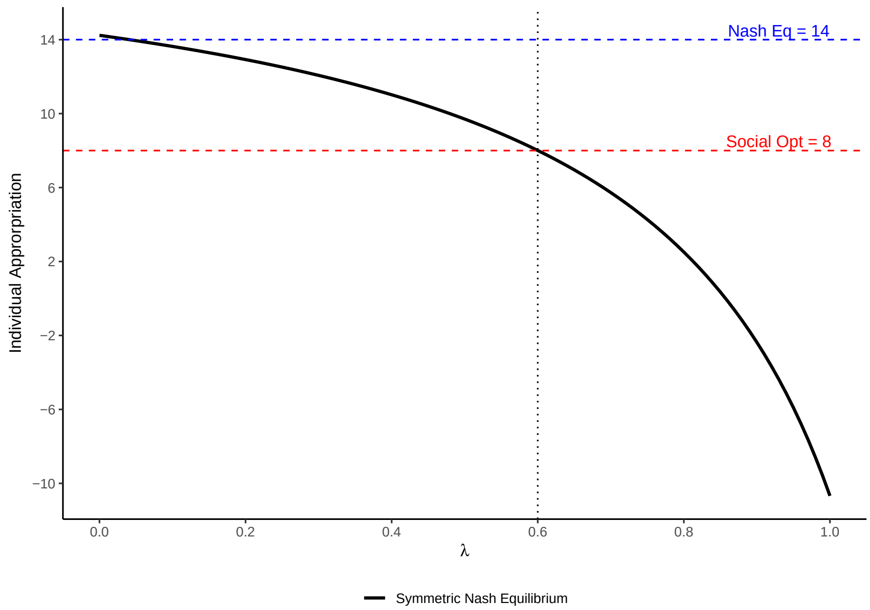


Figure 2: Appropriation benchmark as a function of percentage of sharing (λ) on the chosen parameters.

2.3 Experimental design

I use three different CPR games by varying the intensity of the sharing arrangement, λ. The baseline game is the typical CPR game without any sharing arrangement, which represents the natural state. The second game is a 60% output-sharing game. In this game, everyone in the group is forced to enroll in the partial output-sharing group, thus they must share 60% of their output from CPR to the group account, then it will be distributed equally among group members. The $\lambda^* = 0.6$ is chosen from the symmetric Nash equilibrium prediction in which individuals' selfish decision is equal to the social optimal appropriation. The third game is a 30% output-sharing game. Similar to the second game, everyone in the group is forced to enroll in the partial output-sharing group, thus they must share their output with the group members. But, the sharing arrangement is reduced by half from the second game. For simplicity, I will refer to the baseline game, the 60% output-sharing game, and the 30% output-sharing game as Game S_0, Game S_{60}, and Game S_{30}, respectively.

There are three different treatment sessions in the experiment. All subjects will play game S_0 first, then subjects play one of the three games-—S_0, S_{60}, or S_{30} for the second game. Thus, the experimental design is S_0S_0, S_0S_{60}, and S_0S_{30}. The design has both within-session variation and between-session variation. There are several advantages to this design. First, the institutional changes take place after the natural state, which resembles the real-world implementation. We can observe how subjects react to policy changes that potentially provide insights into how we should implement a partial output-sharing model. Second, playing the baseline game first alleviates the concern for learning during the session. Subjects will gain a sufficient understanding of the game by playing the baseline game for 10 rounds. This will allow me to estimate the treatment effect by comparing the result from the second game S_0, S_{60}, and S_{30}.

3 Experiments

3.1 Implementation

The experiment was conducted at the Experimental Economics Center laboratory at Georgia State University (GSU) in Fall 2024. A total of 144 subjects participated in the experiment over the course of six sessions. Subjects were recruited using an automated system that randomly invites participants from a pool of around 1,000 students who signed up to participate in economic experiments. Undergraduate students at GSU were invited to participate in this experiment via email. Upon arriving at the lab, subjects were randomly assigned to a laboratory computer. Subjects earned experimental dollars (E$), which was converted to U.S dollars at the rate of E$200 = U.S $1 at the end of the session. The experiment was programmed using o-Tree (Chen et al., 2016). Each session lasted approximately one hour. The average payment per subject was $18.93 including a $3 participation fee.

3.2 Procedures

Each session of the experiment had two parts, each with 10 rounds: first game S_0, followed by one of the three games—S_0, S_{60}, or S_{30}. After completing the games, subjects filled out a survey. Subjects were told that their final payoff would be the total of their earnings from both parts.

The session proceeded as follows. At the beginning of a session, subjects read on-screen instructions detailing the experiment. After all subjects completed reading the instructions, the experimenter summarized them and answered any questions. Before starting the experiment, subjects took a short quiz to ensure they understood the consequences of their choices for their payoffs. The computer did not allow subjects to proceed to the next screen until they achieved a perfect score on the quiz. After the quiz, subjects played three practice rounds against the computer. Next, subjects were randomly assigned to a group of eight. They then played 10 rounds of Game S_0 as part 1, followed by either Game S_0, S_{60}, or S_{30} as part 2. During the game, subjects decided how much to appropriate from the CPR, denoted as x_i, for each round. After all group members submitted their decisions privately, payoffs for the round were determined. Subjects received information on their own payoffs, including a breakdown of earnings from appropriation, other work, and group sharing. They also received information on the total appropriation by the group and a history of their earnings for each round.

Once they complete part 2, subjects will complete questionnaire on demographics, strategies, preferences over two games, and questions about Big-Five personality traits using Ten-Item Personality Inventory (Gosling et al., 2003). On top of the payoffs from the games, subjects received a \$3 bonus for filling out the questionnaire at the end of the experiment to avoid the income effect of the participation fee. Table 2 shows the experimental procedures.

3.3 Hypotheses

Using the data obtained from the experiments, I can test the following hypotheses.

