Does water scarcity lead to overuse? Evidence from field experiments

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Abstract:

This paper presents the results from economic field experiments that aim to explore the behavioral responses of socio-economic agents to exogenous changes in resource availability. Subjects in the experiment are rural water users in Colombia that participated in a common pool resource (CPR) experiment in which the levels of the resource vary along the different stages of the game. In the first stage of the experiment all subjects played a baseline experiment with a high level of resource availability. In the second and third stages, the experimentalists exogenously changed the resource size. The results suggest that users take some time to reduce their extractions at stages where the size of the decreases moderately, but immediately extract more when the resource decreases to a size in which they can fully deplete it. Also, we show that experiencing a decrease in the size of the resource can accentuate rent-seeking behavior once the size of the resource rebounds. Lastly, we observe that the behavior of subjects at the specific rounds where the size of the CPR changes is mostly conditioned by whether the subjects have experienced a similar shock previously in the game.

Keywords: Artifactual Field Experiments; Common-pool resources; Water; Scarcity, Colombia.

JEL code: C93; Q25; H4; Q21.

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1. Introduction

Extreme water events such as the occurrence of droughts or floods can be associated either to ecological phenomena (such as increase or decrease in rainfall patterns), social phenomena (e.g. overexploitation of hydrological resources and human constructions in floodplains) or both. Regarding the former, there is strong evidence that rainfall changes are taking place at global and regional scales (Overpeck et al. 2010; Allan 2011; Min et al. 2011). These forecasts predict that rainfall changes will result in droughts and floods among other natural phenomena. Additionally, hydrological studies show that the impact of climate change escalates when considering that most rivers worldwide are within watersheds under great stress by human activities (including development, dams, or extractive uses) that reduce rivers' resilience to shocks (Palmer et al. 2008). Palmer et al (2009) present an overview of the predicted impact of anthropogenic stressors exacerbating climate change effects on river ecosystems. We focus on one of the most relevant stressors according to the authors: droughts driven by water extractions and climate change.

This study aims to contribute to the economic literature on drought management exploring the behavioral responses of socio-economic agents to changes in water availability by means of an experimental approach. Previous research has addressed the relevance of economic instruments (e.g. Merrett 2004; García-Vila et al. 2008), collective action (Ostrom 1990; Cox et al. 2011; Ostrom 2011), and land planning for drought management (e.g. Palmer et al. 2008). However research is still needed on the responses of users to changes in water availability from a behavioral perspective. A good understanding of the behavior of economic agents in contexts of water scarcity is particularly relevant for areas where users have historically enjoyed a situation of (relative) abundance and may not have developed traditional strategies to cope with water scarcity. It could be the case that these water users easily adapt to droughts, mitigating the impact of decreased rainfall or river flows. On the contrary, it could also be the case that they increase their extraction patterns, exacerbating the severity of the environmental shocks.

This paper analyzes how direct users of a watershed in rural Colombia behave in a common pool resource (CPR) economic experiment when confronted with changes in the size of the CPR. We frame the experiment as the management of a watershed by groups of users. Our design builds on recent experimental designs exploring subjects' extraction decisions in CPR games under different stock levels (Osés-Eraso et al. 2007; Osés-Eraso et al. 2008). Contrary to these studies, we undertake a within-subjects design where participants face up to three exogenous changes in the size of the resource along the experiment. This serves a twofold objective. First it allows us to investigate whether, and how, users adapt their extraction patterns to different levels of the CPR across stages. We discuss these findings by observing the averaged response of individuals to changes in the size of the resource at each stage (stage response). Second, the design enables us to explore the response of users in the round when shocks in the size of the resource take place. We explore those responses at the first round of the stages that involve a change in the size of the CPR (round responses). Additionally, we explore whether round-responses depends on the magnitude of the change in the size of the CPR, its direction (decrease vs. increase) or its repetition (fist time vs. second time shocks). Additionally, our experiments further contribute to previous research by conducting the experiments in the field, with individuals who make use of water resources in their daily productive activities.

