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Environmental versus Human-Induced Scarcity in the Commons: Do They Trigger the Same Response?

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Abstract We study appropriation strategies in common pool resources where extinction is a credible threat. Here we present an experimental study of the appropriation of common pool resources in a dynamic setting where resource availability depends on the initial environmental characteristics of the common resource and on human-induced resource depletion due to users' appropriation patterns. Our results show that initial resource scarcity limits appropriation by inducing an initial caution among users that persists throughout of the game. Additionally, we find that subjects restrain their appropriation strategies when scarcity increases. However, this concern for resource scarcity is not enough to prevent resource depletion. Agents do not counteract the previous rounds' appropriation strategies but follow the appropriation trend. High appropriation levels are followed by higher appropriation strategies, thus promoting the well known tragedy of the commons. Often concern for resource preservation is not great enough to limit appropriation.

Keywords Common property resource · Concern for resource preservation · Early extinction · Endogenous and exogenous scarcity · Experimental design

Mathematics Subject Classification (2000) C91 · C92 · H41 · D64

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1 Introduction

The economic literature contains contradictory evidence concerning the effects of resource scarcity on common resource appropriation. On the one hand, several authors have pointed out that society does not start to worry about natural resources until they are in short supply. Arnold (1999) gives some examples of local collective management of common pool resources where villagers are apparently primarily motivated by perceived shortages to reduce their level of appropriation, as forest resources diminish. Grossman and Mendoza (2003), however, show that resource scarcity may also promote appropriative competition, thus leading to a faster rate of exhaustion than would otherwise occur. Leite and Weidmann (1999), on the other hand, show that resource abundance can result in competition for natural resource rents that would inefficiently exhaust the natural resource. Therefore, the response of harvesters to resource stock scarcity is not straightforward. Although the natural resource conditions seem to have a powerful influence on resource appropriation behavior, harvesters' behavior suggests that they also respond to changes in resource availability brought about by users' appropriation decisions. Both types of scarcity seem to influence the appropriative behavior of resource users. Our goal is to analyze the effects of these two types of scarcity on common resource appropriation behavior using an experimental approach.

Since Elinor Ostrom's seminal work (Ostrom 1990; Ostrom et al. 1994), the focus of many experimental studies has been to improve understanding of the appropriation process of common pool resources. However, only a few experimental studies consider the role of resource stock scarcity explicitly in a time-dependent experiment where today's appropriation determines tomorrow's resource availability.[1] Fewer still have considered the possible existence of at least two types of scarcity: exogenous or environment-induced and endogenous or human-induced. Mason and Phillips (1997), for example, presented an oligopoly model where a fixed number of firms exploits a common property resource. The initial stock size is exogenously given and harvest strategies determine stock sizes thereafter. The decrease in the resource stock size is accompanied by increases in the extraction cost and the effect of resource stock size on agents' strategies cannot be isolated from the effect of the rise in extraction costs. Also Herr et al. (1997) examined extraction from a groundwater aquifer that is described by the state variable depth-to-water. They considered the effect of increasing extraction costs on appropriation decisions, but did not state the resource stock size. They concluded that players behave myopically by neglecting the fact that current extraction decreases the future value of the resource and that this myopic behavior intensifies the race for the resource in a time-dependent setting. Fischer et al. (2004), meanwhile, introduced resource stock size into an intergenerational common pool resource game. In this setting, the scarcity of a common resource depends on the current resource stock size and the generation to which the agents belong. Although the size of the reserves is common knowledge, subjects are not aware of the exact number of generations nor of the relative position of their generation, and thus are unable to infer the actual level of scarcity. Using this design, no correlation is found between the resource stock size and the decisions adopted by the subjects. The game proposed by Chermak and Krause (2002) is also an intergenerational game but with overlapping generations. They use the same initial stock

[1] Ostrom et al. (1994) point out that time-independent games are an appropriate representation of the commons when the CPR is clearly self-sustaining. However, this is not the general case and most CPR situations are better described by time-dependent games where the appropriation decisions in one period condition the resource available for appropriation in the next.

size in all treatments and, instead of linking conservation strategies directly with resource scarcity, they investigate whether conservation strategies depend on who is to benefit from them. Closer in purpose to our experiment is that of Rutte et al. (1987) who consider both environmental and human-induced scarcity. Nevertheless, they present a one-shot game and study sequential appropriation from a common pool. In other words, they do not capture the appropriation externalities within a group of users that occur in most natural resources under common property. They observe that subjects harvest more when the resource is abundant than when it is scarce. They also point out that the differences in harvest levels are more extreme in an environmentally induced state of scarcity than in one induced by human behavior.