Table 2: Experimental Procedures

Part 1	Common-Pool Resource Game S_0
	Instructions for CPR Game S_0
	Quiz and Practice
	Game S_0: 10 Rounds
Part 2	Common-Pool Resource Game S_0 or S_{60} or S_{30}
	Instructions for CPR Game S_0 *or* S_{60} *or* S_{30}
	Quiz and Practice
	Game S_0 or S_{60} or S_{30}: 10 Rounds
	Payoff: Pay all sequentially.
Post-Survey	Demographics, decisions, big-Five personality traits
	Payoff: \$3

Hypothesis 1 (H1) *Subjects will appropriate less in the partial output-sharing model than in the baseline model.*

Hypothesis 2 (H2) *Total appropriation decreases as the proportion of sharing increases.*

Hypothesis 3 (H3) *Subjects will appropriate at the socially optimum level in the partial output-sharing model.*

For the first and second hypotheses, I can compare the average appropriation from each game played in the second half of the CPR games. If the average appropriation is less in game S_{60} and S_{30} than game S_0, we can conclude that the first hypothesis is true. If the average appropriation is less in game S_{30} than game S_{60}, we can argue that the second hypothesis is also true. For the third hypothesis, I will compare the average appropriation and net payoff for each round. If the average appropriation converges to the social optimum, and the net payoff converges to the social maximum amount, we can conclude that the third hypothesis is true.

I can also estimate the average treatment effect of the partial output-sharing model using within-subject comparison. Concerning the learning effect, I will exclude the first few rounds for each game when executing the within-subject comparison. Moreover, if I can observe some stylized behavior for each individual, then I can potentially classify subjects into some categories such as free-rider, over-appropriator, or rational player.

4 Results

I conducted six experimental sessions across three different session types: No sharing session (S_0S_0), 30% sharing session (S_0S_{30}), and 60% sharing session (S_0S_{60}). Each session included three groups of eight subjects, totaling 24 subjects per session. In this section we examine the aggregate appropriation of CPR, group and individual decisions to extract from CPR and the distribution of earnings across participants.

Table 3: Experiment Details

	Session Types		
	No Sharing	30% Sharing	60% Sharing
Number of sessions	2	2	2
Group size	8	8	8
Number of groups	6	6	6
Number of subjects	48	48	48

4.1 Aggregate appropriation

In this section, I report group's aggregate appropriation per period and aggregate mean appropriation across treatments. The analysis focuses on group's aggregate appropriation compared to group's Nash equilibrium for each treatment. Figure 3 presents the mean group aggregate appropriation over each period (solid lines) and the group's Nash equilibrium (dashed lines) for the three treatments: No sharing (black circles), 30% sharing (green squares), and 60% sharing (red, triangles). The results broadly align with the underlying theory. The mean aggregate appropriation is 117.3 for No Sharing, 99.8 for 30% Sharing, and 65.3 for 60% Sharing, which are consistent with the group's Nash equilibrium appropriation of 112, 96, and 64, respectively.

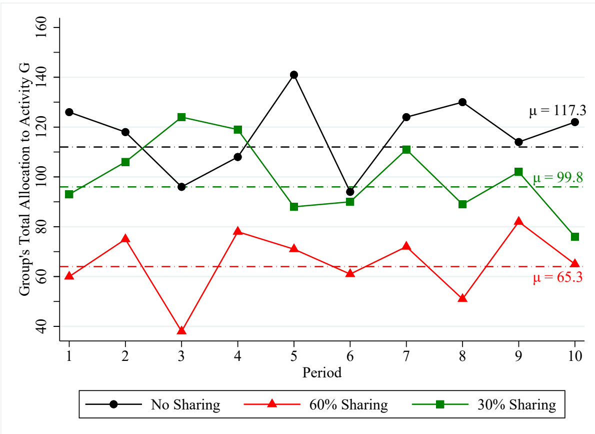
Result 1: Hypothesis H1 is supported. Group appropriation is significantly reduced under the output-sharing treatments compared to the baseline (i.e., no sharing).

Result 2: Hypothesis H2 is supported. The 60% sharing treatment achieved the lowest aggregate appropriation, indicating stronger restraint from over-extraction compared to the 30% sharing group. This trend aligns with Hypothesis 2, which suggested that higher sharing intensity leads to lower overall appropriation.

Figure 4 shows the mean aggregate appropriation for periods 4-9, excluding potential noise from early learning effects and end-of-period behavior. Figure 5 and figure 6 depict the mean aggregate appropriation by treatment for the two parts of the session (i.e., baseline followed by treatment). In figure 5 (baseline), there is a consistent trend where all treatment results in higher appropriation, indicating a typical CPRs over-extraction behavior. In figure 6 (treatment), both sharing treatments, 30% and 60%, lead to noticeable reductions in appropriation. The difference in appropriation between 30% and 60% sharing is clear, with 60% sharing approaching optimal levels of appropriation of 64.

4.2 Individual appropriation

Figure 7 and figure 8 depict the mean individual appropriation by treatment in the baseline and treatment part of the session, respectively. Consistent with the group-level results, individual appropriation is higher in the baseline part and decreases with the introduction of sharing treatments. This provides evidence that partial output-sharing encourages behav-



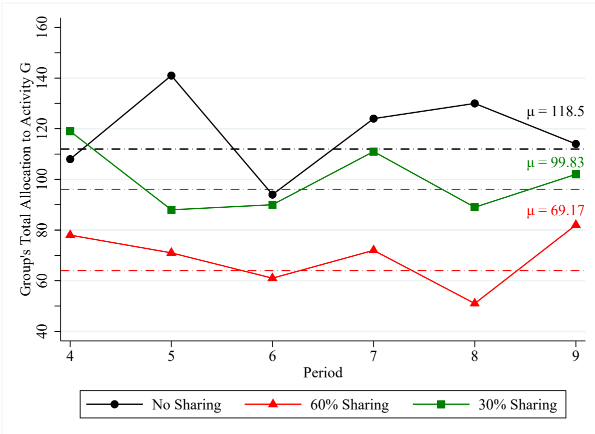
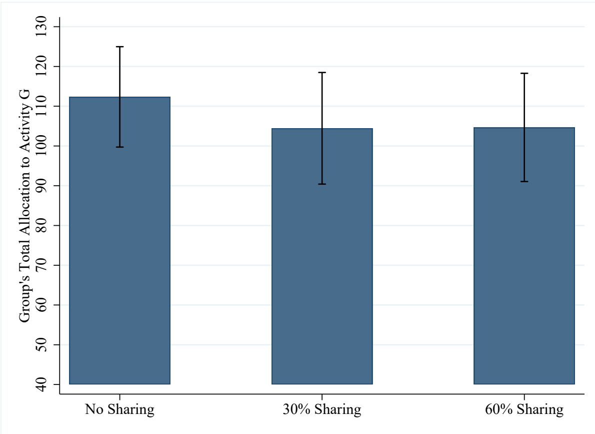