Previous experimental research addressing the effects of changes in the size of CPRs supports that subjects restrain their extractions under increased resource scarcity but not in all contexts. Osés-Eraso and Viladrich-Grau (2007) use a static game exposing different subjects to CPRs of different sizes that are exogenously defined by the experimentalist. Their results support that the lower the initial stock level, the lower the average extraction level. Other authors have focused on endogenous scarcity by modeling dynamic games. Mason and Phillips (1997) introduce dynamic cost externalities into their design by allowing extraction costs to increase with the extraction levels in previous rounds. These authors find very little tendency for players to cooperate but still find that, in the advent of complete resource depletion, subjects reduce their harvests so that the stock rebounds. Adopting a different approach, Fisher et al (2004) allow for different regeneration rates in a dynamic CPR and find that users do not change extraction levels when the resource grows in a slow manner but reduce extractions when the resource grows fast. Other studies consider exogenous and endogenous sources of scarcity simultaneously. Rutte et al (1987) create a static resource dilemma game whereby both are incorporated. Their results support that subjects extract less when the resource is less abundant and that endogenous sources of scarcity imply lower extractions as compared to exogenous sources. Osés-Eraso et al. (2008) also combine endogenous scarcity (which in their case emerges from uses' extraction decisions in a dynamic CPR) with exogenous scarcity imposed by the experimentalist when defining different initial sizes of the CPR. Their findings support differences in responses of subjects to the different sorts of scarcity. While scarcer initial resources (exogenous scarcity) imply lover average appropriation trends, the bigger the scarcity endogenously driven, the larger the extraction levels. As the authors present it "agents' behavior tends to exacerbate the previous reduction in resource stock size." (p. 545). Similarly, Moreno-Sánchez and Maldonado (2010) find in a semi- dynamic CPR experiment[1] that when the size of the CPR in the previous round was high and in the current round is low, extraction significantly decreases.

[1] We refer to it as semi-dynamic because the experimental design allows two levels of stock availability, either

To overcome the comprehension critiques from dynamic games (such as those presented by Moxnes 2000), we present a within-subjects static design that simplifies the decision task but keeps the basic incentive structure to allow us to study how subjects behave when the size of the CPR varies along the game. Most importantly, dynamic CPR models are relevant for stock resources such as fisheries, forestry or groundwater systems, but static models are more compelling for the analysis of flow resources such as rivers. As long as there is no water storage facility (like a dam or an aquifer), the amount of water available for a community in a specific location of a river is exogenous to users (it depends on the ecological conditions and on the upstream extraction behavior), and water levels would be expected to vary over time[2]. Thus, we believe our static CPR game would better describe the structure of incentives that a particular community located in a specific location of the watershed may face.

Our results suggest that users take some time to reduce their extractions at stages where the size of the decreases moderately, but immediately extract more when the resource decreases to a size in which they can fully deplete it. Also, we show that experiencing a decrease in the size of the resource can accentuate rent-seeking behavior once the size of the resource rebounds. Lastly, we observe that the behavior of subjects at the specific rounds where the size of the CPR changes is mostly conditioned by whether the subjects have experienced a similar shock previously in the game.

2. Model and Experimental Design

abundant or scarce. Users start with the high level stock and can remain in that level if they do not extract above a certain level of the resource. In they do so, the whole group ends up in the low level stock.

[2] We do not consider in this illustration the (relevant) capacity of different communities sharing a certain watershed to coordinate for an integral management.

We follow the CPR model presented in Osés-Eraso and Viladrich-Grau (2007) and apply it in a within-subject experimental design with rural users of water resources in Colombia. In the experiment, we model the strategic decisions of a group of n players who can make use of a CPR of total size K_0 in experimental currency units. In the instructions the CPR was presented as a watershed. Each one of the n individuals, i, has an equal endowment e that can be invested in extraction of the CPR, or in a safe outside activity. Every unit invested in extraction, $x_i$where $x_i \in [1, e]$, yields w units for the subject; while every unit placed in the safe option yields α units for the subject, leaving the CPR unchanged. At the end of a round the size of the CPR, K_f, depends on the aggregate group units invested in the extraction, $X = \sum x_i$, as presented in equation 1.

