Does water scarcity lead to overuse? Evidence from field experiments

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Abstract:

The increased variability in rainfall patterns due to external shocks such as climate change can lead to different adaptive actions by socio-economic agents. This paper presents the results from an economic field experiment aiming to explore the responses of rural water users in Colombia to exogenous changes in the availability of water resources. Subjects participated in a within-subjects common pool resources experiment with different levels of the resource along the game. In the first stage of the experiment all subjects played in a baseline with a high level of the resource. In the second and third stage the experimentalists exogenously changed the resource available from the baseline treatment. Our results suggest that users extract more when the level of the resource is low enough for them to fully deplete it.

Keywords: Artefactual 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 or human constructions in floodplains) or both. There is strong evidence that rainfall changes are taking place atglobal and regional scales (Allan, 2011; Min et al 2011; Overpeck and Udall, 2010). Forecasts predict that these changes will result in droughts, floods, frosts and fire events. A historical analysis shows that all of these events have been related to crises in agrarian wealth and overall economic growth in preindustrial societies in Europe (Büntgen et al 2011). 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 impacts of climate change on river ecosystems that may be exacerbated by anthropogenic stressors. We focus on one of the most relevant of these interactions according to the authors: droughts driven by climate change and water extraction.

This study aims to provide relevant information for drought management from an experimental approach. Drought management will be an increasingly relevant policy arena as a result of the predictions of continued declines in rivers' flows (Overpeck and Udall, 2010). Previous research has addressed the relevance of economic instruments (e.g. García-Vila et al. 2008, Merrett 2004), collective action (Cox and Ross, 2011; Ostrom 1990, 2011), and land planning for drought management (e.g. Palmer et al 2008), but has so far ignored behavioral responses of users to changes in the availability of resources. It could be the case that 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 level of the CPR. We frame the experiment as the management of a watershed by groups of users. More precisely, our design builds on recent experimental designs exploring subjects' extraction decisions in CPR games under different stock levels (Osés-Eraso and Viladrich-Grau 2007; Osés-Eraso et al 2008). Contrary to these studies, however, we undertake a within-subjects design where participants face up to three different exogenous levels of the resource along the experiment. This serves a twofold objective. First it allows us to comprehend whether and how users adapt their extraction patterns when playing under different levels of the CPR. And second, it enables us to investigate the response of users to exogenous shocks understood as changes (decreases or increases) in the level of the CPR exogenously imposed by the experimentalist. We will explore whether the reaction to shocks depends on its magnitude, direction or repetition. Additionally, contrary to Osés-Eraso and Viladrich-Grau (2007) and Osés-Eraso et al (2008), we conduct the experiments in the field, with individuals who make use of water resources in their daily productive activities.

From a broader perspective, this paper contributes to a recent literature stressing the need to integrate the study of ecological variables (as a type of contextual variable) into experimental studies (see Anderies et al 2011). Studies in this direction can capture closely the ecological reality of participants in experiments, test the external validity of field experiments as well as increase the relevance of behavioral experiments (Cardenas et al forthcoming, Janssen 2010). Previous experimental research addressing the effects of changes in the size of CPRs arrives at different conclusions. A first group of studies support that subjects show concern for resource scarcity, which implies a reduction in extraction levels (Fischer et al 2004; Mason and Phillips 1997; Osés-Eraso and Viladrich-Graou, 2007; Osés-Eraso et al 2008). On the contrary, Maldonado and Moreno (2010) find that increased scarcity exacerbates the tragedy of the commons. Osés-Eraso et al (2008)[1] investigate scarcity in two manners, first endogenously through a dynamic game where users action have consequences in resource availability in the following rounds; and secondly exogenously by imposing different starting levels of the CPR for different groups of players. Their results support that low initial levels of the CPR limit subjects' extraction because it induces caution for the subsequent rounds. A drawback of their experimental design is that, as the authors recognize, combining environmentally-induced (exogenous) and human-induced scarcity (endogenous) entails a difficulty in disentangling the effects of both factors in appropriation strategies. Other studies have addressed this limitation focusing only on either exogenous or endogenous scarcity. Osés-Eraso and Viladrich-Grau (2007) use a static game exposing different subjects to CPRs of different resource sizes. Their results support that the lower the initial stock level, the lower the average appropriation (extraction) level. Other authors have focused only on endogenous scarcity by modeling dynamic games. Mason and Phillips (1997) introduce dynamic cost externalities into their design by allowing extraction costs of a resource to be negatively related to 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 (although staying at a socially sub-optimal level). The result that restrained resource use may not be sufficient to achieve a