Figure 3: Aggregate group appropriation by treatment over periods 1 - 10

Figure 4: Aggregate group appropriation by treatment over periods 4 - 9



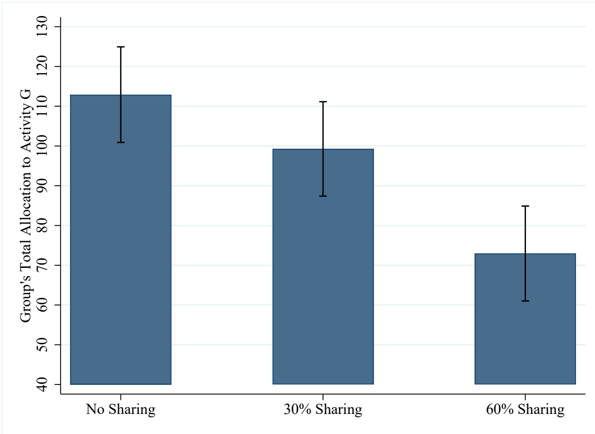


Figure 5: Mean aggregate group appropriation by treatment: Baseline

Figure 6: Mean aggregate group appropriation by treatment: Treatment

ioral changes at the individual level, leading to reduced extraction.

Figure 9 compares the theoretical predictions for individual appropriation—specifically the symmetric Nash equilibrium and social optimum benchmarks, as described in Figure 2—to the observed average decisions in each treatment. The theory predicts that as the proportion of sharing (λ) increases, average individual appropriation decreases, approaching the socially optimal level at 60% sharing. The observed mean individual appropriations are 14.1, 12.4, and 9.1, which are not statistically different from the theoretical predictions of 14, 12, and 8, respectively, at a 95% confidence level. This suggests that participants respond to the sharing incentives by reducing their resource extraction.

Result 3: Hypothesis H3 is supported. The mean individual appropriation in the 60% sharing treatment is 9.1, which is not statistically different from the socially optimal appropriation level of 8 at a 95% confidence level.