$$K_f(X) = K_0 - cX \text{ ,where } c>1 \quad (1)$$

At the end of each round all remaining K_f units are evenly distributed among the n players. Therefore, the marginal benefit from investing in the safe option is $\alpha + \frac{c}{n}$ and payoffs for each player π_i depend on the vector of individual appropriators' investments in the resource $\boldsymbol{x} = (x_1, \dots, x_n)$, as presented in equation 2.

$$\pi_i(\boldsymbol{x}) = wx_i + \alpha(e - x_i) + \frac{K_f}{n}, \text{ where } w>0 \text{ and } \alpha>0 \quad (2)$$

In order to create a social dilemma for the extraction decision of the CPR we assume $(\alpha + \frac{c}{n}) < w < (\alpha + c)$. Consequently, investment in extraction from the CPR, is more efficient from the individual perspective, since marginal net benefit from extraction is higher than investment in the safe option (see Figure 1); that is $w > \alpha + \frac{c}{n}$. At the same time, at the aggregate group level investment in the safe option entails higher net benefits than investment in the common pool resource (see Figure 1); this is $w < (\alpha + c)$, and thus it is more efficient from the social perspective. In this game, the dominant individual strategy is full appropriation, $x_i = e$, while social efficiency requires a minimum level of resource extraction $x_i = 0$.

INSERT FIGURE 1 ABOUT HERE

Note that the level of the natural resource K_0 does not influence the incentive structure of agents. Both the Nash equilibrium and the social optimum are independent of the abundance or scarcity of the resource. Therefore, changes in subjects' extraction decisions under different levels of the CPR can be equally analyzed in absolute terms or as deviations from the Nash equilibrium. The values for each parameter used along the experiment are the same as in Osés-Eraso and Viladrich-Grau (2007) with the exception that our groups are of five rather than four players. Our parameters are presented in Table 1.

INSERT TABLE 1 ABOUT HERE

As described before, during the experiment three sizes (heretofore levels) of the CPR are evaluated: a high level (H), a medium level (M) and a low level (L) that appear at different stages of the game (each stage consist of 10 rounds). Subjects participate in one of the following treatments: HHH, HMM, HMH, HML and HLL, where each letter refers to the level of the CPR for each stage of the game (see Table 2). Notice that all treatments start with a high level of the CPR in stage 1, it decreases to a medium level in stage 2 for treatments HMM, HMH, HML and to a low level in treatment HLL. For treatment HML it decreases again in stage 3 and it increases for HMH. For HHH the level of the CPR remains constant for the whole experiment. By design, evaluating the different levels of the CPR implies the imposition of different shocks at the beginning of each stage of the game for some treatments. We will consider that a shock occurs at the round where the experimentalist exogenously changes the level of the CPR. Thus, for treatments HMH, HMM, HML, HLL there is a shock at round 11, and for treatments HMH, HML there is a shock at round 21.

INSERT TABLE 2 ABOUT HERE

We set the level of the CPR available in the low level $K_{0,L}$, so that when all players in a group extract their whole endowment, there is no resource left at the end of the round to be distributed among players $K_f(100) = 0$.[3] This results in $K_{0,L}$=300. Thus, with a low initial level, full-extraction by all users results in the exhaustion of the CPR. The medium level, $K_{0,M}$=450, is arbitrarily defined as 50% higher than the low level and the high level, $K_{0,H}$=675, as 50% higher than the medium level. Table 2 presents a summary of the different treatments, including the level of the CPR in every stage as well as the change in the size of the CPR from one stage to the other. Table 3 presents the Nash extraction prediction and the social optimum for the different levels of the CPR (100 and 0 respectively for all resource levels). Additionally, Table 3 includes the level of the CPR at the end of a round if all the subjects in the group behave as the Nash prediction (K_f Nash) as well as if all subjects behave following the social optimum (K_f social).

INSERT TABLE 3 ABOUT HERE

A total of 25 groups, evenly divided among five treatments (five groups per treatment), were conducted in different communities of the Colombian Coello watershed in July 2010. The Coello watershed is located in the central Andean Cordillera. It covers an area of 190,000 ha, ranging from 280 to 5300 meters above sea level and annual rainfall ranges from below 1000 mm to more than 3970 mm (Johnson et al. 2009). Currently water quantity is not a problem in the region, but there is a growing concern about future scarcity problems.