[1] Rutte et al (1987) create a resource dilemma game whereby both exogenous and endogenous sources of scarcity are considered. They develop a one-shot game and with sequential decisions. 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.

socially optimum level of a CPR in a dynamic (inter-generational) game is also supported by Fischer et al. (2004). Maldonado and Moreno (2010) conducted a semi- dynamic CPR experiment[2] with individuals from eight fishing communities in Colombia. As opposed to previous laboratory results, their findings support that players over-extract the resource when confronted with a situation of scarcity, even if this constitutes inefficient behavior from an economic perspective.

However, results from dynamic games need to be accepted with caution, as previous literature has shown that subjects have problems understanding that kind of games (Moxnes 2000). This is particularly relevant in field experiments in rural impoverished communities where education and literacy levels are low (Cardenas and Carpenter 2008, Lopez et al. forthcoming, Anderies et al 2011). Therefore, it could be claimed that the inconsistency of findings from laboratory and field experiments may be due to the complexity imposed by the dynamic game to participants with low literacy levels. But it could be also the case that the results respond to participants in the field taking into account other aspects affecting their utility functions in addition to the monetary payoffs when making their decisions (as supported by Cardenas and Ostrom 2004). To overcome the comprehension critiques from dynamic games, 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 under different levels of the resource.

Additionally, 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 in the river in a specific location of the watershed

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

for a given community is exogenous to them (it depends on the ecological conditions and on the upstream extraction behavior), and it might vary over time[3]. Thus, 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 extract more when the level of the resource gets low to fully deplete it. Extraction patterns for intermediate resource levels are not consistent across treatments. In this paper we also explore the responses to resource level shocks and we find that only when a shock is repeated do subjects react to it. Results 1-5 develop these findings in detail.

The rest of the paper is organized as follows: Section 2 presents the model and experimental design. Section 3 contains the data analysis and describes the main results. In section 5 we draw our conclusions.

2. Model and experimental design

We follow the CPR model presented in Osés-Eraso and Viladrich-Grau (2007). In the experiment, we model the strategic decisions of a group of n users 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 with marginal payoff α. Every unit invested in extraction, x_i, where $x_i \in (1, e)$, yields w units for the subject, but

[3] We do not consider in this illustration the (relevant) capacity of different communities sharing a certain watershed to coordinate for an integral management. Here we focus instead in the fist-order dilemma of extraction decisions within a single community. Taking into account these vertical characteristics of the watershed Cardenas el al (2008) designed an irrigation game that accounts for the different locations in the ecosystem.

reduces the CPR by c units; while every point 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 all n players. Therefore, as presented in equation 2 payoffs for each player π_i depend on the vector of individual appropriators' investments in the resource $\boldsymbol{x} = (x_1, \dots, x_n)$.

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

In order to describe a social dilemma for the extraction decision of the CPR we assume $(\alpha + \frac{c}{n}) < w < (\alpha + c)$. Investment in 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); this 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 [4]. The values for each parameter used along the experiment are presented in Table 1.INSERT TABLE 1 ABOUT HERE

As described before, during the experiment three levels of the CPR are evaluated: a high level (H), a medium level (M) and a low level (L) that appear at different stages (10 rounds) of the game. Subjects participated 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 in stage 2 for treatments HMM, HMH, HML and HLL. For treatment HML it decreases again in stage 3 and it increases for HMH. For HHH, our baseline, it remains constant for the whole experiment. By design, evaluating these different levels implies the imposition of different shocks at the end of each stage of the game for some treatments. We will refer to a shock as the exogenous change in the level of the resource by the experimentalist. Thus, for treatments HMH, HMM, HML, HLL there is a shock in round 11, and only for treatments HMH, HML there is a shock for 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 ($K_f(100) = 0$).[5] 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 30% higher than the low level and the high level,

[4] As opposed to Maldonado and Moreno (2010) that must interpret subjects' behavior as deviation from Nash equilibrium. In their model the two possible resource levels have different Nash equilibriums. Consequently, the behavior of individuals who do not change their extraction strategy when the level of the CPR changes entails a deviation from the Nash equilibrium from one scenario to the other.

[5] 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 users of water resources such as those participating in the experiments.