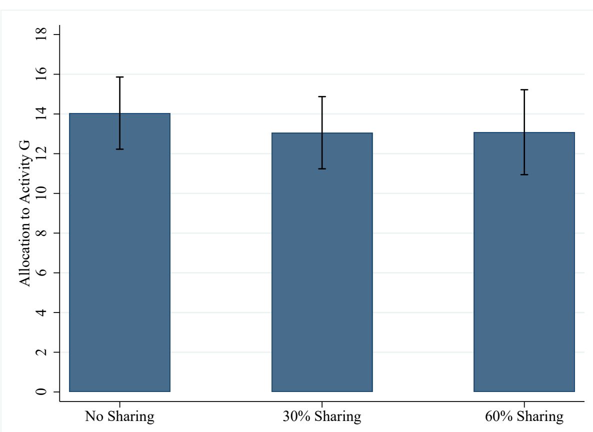


Figure 7: Mean individual appropriation by treatment: Baseline

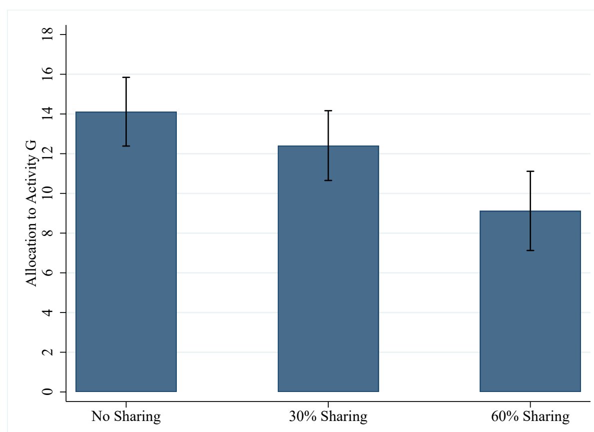


Figure 8: Mean individual appropriation by treatment: Treatment

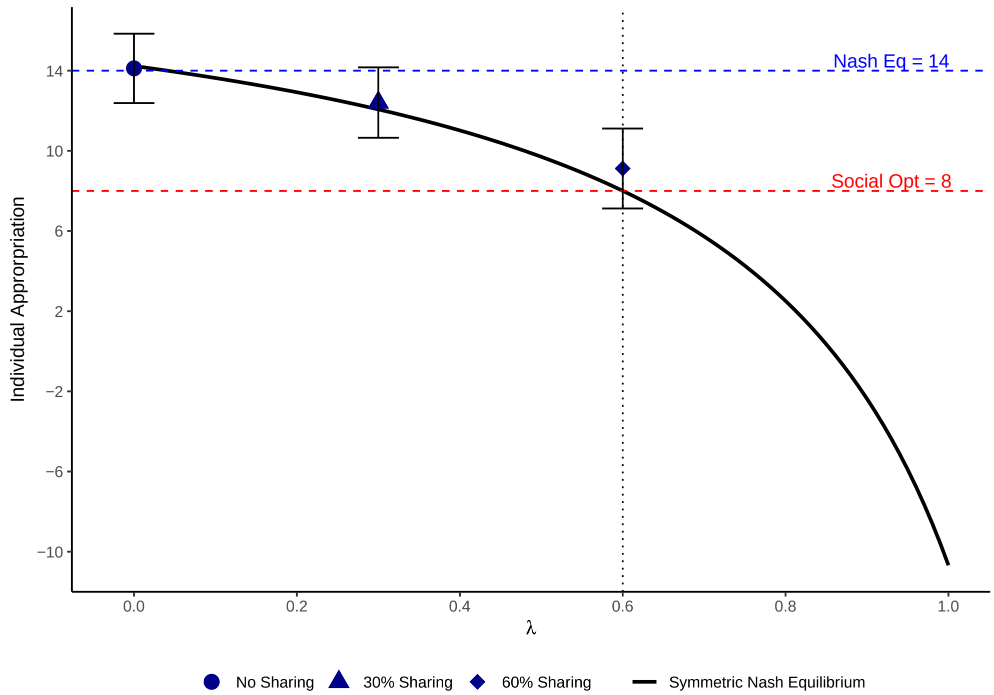


Figure 9: Theory prediction vs. mean individual appropriation by treatment

4.3 Earnings

Figure 10 shows the distribution of individual earnings in the treatment part of the session across different treatments. The median individual earnings (dotted lines) are highest under the 60% sharing treatment and lowest in the no-sharing baseline. Additionally, the variance of individual earnings is lowest under the 60% sharing treatment, as expected. This suggests that the social optimum is achieved in the 60% sharing treatment, supporting Hypothesis H3. The median individual earnings are lowest in the no-sharing baseline, indicating the over-extraction of CPRs. The median earnings increase as the intensity of partial sharing rises, implying that the output-sharing arrangement not only mitigates over-extraction but also improves earnings, benefiting participants collectively.

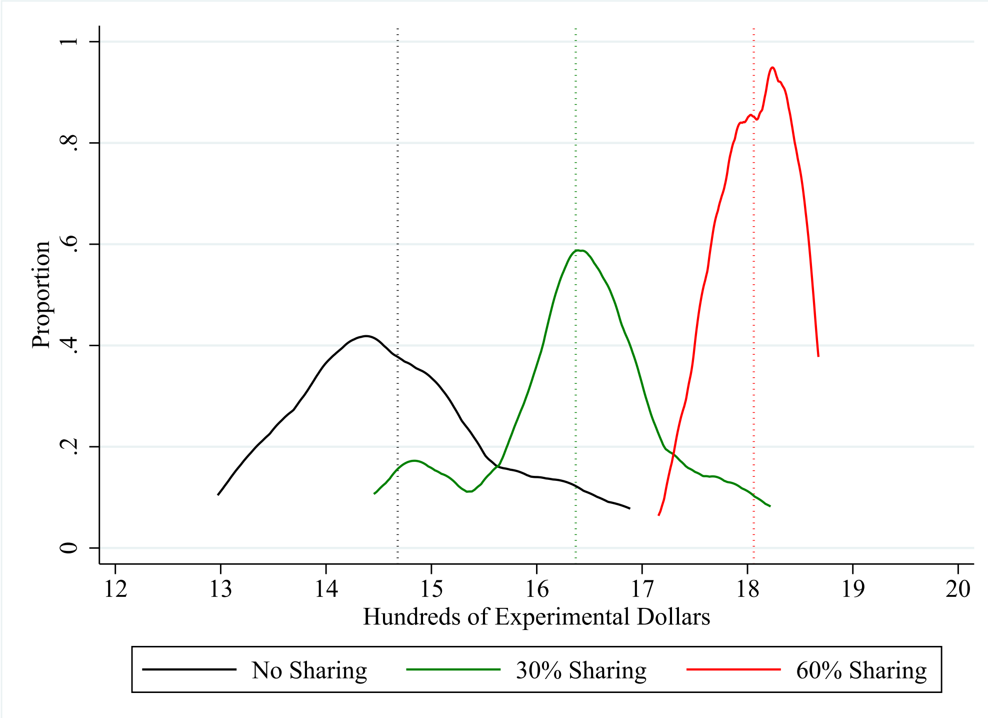


Figure 10: Distributions of individual earnings in treatment part

5 Conclusion

This study examined the effectiveness of partial output-sharing as a mechanism to manage common-pool resources (CPRs). Through a laboratory experiment, I tested the impact of different levels of output-sharing on individuals' resource extraction behavior. The results indicate that partial output-sharing significantly reduces over-extraction of CPRs and leads to higher collective earnings, thereby supporting socially optimal outcomes.

Specifically, the findings demonstrate that increasing the proportion of output shared among participants decreases the incentive to over-extract resources. The 60% sharing treatment resulted in appropriation levels that were not statistically different from the social optimum, while also showing the highest individual earnings with the lowest variance across participants. This indicates that the partial output-sharing model can effectively align individual incentives with the community's interest in resource sustainability.

The implications of these findings are substantial for designing CPR management policies.

The partial output-sharing model offers a promising alternative to traditional top-down regulatory approaches, as it preserves resource rents within the community, which enhances its political acceptability. Future research should explore the ways to implement this model, such as testing voluntary participation and management schemes.

Overall, the study suggests that partial output-sharing can be an effective tool to mitigate the 'Tragedy of the Commons' and improve sustainability outcomes for CPRs, benefiting all participants collectively.

6 Discussion

6.1 Policy implications

The results demonstrate the effectiveness of the partial output-sharing model in reducing over-extraction in the CPR environment. This suggests that the partial output-sharing model could be considered a potential policy tool to enhance the sustainability of common resources. Although it is challenging to conclude that the model will work in field settings based on evidence from a single laboratory experiment, this study provides valuable insights into a potential real-world solution.

6.2 Future works

The partial output-sharing model can be further tested in the laboratory with settings that resemble the real world. After sufficient knowledge of the model is gained from the laboratory experiments, the model can be tested outside the laboratory in the field, possibly a fishery, to provide insights on the implementation of the model.

6.2.1 Voluntary participation

The first extension of the partial output-sharing model is to let people freely join the sharing group. In the previous experiment, we forced every subject to be enrolled in the sharing group. However, in this experiment, all subjects are in a natural state, and they can decide whether to join the partial output-sharing group at the beginning of each round. To encourage the subject to join, a subsidy such as a sign-up bonus will be provided. Once they decided to join, they must stay with the group. This experiment would shed light on voluntary participation in resource preservation. It can also provide insights into how to implement the model in the real world.

6.2.2 Deciding how much to share: Centralized vs Decentralized

The second extension of the partial output-sharing model is to test which system of management is more efficient and more preferable. In the centralized setting, people will vote for the leader and the leader will choose how much to share among group members. In the decentralized setting, people will discuss and come up with an agreement of how much to share among group members. It would be interesting to see if subjects or the leader can find the optimum sharing arrangement and if subjects can achieve social optimum under the new settings. This experiment would shed light on the details of the implementation of partial output-sharing model in the real world.