In this study we depart from the traditional time-independent common pool resource (CPR) games used in most experiments, where the trade-offs in a CPR setting are described without any explicit mention of resource stock size.[2] Ours is a time-dependent setting where today's appropriation determines tomorrow's resource availability. The resource stock and its evolution is the main point of the experiment. The resource stock is exogenously given only in the first round; thereafter, it is endogenously determined by the agents' appropriation strategies. The maximum duration of the game is also common knowledge. Thus, the scarcity conditions are fully defined. Moreover, extinction is a credible threat. The abundance or scarcity of a resource stock may be due either to initial environmental conditions or to common resource users' behavior. Both factors have an effect in appropriation decisions. Agents can adjust their strategies as the resource stock approaches extinction, and we test whether concern for resource preservation is capable of restraining appropriation.

Although the experimental design introduces great incentives for preservation, our results show that a significant percentage of the participants do not succeed in preserving their common pool resource and do not avoid resource destruction before the final round. Surprisingly, the proportion of participants that manage to preserve their resource is the same, irrespective of the initial resource stock size, which shows that initial resource scarcity has a limiting effect on appropriation. We show, furthermore, that this limiting effect persists through the last rounds. Thus, we expect societies facing environmentally induced scarcity to be more cautious in their initial choice of exploitation strategies than those with environmentally abundant resources. Additionally, we conclude that actual, and not only initial, scarcity is relevant in determining appropriation behavior patterns. We observe that the scarcer the common resource becomes, the lower the appropriation. Further, our results show that the reduction in appropriation due to increased scarcity is smaller the larger the initial resource stock. That is, participants facing the same level of actual scarcity behave differently, depending on their initial scarcity level. Moreover, appropriation history matters, agents follow the appropriation trend and do not counteract the appropriation strategies of previous rounds, often they are unable to offset the reduction in stock size and concern for resource preservation is not enough to prevent resource extinction.

This paper is organized as follows. In Sect. 2, we present the dynamic game for common property resource appropriation with the corresponding theoretical benchmarks. Section 3 introduces the experimental design. The results, in which the role of scarcity is analyzed, are presented in Sect. 4. Finally, in Sect. 5 we present our conclusions.

[2] The traditional CPR experiment is based on the long-run sustainable yield function that characterizes renewable resources and relates exploitation effort to sustainable yield. *A* complete description of the intricacies of the original biological model can be found in any manual of natural resource economics, see Tietenberg (2006) as an example. Also, for a full description of the traditional CPR game see Ostrom et al. (1994).

2 The Dynamic Game

2.1 The Game

A community of n subjects shares an initial stock of F_0 points. In each round t, each agent receives an endowment of e points that can be invested either in project A, (let this be called x_{it}) or in project B, $(e - x_{it})$. For every point that subject i invests in project A, he gains w points, while the cost is that the common pool resource stock is reduced by c points. We refer to investment in project A as *appropriation*. Meanwhile, for every point he invests in project B, the agent gets α points and the common pool resource stock grows by g points. The payoff received by subject i at the end of a round t is given by:

$$\pi_{it} = wx_{it} + \alpha(e - x_{it}) \tag{1}$$

We assume that $w > \alpha$. The investment decisions go on for a maximum of T rounds, as long as the resource stock remains above zero. T is the *time horizon*. If, at round T the remaining resource is positive, it will be equally distributed among the n community members. The investment decisions in any round can lead either to an increase, a decrease, or no change in the resource stock. The remaining stock at the end of any round $\bar{t}$, $F_{\bar{t}}$, depends on all past investment decisions. Unless the resource has been exhausted, it will be equal to:

$$F_{\bar{t}} = F_{\bar{t}-1} + gne - (c+g)\sum_{i=1}^{n} x_{i\bar{t}} = F_0 + \bar{t}gne - (c+g)\sum_{t=1}^{\bar{t}}\sum_{i=1}^{n} x_{it} \tag{2}$$