The recruitment process for these experiments was done with the aid of local leaders and NGOs. In the invitation to participate, the experiments were presented to

[3] This is aimed to avoid negative units of the resource to be distributed among players at the end of a round, which may be counter intuitive for rural users of water resources such as those participating in the experiments.

participants as a decision-making activity. In order to have a diverse sample we invited all the inhabitants of communities who were older than 18 years. People from the same household were not allowed to participate in the same group. In each session, we run the experiment with up to three groups of five subjects living in the same community. We started the experiment by reading aloud the instructions[4] and handing out the forms where users had to record their decisions. During the instructions, subjects were told that the experiment had three stages, each with 10 rounds and that they had to decide at each round how to allocate their endowment among the extractive activity or the safe option, as developed in the model above. In the instructions we emphasized that the game was static, meaning that extraction level in a round did not affect the size of the CPR in the next round or stage. Subjects were asked to remain silent for the entire experiment and to sit back to back so that it was impossible for them to see other participants' forms. Questions were responded to in private. Subjects played several practice rounds in order to familiarize them with the game and the different forms. Field assistants helped subjects with reading and/or writing difficulties; but in these situations participants had to make their own decisions and the assistant only transcribed the decision into the game forms. Each session lasted about four hours.

In all stages of the experiment, each subject had to write down his decision in a "decision card" that was collected by the experimenter. Once the experimenter collected the decision cards from the group, he announced in public the total extraction of the group, the level of experimental units remaining in the watershed and the resource share earned by each participant. Then, each subject was able to calculate his payoff in that round[5].

[4] Instructions are available upon request.

[5] Each one of the subjects participating in the experiment was provided with a calculator to facilitate all the calculations. Additionally at each round the experimenter was randomly verifying the calculations.

Table 4 presents socio-demographic characteristics of the subjects. Agriculture, livestock or daily labor in farms is one of the main economic activities of 52.8% of the participants. The majority of subjects participating in the experiment are males (63%), with an average age of 44 years and slightly more than 8 years of education. Further, most subjects (76%) have been living in the area for more than 10 years.

INSERT TABLE 4 ABOUT HERE

At the end of each session we calculated each person' earnings for the 30 rounds and paid in cash while subjects were filling a socioeconomic survey. Subjects' earnings ranged from 8,322 to 18,037 Colombian pesos with an average of 13,218 pesos (about US $7.27[6])

3. Results

Figure 2 provides an overview of the average individual extraction level in each stage of the experiment, differentiating for subjects playing under the different levels of the CPR. The first panel in Figure 2 represents average individual extraction in rounds 1 to 10 (stage 1) for all treatments. In the first stage of the experiment average extraction for all treatments is around 7.2, (out of an endowment of 20), Thus, consistent with previous findings in the field (Cardenas et al. 2000; Lopez et al. 2010; Cardenas 2011) individual decisions without external regulations or communication falls between the Nash equilibrium and the social optimum. The remaining six panels in Figure 2 represent individual extraction of subjects playing under a high, medium and low CPR levels at stage 2 and stage 3.

INSERT FIGURE 2 ABOUT HERE

[6] At the time of the experiment the exchange rate was 1,819.06 pesos for one dollar. The daily wage in the area was 8 dollars.

We undertake an econometric analysis of the data based on a panel dataset of 125 unique subjects over 30 rounds, for a total of 3750 observations. We regress individual extraction as a continuous variable in four individual fixed effects models. In Model 1 (column 1 of Table 5), we examine differences in individual extraction across CPR levels (high, medium and low), without considering the sequencing of those levels across the different stages of the game. Variables M and L are dummies representing medium and low levels of the resource. The constant in this model is average individual extraction under the high CPR level. Thus, the coefficients provide information about differences in average individual extractions under a medium or low level of the CPR vs. the high level. This simple model shows that the extraction behavior of subjects under the medium level condition (M coefficient) is not statistically different from the behavior of subjects under the high level condition (constant). [7] Alternatively, average individual extractions under the low level condition (L coefficient) are significantly higher (1% level) than extractions under the high level condition. Further, the difference between extractions under the medium level condition and the low level condition is significant (p=0.018[8]). That is, subjects extract significantly more under the low level condition.