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Appendix A. Subject Instructions

General Information

Welcome

No Talking Allowed

Now that the experiment has begun, we ask that you do not communicate with other participants. If you have any questions after we finish reading the instructions, please raise your hand and the experimenter will answer your question in private.

Complete Privacy

This experiment is structured so that no one, including the experimenters, the monitor, and the other subjects will ever know the personal decision of anyone in the experiment. Every person's privacy is guaranteed because neither his/her name nor student ID number will appear on any form that records decisions in this experiment.

Random Matching and Anonymity

In this experiment, you will be randomly assigned to a group of 8 people. The group you are assigned to will stay the same throughout each part. The group will be reassigned randomly at the beginning of Part 2.

Two Parts: 10 Rounds Each

In this experiment, there will be two parts, each consisting of ten rounds. Your final earnings will be the sum of the earnings from both parts.

Cash Payoffs

Your earnings in this experiment are expressed in EXPERIMENTAL Dollars (E$), which we will refer to as E$. At the conclusion of the experiment you will be paid in U.S. dollars using a conversion rate of $1 for every E$ 200 of earnings from the experiment.

E$ 200 = $1

If you read the instructions carefully and act wisely, you can earn a considerable amount of money. Your earnings in this experiment depend both on your decisions and the decisions of others.

If you have any questions, please raise your hand and wait for the experimenter to come and help you.

Part 1: S_0-Baseline

Settings
You will be playing an **effort allocation game** in a group of 8 people. In each round, you will decide how to allocate efforts between two different activities. Each round, you are endowed with **25 efforts** and must decide how many to allocate to **Activity F** and **Activity G**.

- **Activity F**: For each effort allocated to Activity F, you will receive a **fixed return of E$5**.

- **Activity G**: The return on efforts allocated to Activity G is **variable** and depends on the **total efforts allocated by the entire group, including yours**.

  The return for each effort allocated to Activity G is:

  $$\mathbf{20 - 0.1171 * (group's\ total\ effort\ allocated\ to\ Activity\ G)\ E\$\ per\ effort}$$

Note that the return from Activity G **decreases** as the total efforts allocated to Activity G by the group **increases**.

Your earnings for each round will depend on both **your own decisions** and the decisions of **others in your group**.

Multiple Rounds
The part 1 consists of **10 decision rounds**. In each round, you will face the same decision task, where you will allocate efforts between Activity F and Activity G.

Earnings
After everyone has submitted, the earnings of the round will be calculated and shown to you. For each round, your earnings are:

- Earnings from **Activity F**

- Earnings from **Activity G**

Your final earnings will be the sum of every round's earnings.

Example Calculations

Situation 1:
In round 1, assume the group's total allocation to Activity G is **80 efforts**. The return for each effort allocated to Activity G will be:

$$20 - 0.1171 \times 80 = 10.632 \ \textbf{E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 10.632 = \textbf{E\$ } 106.32$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \textbf{E\$ } 75$$

Thus, your total earnings for this round will be:

$$106.32 + 75 = \textbf{E\$ } 181.32$$

Situation 2:
In round 2, assume the group's total allocation to Activity G is **150 efforts**. The return for each effort allocated to Activity G will be:

$$20 - 0.1171 \times 150 = 2.435 \textbf{ E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 2.435 = \textbf{E\$ } 24.35$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \textbf{E\$ } 75$$

Thus, your total earnings for this round will be:

$$24.35 + 75 = \textbf{E\$ } 99.35$$

After everyone has submitted, the earnings of the round will be calculated and shown to you.

Rules

- The game consists of **10 rounds**.
- You will be **given 25 efforts** in every round and submit how much to allocate in Activity G.
- The return on Activity G is decided by the group's total allocation in Activity G.

$$\mathbf{20 - 0.1171 * (group's\ total\ effort\ allocated\ to\ Activity\ G)\ E\$\ per\ effort}$$

- The return on Activity A is **E$ 5** per effort.
- Your earnings for the round is:
  - Earnings from **Activity F**
  - Earnings from **Activity G**

- After everyone submitted, you will see your earnings.

Part 2: S_{60}-60% Partial-Output Sharing

Settings
You will be playing an **effort allocation game** in a group of 8 people. In each round, you will decide how to allocate efforts between two different activities.

But the following is new in this game:

Sharing Rule
Now you are **sharing 60% of returns from Activity G** with the group members. You will only keep 40% of returns from Activity G. This means that you will also **receive an equal amount from the group's share**. You will **not be sharing the returns from Activity F**.

Each round, you are endowed with **25 efforts** and must decide how many to allocate to **Activity F** and **Activity G**.

- **Activity F**: For each effort allocated to Activity A, you will receive a **fixed return of E$ 5**. You will **not be sharing the returns from Activity F** with anyone.
- **Activity G**: The return on efforts allocated to Activity G is **variable** and depends on the **total efforts allocated by the entire group, including yours**. In this game, you are **sharing 60% of the returns from Activity G** with the group members.

  The return for each effort allocated to Activity G is 40% of the following:

  $$\mathbf{20 - 0.1171 * (group's\ total\ effort\ allocated\ to\ Activity\ G)\ E\$\ per\ effort}$$

Note that the return from Activity G **decreases** as the total efforts allocated to Activity G by the group **increases**.

Your earnings for each round will depend on both **your own decisions** and the decisions of **others in your group**, as well as **the sharing rule for Activity G**.

Multiple Rounds
The part 2 consists of **10 decision rounds**. In each round, you will face the same decision task, where you will allocate efforts between Activity F and Activity G.

Earnings
After everyone has submitted, the earnings of the round will be calculated and shown to you. For each round, your earnings are:

- Earnings from **Activity F**

- **40%** of the Earnings from **Activity G**

- Earnings from the **group's sharing**

Your final earnings will be the sum of every round's earnings.