$K_{0,H}$=675, as 30% higher than the medium level. In Table 3 we present a summary of the different CPR levels we use in the experiment, the Nash extraction prediction and the social optimum (100 and 0 respectively for all resource levels). Additionally, Table 3 includes the level of the resource at the end of the round if all the subjects in the group behave as the Nash prediction (K_f Nash) as well as if subjects behave following the social optimum (K_f social). As presented in Table 2, this setting defines a shock reducing by 25% the size of the CPR in round 11 for treatments HMH, HMM, HML and by 50% for HLL. In Round 21 the shock for HML is a 37.5% reduction in the CPR and an increase in 30% for HMH.INSERT TABLE 3 ABOUT HERE

A total of 25 groups, evenly divided among five treatments (5 groups per treatment), were conducted in different locations 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 (masl) and annual rainfall ranges from below 1000mm to more than 3970 mm (Johnson et al 2009). Currently water quantity is not a problem in the region, however there is a growing concern about future scarcity problems.

The recruitment process for these experiments was done with the aid of local leaders and NGO's. In the invitation to participate, the experiments were presented to participants as a decision-making activity. In order to have a diverse sample we invited all the inhabitants of the community 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 5 subjects living in the same community. Once a group was completed we started the experiment by reading aloud the instructions. During the instructions, subjects were told that the experiment had three stages, each one of 10 rounds. In the instructions we emphasized that the game was static, meaning that extraction level in a round did not affect the water availability in the next round or stage. From this point on, subjects were asked to remain in silence for the whole experiment and were asked to seat back so that it was impossible for them to see other participants' forms. The experimentalists responded to questions in private. Next, several practice rounds were played in order to familiarize the subjects with the game, and the different forms. Field assistants helped subjects with reading and/or writing difficulties; but participants had to make their own decisions and the assistant only transcribed the decision into the game forms. During the three stages of the whole experiment subjects were not allowed to communicate or to use any other means to coordinate their actions. 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 whole group, he announced in public the total extraction of the group, the level of experimental units remaining in the watershed and the even share earned by each participant. Then, each subject was able to calculate his or her payoff in that round.

Table 4 presents some of the socio-demographic characteristics of the subjects. Agriculture, livestock or daily labor in farms is one of the two 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 all 30 round to be paid in cash while subjects were filling a socioeconomic survey[6]. Subjects' earnings ranged between 8,322 and 18,037 Colombian pesos with an average of 13,218 pesos (about US $7.27[7])

[6] The socioeconomic survey was designed in collaboration with an NGOs working in the area.

[7] In August 2010 the exchange rate was for one dollar= 1,819.06 pesos. At the time of the experiment the daily wage in the area was 8 dollars.

3. Results

A first approximation to the average extraction level by subjects in each treatment is provided in Figures 2 and 3. Figure 2 represents the average individual extraction days in rounds 1 to 10 (stage 1) for all treatments. In the first stage of the experiment average extraction days are around 7.2 for all treatments. Thus, consistent with previous findings in the field (Cardenas 2011, Lopez et al 2010, Cardenas et al. 2000) individual decisions without external regulations or communication (very often referred to open access in the literature) deviate from the Nash Equilibrium (in our case, 20 days), but it is also different to the social optimum (in our case, no extraction at all). This result is also consistent with previous experiments (VCM and irrigation game) conducted in the same watershed (Cardenas et al. 2010)

INSERT FIGURE 2 ABOUT HERE

Figure 3 represents time series of average individual extraction in each treatment over the 30 rounds.

INSERT FIGURE 3 ABOUT HERE

We undertake an econometric analysis 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 three individual fixed effects models. In Model 1 (column 1 of Table 5), we examine differences in individual extraction days across CPR levels (high, medium and low), without considering the sequencing of those levels along the game. The intercept in this model is the individual extraction in the high level. In Model 2 (column 2 of Table 5), we discriminate between water stock levels depending on the sequencing at which they occur. In Model 3 (column 3 of Table 5), we control for the rounds for which a change in the level of the CPR occurs, a shock from one stage of the experiment to the other. The variable Round 11 H-M captures the effect of changes from a high to a medium level between stages 1 and 2. This refers to treatments HMM, HMH, HML. Variable Round 11 H-L is the equivalent for a change from high to a low level in stage 2, treatment HLL. Two other variables are included for round 21, capturing changes in the level of the resource from stage 2 to 3. Variable Round 21 M-L, capturing a reduction for that round from medium to low and Round 21 M-H an increase from medium back to high.