INSERT TABLE 5 ABOUT HERE

In Model 2 (column 2 of Table 5), we introduce a set of variables for different interactions between the stage of the game and the level of the CPR. The intercept in this and subsequent models in Table 5 is the average individual extraction of individuals facing the high level condition at stage 1. Hstage2 and Hstage3 are dummy variables for subjects

[7] The Baltagi-wu LBI test for Model 1 is 1.692, which is close to 2. Therefore, after controlling for individual fixed effects autocorrelation is not a problem in our data and our estimates are consistent. The value of the test for Models 2, 3 and 4 is 1.694, 1.693 and 1.695 respectively.

[8] Unless otherwise noted, statistical comparisons of regression coefficients were conducted with Wald tests.

playing under a high CPR level at stage 2 in the first case and at stage 3 in the second. Variables Mstage2 and Mstage3 and variables Lstage2 and Lstage3 are the corresponding dummy variables for a medium and low CPR levels at stages 2 and 3. Model 2 shows that average individual extractions under the high resource level condition at stages 2 and 3 are not significantly different from average individual extractions under the high level at stage 1. Additionally, average individual extractions under a high level at stages 2 and 3 are not significantly different from each other (p=0.43).

Results from Model 2 also show that subjects change their extraction patterns when the level of the CPR varies along the game. The medium level condition results in a decrease of individual extractions with respect to the high level at stage 1, yet these reduced extractions are only significant for stage 3 at the 5% level of significance (see coefficients of Mstage2 and Mstage3 in Model 2). For the low level condition we obtain the opposite result; extractions increase with respect to the first stage of the experiment but again only significantly for stage 3, in this case at the 1% level of significance.

In Model 3 (column 3 of Table 5), we test for the robustness of results in Model 2 by controlling for response of subjects to the specific rounds at which a change in the resource level (i.e. shock) occurs. The variable Round 11 H-M is a dummy capturing the effect of the shock from a high to a medium level at round 11. This shock occurs in treatments HMM, HMH and HML. Variable Round 11 H-L is a dummy capturing a shock from high to a low level at round 11, which occurs in treatment HLL. Two other variables are included capturing different shocks occurring at round 21. Variable Round 21 M-L, captures a reduction from medium to low level, and Round 21 M-H an increase from medium back to high level. The sign and significance of coefficients for the stage-response of subjects in Model 3 do not vary with respect to those in Model 2. The sole exception is variable Lstage2, which is now statistically significant at the 5% level of significance. Thus, reinforcing results in Model 1, subjects playing under a low resource level condition extract more than in the baseline, both at stages 2 and 3 (see coefficients of Lstage2 and Lstage3 in Model 3).

Stage results from Model 1 and 2 are summarized in Result 1 and Result 2. The results regarding the shock variables will be explored later in the paper.

Result 1: Subjects show a slow response to the medium level condition; when they respond they reduce their extraction levels.

Subjects under the medium level take time to react to the (slightly) scarcer environment, i.e. a 33.3% reduction from the high to the medium CPR level. Further, when they react, they show more cautious extraction levels than in the baseline situation (i.e. high resource level condition at stage 1).

Result 2: Subjects show a fast response to the condition where it is possible to fully deplete the CPR (low level); when they respond they increase their extraction levels.

Sharp reductions in the level of the CPR, i.e. from a high level at stage 1 to a low CPR level at stage 2, result in a change in behavior straight from the second stage. Under the low resource level, subjects increase extractions (both at stage 2 and 3) as compared to their extractions under the high level. The faster reaction of subjects to the low level than to the medium level might be due to the higher magnitude of the change from the high to the low CPR level higher (-55.5%) than from the high to the medium level (-33.3%).

We next continue exploring subjects' responses at a stage depending on their previous experiences during the game. In Model 4 (column 4 of Table 5) we extend model 3 by controlling the behavior of subjects at stage 3 depending on the level they had been exposed at stage 2. Variable (H)Hstage3 is a dummy for subjects who had been exposed to a high resource level at stage 2 and were playing under a high level at stage 3, whereas variable (M)Hstage3 is for subjects that had been confronted to the medium level at stage 2 and played under the high level at stage 3. Similarly variables (M)Lstage3 and (L)Lstage3 identify subjects that had been exposed to a medium and low levels at stage 2 respectively and played under a low level at stage 3. All subjects playing under a medium level at stage 3, had also experienced a medium level at stage 2, so no further variables were introduced in the model.