Example Calculations

Situation 1:
In round 1, assume the group's total allocation to Activity G is **80 efforts**. The return for each effort allocated to Activity G will be:

$$20 - 0.1171 \times 80 = 10.632 \textbf{ E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 10.632 = \textbf{E\$ } 106.32$$

Since you only keep **40%** of your returns, your personal earnings from Activity G will be:

$$10.632 \times 0.4 = 42.528 \approx \textbf{E\$ } 42.53$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \textbf{E\$ } 75$$

You will also receive **1/8 of the group's 60% share** of Activity G returns, which is:

$$(10.632 \times 80) \times 0.6 \div 8 = 63.792 \approx \textbf{E\$ } 63.79$$

Thus, your total earnings for this round will be:

$$42.53 + 75 + 63.79 = \textbf{E\$ } 181.32$$

Situation 2:
In round 2, assume the group's total allocation to Activity G is **150 efforts**. The return for each effort allocated to Activity G will be:

$$20 - 0.1171 \times 150 = 2.435 \textbf{ E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 2.435 = \textbf{E\$ } 24.35$$

Since you only keep **40%** of your returns, your personal earnings from Activity G will be:

$$24.35 \times 0.4 = \textbf{E\$ } 9.74$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \mathbf{E\$}\ 75$$

You will also receive **1/8 of the group's 60% share** of Activity G returns, which is:

$$(2.435 \times 150) \times 0.6 \div 8 = 27.393 \approx \mathbf{E\$}\ 27.39$$

Thus, your total earnings for this round will be:

$$9.74 + 75 + 27.39 = \mathbf{E\$}\ 112.13$$

After everyone has submitted, the earnings of the round will be calculated and shown to you.

Rules

- The game consists of **10 rounds**.
- You will be **given 25 efforts** in every round and submit how much to allocate in Activity G.
- The return on Activity G is decided by the group's total allocation in Activity G.

$$\mathbf{20 - 0.1171 * (\text{group's total effort allocated to Activity G})\ E\$ \text{ per effort}}$$

- The return on Activity A is **E$ 5** per effort.
- You must **share 60% of your returns from Activity G with group members**.
- The shared return will be **distributed equally to group members**.
- Your earnings for the round is:
  - Earnings from **Activity F**
  - **40%** of the Earnings from **Activity G**
  - Earnings from the **group's sharing**
- After everyone submitted, you will see your earnings.

Part 2: S_{30}-30% Partial-Output Sharing

Settings
You will be playing an **effort allocation game** in a group of 8 people. In each round, you will decide how to allocate efforts between two different activities.

But the following is new in this game:

Sharing Rule
Now you are **sharing 30% of returns from Activity G** with the group members. You will only keep 70% of returns from Activity G. This means that you will also **receive an equal amount from the group's share**. You will **not be sharing the returns from Activity F**.

Each round, you are endowed with **25 efforts** and must decide how many to allocate to **Activity F** and **Activity G**.

- **Activity F**: For each effort allocated to Activity F, you will receive a **fixed return of E$ 5**. You will **not be sharing the returns from Activity F** with anyone.
- **Activity G**: The return on efforts allocated to Activity G is **variable** and depends on the **total efforts allocated by the entire group, including yours**. In this game, you are **sharing 30% of the returns from Activity G** with the group members.

  The return for each effort allocated to Activity G is 70% of the following:

  $$\mathbf{20 - 0.1171 * (group's\ total\ effort\ allocated\ to\ Activity\ G)\ E\$\ per\ effort}$$

Note that the return from Activity G **decreases** as the total efforts allocated to Activity G by the group **increases**.

Your earnings for each round will depend on both **your own decisions** and the decisions of **others in your group**, as well as **the sharing rule for Activity G**.

Multiple Rounds
The Part 2 consists of **10 decision rounds**. In each round, you will face the same decision task, where you will allocate efforts between Activity F and Activity G.

Earnings
After everyone has submitted, the earnings of the round will be calculated and shown to you. For each round, your earnings are:

- Earnings from **Activity F**
- **70%** of the Earnings from **Activity G**
- Earnings from the **group's sharing**

Your final earnings will be the sum of every round's earnings.

Example Calculations

Situation 1:
In round 1, assume the group's total allocation to Activity G is **80 efforts**. The return for

each effort allocated to Activity G will be:

$$20 - 0.1171 \times 80 = 10.632 \textbf{ E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 10.632 = \text{E\$ } 106.32$$

Since you only keep **70%** of your returns, your personal earnings from Activity G will be:

$$106.32 \times 0.7 = \text{E\$ } 74.42$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \text{E\$ } 75$$

You will also receive **1/8 of the group's 60% share** of Activity G returns, which is:

$$(10.632 \times 80) \times 0.3 \div 8 = 31.89 \approx \text{E\$ } 31.9$$

Thus, your total earnings for this round will be:

$$74.42 + 75 + 31.9 = \text{E\$ } 181.32$$

Situation 2:
In round 2, assume the group's total allocation to Activity G is **150 efforts**. The return for each effort allocated to Activity G will be:

$$20 - 0.1171 \times 150 = 2.435 \textbf{ E\$ per effort}$$

If you allocate **10 efforts** to Activity G, your earnings from Activity G will be:

$$10 \times 2.435 = \text{E\$ } 24.35$$

Since you only keep **70%** of your returns, your personal earnings from Activity G will be:

$$24.35 \times 0.7 = 17.045 \approx \text{E\$ } 17.05$$

For your remaining **15 efforts** allocated to Activity F, your earnings from Activity F will be:

$$15 \times 5 = \text{E\$ } 75$$

You will also receive **1/8 of the group's 60% share** of Activity G returns, which is:

$$(2.435 \times 150) \times 0.3 \div 8 = 13.696 \approx \text{E\$ } 13.70$$

Thus, your total earnings for this round will be:

$$17.05 + 75 + 13.70 = \text{E\$ } 105.75$$

After everyone has submitted, the earnings of the round will be calculated and shown to you.

Rules

- The game consists of **10 rounds**.
- You will be **given 25 efforts** in every round and submit how much to allocate in Activity G.
- The return on Activity G is decided by the group's total allocation in Activity G.

$$\mathbf{20 - 0.1171 * (group's\ total\ effort\ allocated\ to\ Activity\ G)\ E\$\ per\ effort}$$

- The return on Activity F is **E$ 5** per effort.
- You must **share 30% of your returns from Activity G with group members**.
- The shared return will be **distributed equally to group members**.
- Your earnings for the round is:
  - Earnings from **Activity F**
  - **70%** of the Earnings from **Activity G**
  - Earnings from the **group's sharing**
- After everyone submitted, you will see your earnings.