INSERT TABLE 5 ABOUT HERE

Model 1[8] shows that the 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). Alternatively, the behavior of participants under the low level condition (L coefficient) is significantly different at the 1% level with respect to the high level condition, whereby subjects extract significantly more under the low level condition. Further, the difference between extractions under the medium level condition and the low level condition is significant (p=0.018[9]).

Result 1: The high level condition generates the same results across stages.

Table 5 shows that, in treatment HHH, individual extractions at stages 2 and 3 are not significantly different from extractions at stage 1. Additionally, extractions at stages 2 and 3 are not significantly different from each other (p=0.156). That is to say, individual water extraction levels are constant if the high level remains unchanged over time. This observation is consistent with findings from other baseline common pool resources

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[8] The Baltagi-wu LBI test for this regression is 1.681, 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.

[9] All statistical analyses between average extractions from the CPR for different treatments are presented based on Waldt tests.

conducted in the lab and in the field (Cardenas 2011, Cardenas and Carpenter 2008, and Velez et al 2010). Thus, any results are attributable to treatment effects rather than some bias in the selection of our sample.

Result 2: The medium level condition does not have a clear effect on subjects' behavior.

Model 1 shows a non-statistically significant effect of the medium level compared with the baseline treatment. Further, when considering the sequencing of the medium level (models 2 and 3) we see that subjects' exposure to a medium level of the CPR has different effects on users' extraction decisions across treatments. In treatment HMH, extraction levels vary across stages. Subjects under the medium level condition at stage 2 (HMHstage2) extract significantly less (1%) than under the high level condition at the first stage (baseline); however, when exposed again to the high level condition, at stage 3, subjects' extractions are similar to those in the first stage. This significant decrease in extraction under the medium level condition at stage 2 is not present in all treatments. The coefficient of HMMstage2 (stage 2 of the HMM treatment) is also negative but is not statistically significant, whereas the coefficient of HMLstage2 (stage 2 of the HML treatment) is positive and statistically significant (although only at the 10% level). Treatment HMM is the only one with a medium level condition at stage 3, and it entails significantly (at the 10%) lower extractions than in the baseline. Despite being different from the baseline, the coefficient is not statistically different from that of HMM´s Medium level condition at stage 2 (p=0.1281). Thus, despite being confronted by the same Medium level condition, individuals respond in different ways across treatments and stages.

It may be the case that this medium level generates confusion among the users, generating a diverse set of extraction responses. Some of the possible explanations of these differences may come from differences in the distributions between treatments HMM and

HML in the second stage, which are significantly different at the 1% with a Kolmogorov-Smirnov test for differences in distributions. However, these remain so far unexplained.

Result 3: In the condition where it is possible to fully deplete the CPR (low level), subjects extract more.

Consistent with results in Model 1, the low condition implies a consistent pattern of behavior in all treatments also in Models 2 and 3. Subjects playing under a low condition extract in all cases significantly more than in the baseline (significance levels range from 1% to 5% and coefficients for Model 2 from 0.74 to 1.2). Furthermore, in stage 3, this race for the scarce resources is maintained, with average extractions in the third stage of HML statistically significant higher at 5% than the baseline and at the 1% for the third stage of HLL. Extractions under the low level condition at stages 2 and 3 for treatment HLL are not statistically different (p=0.2848). Thus, our results indicate that prolonged exposition to a level of the CPR does not further increase average extraction levels. These results are consistent with the theoretical predictions of Grossman and Mendoza (2003), supporting that resource scarcity causes appropriation competition among users. This result holds for both a transitory or permanent resource scarcity but it is larger if the resource scarcity is transitory.

Comparing Result 2 and 3 could suggest that levels of the CPR, which cannot result in the exhaustion of the resource with full appropriation by users, generate somehow mixed responses among participants whereas when the resource can be exhausted, participants unambiguously increase their extraction levels. Our within-subjects findings, as opposed to Osés-Eraso and Viladrich-Grau (2007) between-subjects results, support that when users are aware that the resources are becoming scarcer they increase their extraction levels.

Result 4: The level of the CPR in stage 2 does not affect extraction levels in stage 3; individuals only respond to the level of the resource for the current stage.

Independently on the level of the resource in stage 2, individual extraction levels in stage 3 for treatments HML and HLL are not statistically different when both are exposed to a low level of the resource for the last 10 rounds. Further, there is no statistical difference in behavior between subjects playing under a high level condition at stage 3 in treatments HMH and HHH, regardless of whether they had experienced a medium or a high condition in stage 2.