Results 3, 4 and 5 summarize subjects' average individual response at a stage depending on the CPR levels they have been exposed to at previous stages and result 6 does so for specific rounds at which the resource level changes.

Result 3: When the level of the resource does not change for the high and low levels, subjects do not change behavior.

This result holds firstly for subjects playing under the high level during the three stages of the experiment. Both in Model 3 and 4 the difference between average extraction for the high level at stage 2 and 3 is not significant (p= 0.45 and p= 0.16 respectively). Secondly, the result also holds for subjects that play under the low level at stage 2 and continue to play that level at stage 3. We do not find statistical differences between average individual extraction of subjects playing under the low level condition at stage 2 and stage 3 in model 4 (p=0.29). Thus, our results indicate that prolonged exposition to a low level of the CPR does not entail a continuous increase of average extractions.

Result 4: When deepening the decrease from a medium to a low level, subjects do not behave significantly different than those who directly experienced the low level condition.

We did not find a statistical difference (p=0.329) between the average individual extractions at stage 3 of those subjects who played under the low level condition at stages 2 and 3 and extractions at stage 3 of those who played under the medium condition at stage 2 and moved to a low condition just at stage 3. This means that when players face a low level at stage 3 the level of the resource with which they placed at stage 2, does not behave a significant influence in their behavior.

Result 5: After recovering from a medium level back to a high level, subjects extract more than those who did not experience a reduction in the resource at stage 2.

A Wald-test comparison of individual extractions under a high resource level at stage 3, shows significant differences (p= 0.053) between individuals who had played under the medium and a high level at stage 2. More precisely, subjects who were confronted to a moderate scarcity situation at stage 2 extracted significantly more when exposed back to a high resource level at stage three than those who were not exposed to a scarcity situation at stage 2. This suggests that previous scarcity experiences during the game can influence subjects' stage-response to subsequent changes in the level of the resource.

Result 6: Repetition of a shock in the same direction affects individuals' round response but not the stage response.

In models 3 and 4 we find different round-responses of subjects to different exogenous shocks in the level of the CPR. None of the first shocks of the game (-33.3% change from high to medium level at stage 11 and a -55.5% change from high to low level at round 11)) significantly affect individuals' behavior. However in the second shock (from the second to the third stage of the experiment, i.e. round 21) we see some variations. When the shock entails an increase in the resource level from medium to high level (variable Round 21 M-H) we do not find any significant response. Only variable Round 21 M-L capturing a -33.3% change from a medium to low CPR level is statically significant, at the 1% level. Subjects exposed to this shock had already experienced a -33.3% shock at round 11. According to the coefficient of Round 21 M-L, subjects reacted to the shock at round 21 by reducing their extractions in more than two units at that round. This effect is particularly relevant when compared to the not-significant effect of the Round 11 H-L, which represents a bigger reduction in the size of the CPR (-55.5%). This suggests that the repetition of a shock in the same direction rather than its magnitude might drive the reaction by users. Yet, the reduced extractions in response to the Round 21 M-L shock are short-termed. The reduction of subjects' extraction levels at round 21 dissipates along the stage. Participants' behavior over the remaining rounds entail an increasing extraction levels to the point that the average individual extraction for the stage is bigger than under the high level condition and not different from the behavior of participants playing under other low level conditions (see Result 4).