Appendix B. Decision Screens

S_0-Baseline

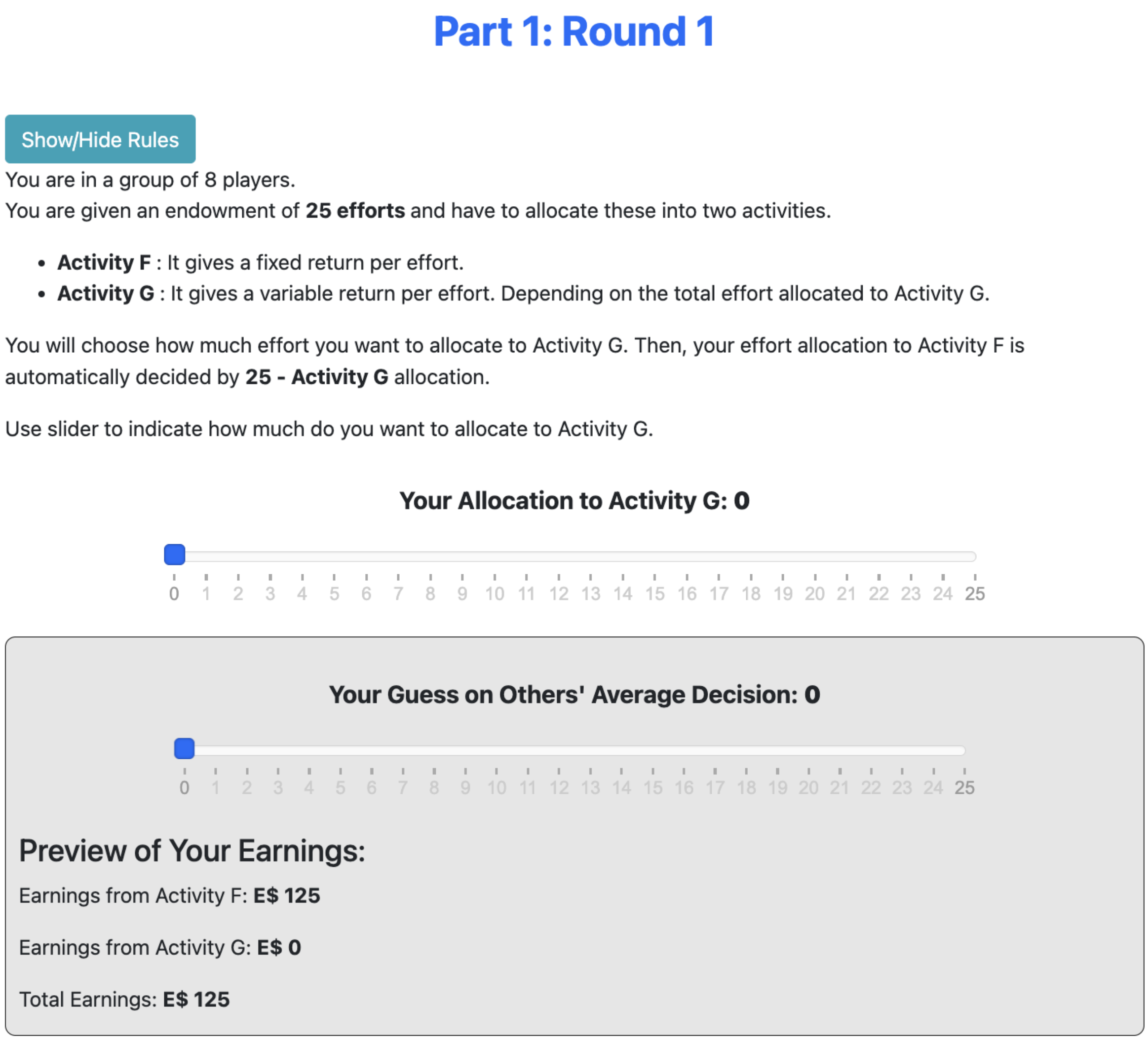

Figure 11: Decision page for S_0-Baseline

S_{60}-60% Partial Sharing

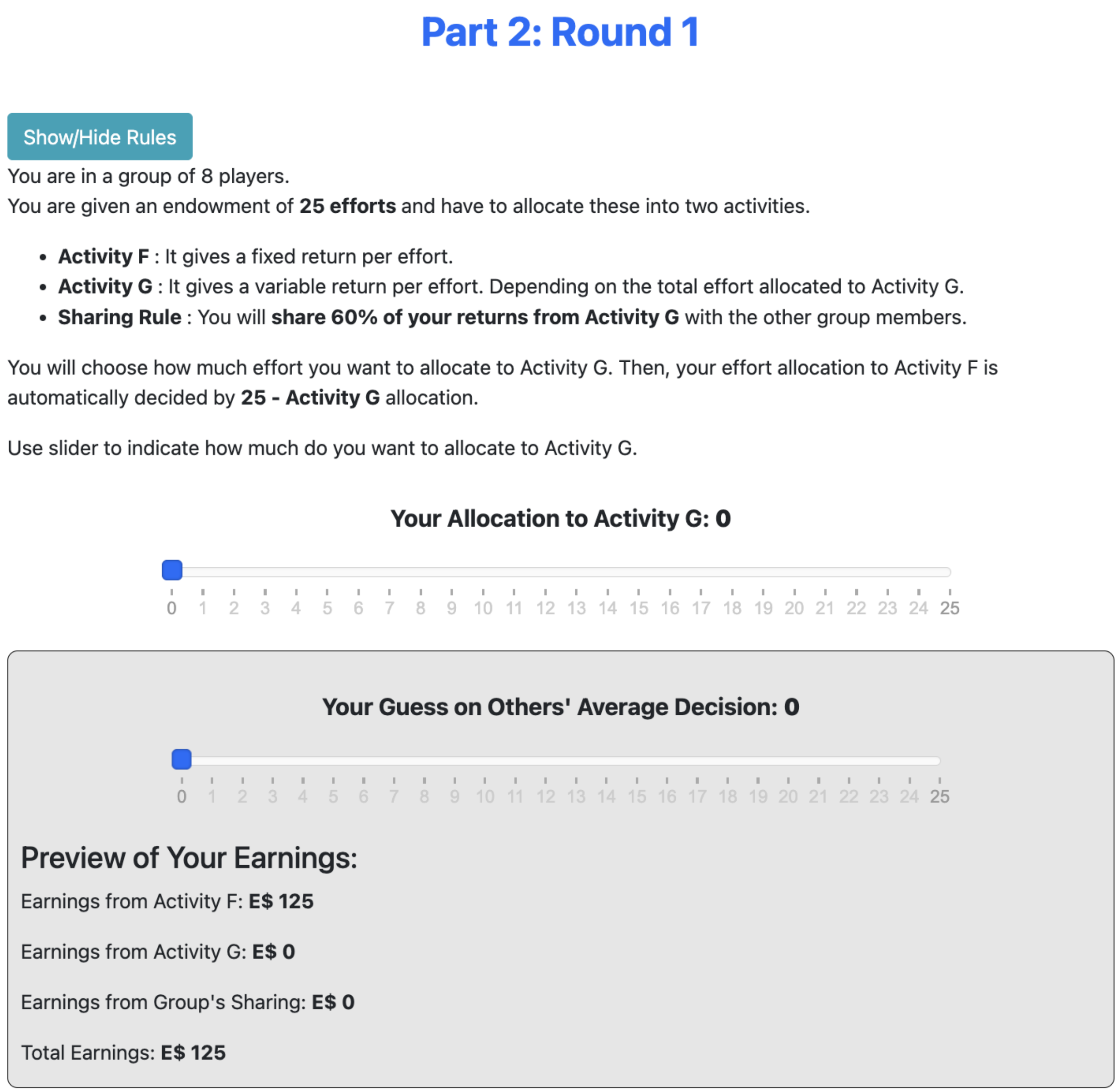