Result 5: Repetition of a shock in the same direction affects individuals' short-term behavior.

We find a different response of subjects to exogenous shocks in the level of the CPR. As presented in Model 3, none of the shocks from the first to the second stage of the game significantly affect individuals' behavior. The coefficients from variables Round 11 H-M and Round 11 H-L are non significant. Variable Round 21 M-H, where the resource level increases from medium to high is neither significant. Only variable Round 21 M-L is statically different at the 1% level, implying a reduction in more than 2 units of extraction from the CPR. This effect is particularly relevant when considering that it does not imply the bigger reduction in the size of the CPR (which is bigger in round 11 when moving from high to low). This suggests that the repetition of a shock in the same direction rather than its magnitude is what drives the reaction by users.

Finally, the impact of shocks seems to be a short-term one. Despite the shock in round 21 from medium to low level had a significant effect on subjects' extraction levels, this effect dissipates along the stage. Participants' behavior over the remaining rounds entailed increasing extraction levels to the point that the average extraction for the stage was not different from the behavior of participants playing under other low level conditions.

4. Conclusion

In this paper we aim to model the effect of exogenous ecological changes reducing the amount of resources available to users. We do so by conducting a CPR experiment where subjects face different levels of resources in different stages of the experiment. More precisely, we explore whether different levels of the CPR and/or the shocks in the level have an effect on users' behavior.

Our findings support that the individual extractions from the CPR depend on the level of the resource. When the level of the resource is low enough to jeopardize resource conservation, individuals' behavior seems to consistently result in an intensification of uncooperative strategies. Alternatively, low levels of the resource for which conservation can be guaranteed do not affect individuals' behavior consistently; in some treatments subjects extract less and in other treatments they extract more than in the baseline. This result contrasts with previous between-subjects findings in the lab (Osés-Eraso and Viladrich-Grau 2007) and is consistent with semi-dynamic field results (Maldonado and Moreno 2010) and the theoretical predictions by Grossman and Mendoza (2003).

Our results raise some immediate questions about the resource level generating subjects' consistent changes in behavior. The level of the CPR that we evaluate in this study is the only condition for which the resource can be depleted due to subject's behavior. However, it is an issue for further research if subjects' behavior under an even lower level of a CPR would also extract more than in a baseline condition or even more than in the low level.

Furthermore, our analysis supports that although previous experience in the game with different levels of the resource does not have an impact on behavior, previous experience with scarcity shocks does affect reaction to subsequent shocks. This result supports scholarship relating frequency of experiences to learning, the emergence and maintenance of cooperation (Ostrom, Gardner and Walker 1994) and policy effectiveness (Bennett and Howlett 1992).

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 collective strategies, adaptation institutional development or technological improvements, all of which have been shown to be relevant in CPR users' responses to scarcity. This does not diminish the importance of our results insofar as both short-term and long-term reactions are relevant for sustainability success. The relevance of short-term reactions rests on the fact that during the transition to long-term strategies, the pressures over resources may surpass the regenerative capacity of renewable resources, thus depleting the resource.

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. The positive relationship between communication and cooperation in CPR games is well proven, but it is unclear if the impact of communication would be affected by scarcity shocks in CPR games. Most empirical and experimental applications do not take into consideration that risks and time preferences may influence the way users make decisions about their extraction patterns in contexts of increased risk of future droughts.

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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

* The values of *w*, *c*, *e*, and α follow the values used in Osés and Viladrich (2007).

Table 2. Scarcity shocks and resulting resource stock levels for different treatments.

Stage	Stage 1 Rounds 1-10	Shock	Stage 3 Rounds 11-20	Shock	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	↓25%	$K_{0,M}$=450	↑30%	$K_{0,H}$=675
Treatment HMM	$K_{0,H}$=675	↓25%	$K_{0,M}$=450	No	$K_{0,M}$=450
Treatment HML	$K_{0,H}$=675	↓25%	$K_{0,M}$=450	↓37.5%	$K_{0,L}$=300
Treatment HLL	$K_{0,H}$=675	↓25%	$K_{0,L}$=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.