4. Conclusion

In this paper we aim to model the effect of exogenous ecological changes on the behavior of natural resource users when reducing the amount of natural resources. We do so by conducting a CPR experiment where subjects face different levels of the CPR at different stages of the experiment. More precisely, we explore whether average individual extractions vary across different levels of the CPR. For this purpose we developed different specifications of a fixed effects model explaining average individual extractions. By means of those specifications, we controlled the analysis for different levels of the resource, both alon and in interaction with the stages of the experiment, as well as for the effects of the specific rounds when changes in the level of the resource were introduced,

Our findings support that the individual behavior is sensitive to the level of the resource. When decreases in the level of the resource do not put resource conservation in jeopardy, subjects do not change average individual extractions at stage 2 but significantly reduce extractions at stage 3. That is to say, subjects take some time to react but do so by restricting their extraction levels. On the contrary, when the decrease in the level of the resource is large enough that there is a risk of resource exhaustion, individuals respond more selfishly by increasing extractions. This result contrasts with previous between-subjects findings in the lab (Osés-Eraso et al. 2007) supporting further reductions in extraction levels the lower the size of a CPR. Alternatively, our results with users of a watershed are consistent with the observation by field researchers presented by Ostrom's (2009) on the curvilinear relationship between cooperation and resources productivity.

According to the author, users of resources, including water sources, need to be exposed to some (but not much) scarcity before cooperative strategies emerge. But when the resource is close to depletion, users do not see any benefit on cooperation and then follow selfish strategies. Our findings suggest that experiencing changes in the size of the CPR can affect not only the direction of the individual responses of users but also the speed at which they adjust to the new conditions.

Also, we show that individual extractions of users who experienced moderate scarcity in previous rounds increase when the size of the resource levels up to the initial size. Thus, not only the level at which a subject plays, but also her previous experience during the game affects their behavior. Similarly, subjects' round-reaction to shocks in the size of the CPR is significantly affected by whether subjects have previous experience with similar shocks rather than by the magnitude of the shock or its direction. This latter result supports scholarship relating frequency of experiences to the emergence and maintenance of cooperation (Ostrom et al. 1994) as well as policy effectiveness (Bennett et al. 1992). Policies addressing frequent events have higher probability of being effective in mitigating the negative effects deriving from the events as a result of adaptive policy-making. For example, drought policies in regions with frequent drought events have evolved over the years to provide effective responses adapted to the local conditions.

All our results should be interpreted as providing some information on short-term subjects' reaction to changes in the availability of water resources. Within our game there was no scope for relevant responses in real life settings such as collective strategies, institutional adaptation or technological improvements, which take time to be implemented. Yet, all these have been shown to be relevant in CPR users' responses to scarcity (Ostrom 2009) and deserve consideration in future research. This does not diminish the importance of our results insofar both short-term and long-term reactions are potentially relevant for sustainability success. The relevance of short-term reactions rests on the fact that these determine the pressures over resources during the transition to long-term strategies. If pressures surpass the regenerative capacity of renewable resources during the process of developing adaptations to the new conditions the resource may deplete.

Our results support the need of further experimental research addressing the relationship between the magnitude of changes in the level of resources and users' reactions. The low level of the CPR that we evaluate in this study entails a total depletion of the resource if all members of a group extract according to the Nash equilibrium but we cannot assess if subjects' rent seeking behavior would be aggravated or tempered under an even lower level of a CPR. Similarly, our focus is on scarcity conditions, that is why our treatments mainly focus on reductions in the size of the CPR and only one treatment (HMH) considers an increase in the resource (from stage 2 to stage 3). Future research aiming to generalize our design to changes (not necessarily entailing scarcity) may consider evaluating treatments testing the behavior of subjects when exposed to a low level in stage 2 and then to a high or medium levels at stage 3.

Other open questions for further research include, to mention a few, the effect of communication, uncertainty and other contextual variables in subjects' response to scarcity shocks. Further, most empirical and experimental applications do not take into consideration that risk and time preferences may influence the way users make decisions about their extraction patterns in contexts of uncertainty due to resource stock variability.

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TABLES AND FIGURES

Table 1. Parameter values of the model for the experimental game.

Parameter	n	E	w	c	α
Value	5	20	2	3	1

Table 2. Resource levels for different treatments and scarcity shocks

Stage	Stage 1 Rounds 1-10	Shock Round 11	Stage 2 Rounds 11-20	Shock Round 21	Stage 3 Rounds 21-30
Treatment HHH	$K_{0,H}$=675	No	$K_{0,H}$=675	No	$K_{0,H}$=675
Treatment HMH	$K_{0,H}$=675	-33.3%	$K_{0,M}$=450	+50%	$K_{0,H}$=675
Treatment HMM	$K_{0,H}$=675	-33.3%	$K_{0,M}$=450	No	$K_{0,M}$=450
Treatment HML	$K_{0,H}$=675	-33.3%	$K_{0,M}$=450	-33.3%	$K_{0,L}$=300
Treatment HLL	$K_{0,H}$=675	-55.5%	$K_{0,L}$=300	No	$K_{0,L}$=300

Table 3. Initial levels of the resource and final levels for group extractions in the Nash behavior and Social Optimum.