Figure 12: Decision page for S_{60}-60% Partial Sharing

S_{30}-30% Partial Sharing

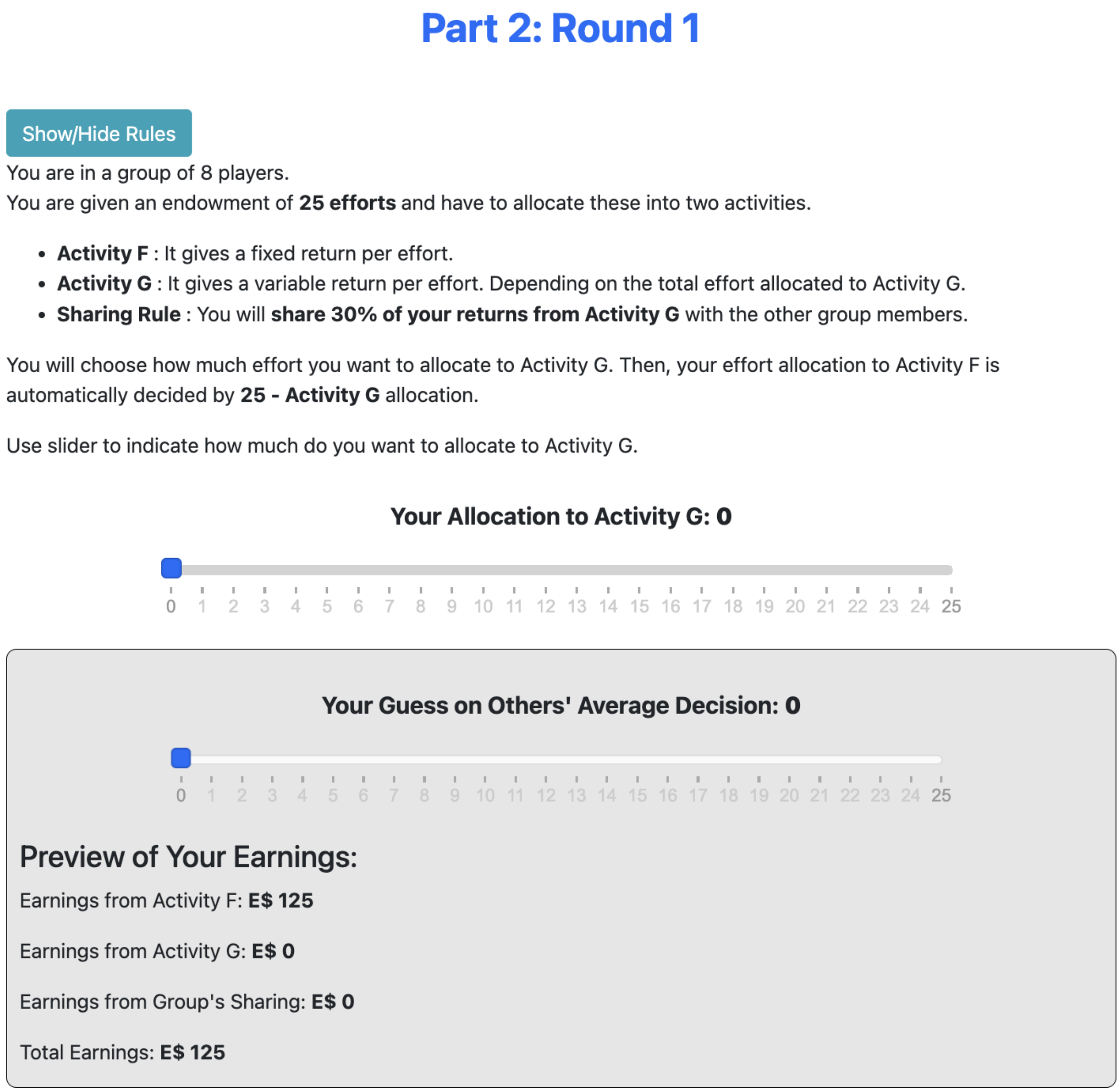

Figure 13: Decision page for S_{30}-30% Partial Sharing