	(1)	(2)	(3)
Dependent variables	Model 1	Model 2	Model 3
M	0.132		
	(0.238)		
L	0.824***		
	(0.238)		
HHHstage2		0.124	0.124
		(0.375)	(0.374)
HHHstage3		-0.408	-0.408
		(0.375)	(0.374)
HMHstage2		-1.296***	-1.277***
		(0.375)	(0.378)
HMHstage3		-0.036	-0.00587
		(0.375)	(0.384)
HMM stage2		-0.092	-0.073
		(0.375)	(0.378)
HMM stage3		-0.648*	-0.648*
		(0.375)	(0.374)
HML stage2		0.696*	0.715*
		(0.375)	(0.378)
HML stage3		0.944**	1.176**
		(0.375)	(0.385)
HLL stage2		0.744**	0.804**
		(0.375)	(0.385)
HLL stage3		1.216***	1.216***
		(0.375)	(0.374)
Round11H-M			-0.193
			(0.510)
Round11H-L			-0.604
			(0.883)
Round21M-L			-2.32**
			(0.883)
Round21M-H			-0.946
			(0.882)
Constant	7.010***	7.118***	7.118***
	(0.102)	(0.118)	(0.118)
Observations	3750	3750	375
Number of groups	125	125	125

*Note: The independent variable in Models 1-3 is number of individual extractions from the CPR, which is truncated between 0-20. *,** and *** indicate 10%, 5% and 1% levels of significance respectively. Standard errors are in parenthesis.*

Figure 1. The problem 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.

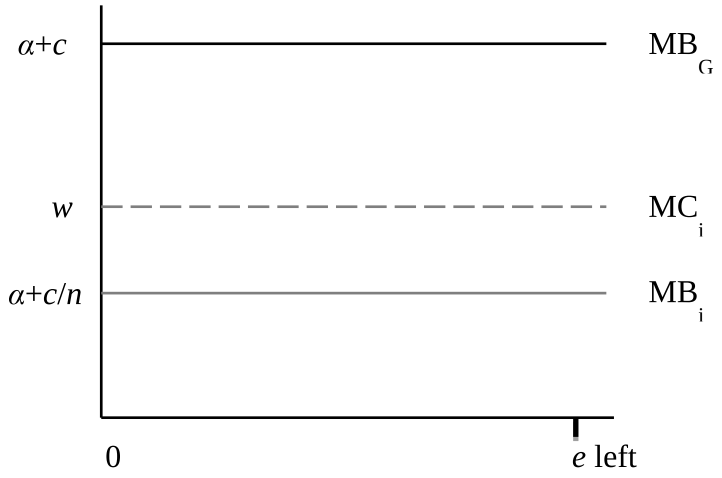

Figure 2. Average individual extraction levels for the first stage of the game (rounds 1-10) for all treatments.

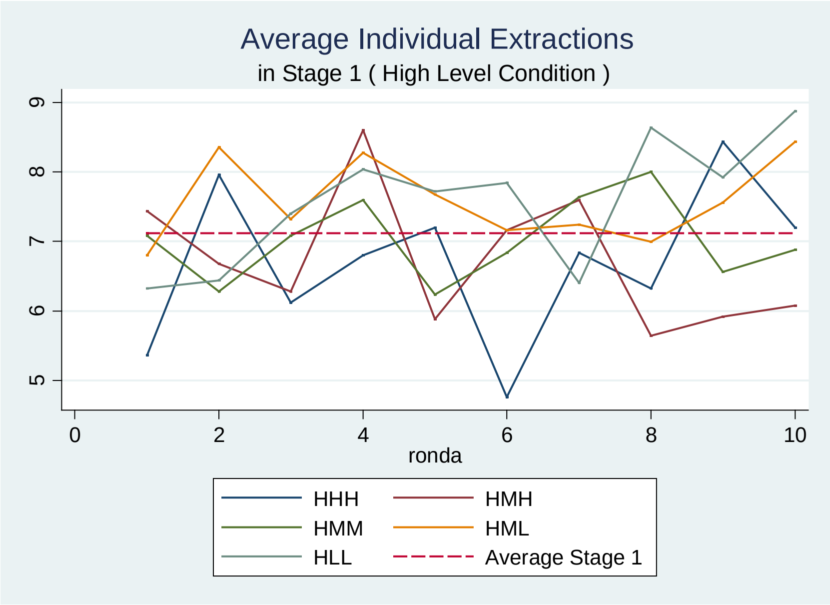

Figure 3. Average individual extraction levels for each treatment and stage of the game. Panel a: treatment HHH; Panel b: treatment HMH; Panel c: treatment HMM; Panel d: treatment HML; Panel e: treatment HLL.