Levels	K_0	X Nash	X social	K_f Nash	K_f social
High	675	100	0	375	675
Medium	450	100	0	150	450
Low	300	100	0	0	300

Table 4. Subjects' Socio-Economic Characteristics

Number of participants	125
Percent Male	63
Mean age	44
Percentage of people living in the area for over 10 years	76
Mean years of formal education	8.06
Percentage of people who mainly live from agriculture or working for days in farms	52.8

Table 5. Panel individual fixed effects OLS of number of individual extraction from the CPR.

Independent variables	(1)	(2)	(3)	(4)
M	0.132			
	(0.238)			
L	0.820***			
	(0.238)			
Hstage2		0.380	0.395	0.124
		(0.349)	(0.350)	(0.375)
Hstage3		0.105	0.134	
		(0.253)	(0.257)	
(H)Hstage3				-0.408
				(0.375)
(M)Hstage3				0.591*
				(0.354)
Mstage2		-0.245	-0.253	-0.211
		(0.207)	(0.214)	(0.223)
Mstage3		-0.725**	-0.738**	-0.717**
		(0.341)	(0.341)	(0.342)
Lstage2		0.531	0.660*	0.804**
		(0.349)	(0.361)	(0.385)
Lstage3		0.791***	0.926***	
		(0.253)	(0.257)	
(M)Lstage3				0.713**
				(0.354)
(L)Lstage3				1.216***
				(0.375)
Round11H-M			-0.193	-0.193
			(0.511)	(0.510)
Round11H-L			-0.604	-0.604
			(0.884)	(0.884)
Round21M-L			-2.481***	-2.320***
			(0.871)	(0.884)
Round21M-H			-0.646	-0.947
			(0.871)	(0.884)
Constant	7.010***	7.118***	7.118***	7.118***
	(0.102)	(0.119)	(0.119)	(0.119)
Observations	3750	3750	3750	3750
Number of individuals	125	125	125	125

*Note: The dependent variable in Models 1-4 is individual extractions from the CPR. The intercept in Model 1 is all observations of subjects playing under a high level conditions, and on Models 2-4 the observations of subjects in the high level condition in the first stage of the game. *,** and *** indicate 10%, 5% and 1% levels of significance respectively. Standard errors are in parenthesis.*

Figure 1. The problem of the game from the perspective of leaving units in the resource.

MB_G represents the marginal benefit at the group level and MB_i and MC_i the marginal costs and benefits at the individual level of leaving (not extracting) one unit in the CPR.

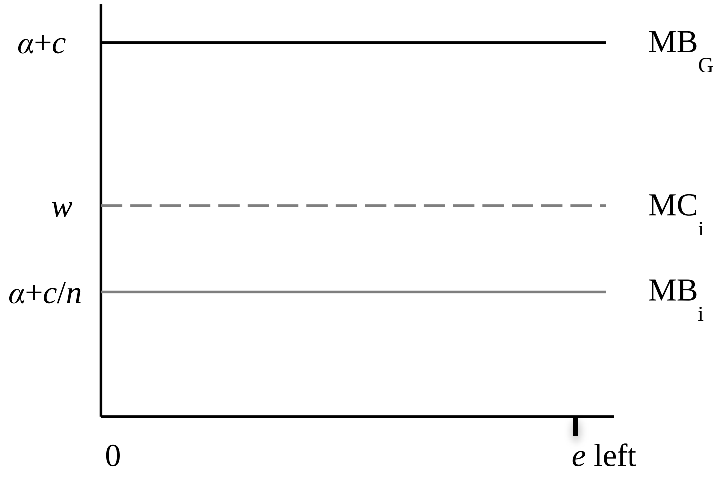

Figure 2. Average individual extraction levels for each treatment and stage of the game.