Therefore, suppose that the total number of rounds played by community members is t^*, where $t^* \leq T$, then the total payoff obtained by subject i is equal to:

$$\Pi_i = \begin{cases} \sum_{t=1}^{T} \pi_{it} + \dfrac{F_T}{n} & \text{if } t^* = T \text{ and } F_T > 0 \\ \sum_{t=1}^{t^*} \pi_{it} & \text{otherwise} \end{cases} \tag{3}$$

We say that *early extinction* has been reached whenever $t^* < T$.[3] Let us define total appropriation in period t as $X_t = \sum_{i=1}^{n} x_{it}$. From Eq. 2, it is easy to observe that, in any period t, the common resource will be exhausted if $X_t \geq (F_{t-1} + gne)/(c+g)$. This represents an upper limit for the total appropriation in period t if the goal is resource preservation. We refer to this upper limit as X_t^{up}. Further, we assume that $(w - c/n) > (\alpha + g/n)$ and $(w - c) < (\alpha + g)$ to describe the social dilemma associated with common pool resources.

2.2 The Benchmarks: Incentives for Preservation

We use backward induction to determine the best *individual* investment strategy. In the final round, T, subject i faces a common resource $F_{T-1} > 0$. He will obtain the payoff associated with his appropriation strategy, π_{iT}, and also a share in the remaining resource, F_T/n, if any.

[3] Observe that, in a given round t, whenever the remaining resource has a number of points such that $F_t \geq cne(T - t)$, the players have prevented extinction; whatever the investment decisions taken by community members from then on, they will reach round T and the common pool resource will be positive (or zero). In any other situation, there exists the possibility of early extinction. Moreover, given the initial common pool resource F_0 and the total number of rounds T, extinction can be avoided in any round above $\hat{t}$ where $\hat{t}$ is the smallest integer greater than or equal to $(cneT - F_0)/(ne(g+c))$.

The best investment decision for subject i would be to maximize the total payoff in period T, Π_{iT}.

$$\Pi_{iT} = wx_{iT} + \alpha(e - x_{iT}) + \frac{F_T}{n} \quad (4)$$

where, from Eq. 2, $F_T = F_{T-1} + gne - (c+g)X_T$. Note that it is individually rational to invest the entire endowment in project A as we have assumed that $(w-(c/n)) > (\alpha+(g/n))$. Observe that $(w-(c/n))$ is the individual marginal net benefit of project A while $(\alpha+(g/n))$ is the individual marginal net benefit of project B. Therefore, from an individual point of view, the best decision is full-appropriation in round T, $x_{iT}^N = e$.

Now consider the investment decision in the next to last round, $(T-1)$. Knowing the optimal decision in round T, subject i will choose the option that maximizes the payoff in round $(T-1)$ plus the payoff in period T.

$$\Pi_{i(T-1)} = \begin{cases} \left[wx_{i(T-1)} + \alpha(e - x_{i(T-1)})\right] + \left[we + \frac{F_{(T-1)}-cne}{n}\right] & \text{if } F_{(T-1)} > cne \\ \left[wx_{i(T-1)} + \alpha(e - x_{i(T-1)})\right] + [we] & \text{if } 0 < F_{(T-1)} \leq cne \end{cases} \quad (5)$$

In the subgames that arise when the resource stock is not exhausted in round $(T-1)$, subject i obtains in round $(T-1)$ the payoff showed in the first square bracket and in round T the payoff showed in the second square bracket. Let X_{T-1}^{-i} be the appropriation in round $(T-1)$ of all the community members but i. Whenever $0 < X_{T-1}^{up} - X_{T-1}^{-i} \leq e$, subject i has incentives to appropriate less than the total endowment as this guarantees a minimal level of resource stock and future payoffs different from zero. Therefore, $x_{i(T-1)}$ will take the maximum value that guarantees resource survival.[4] On the contrary, whenever $X_{T-1}^{up} - X_{T-1}^{-i} \leq 0$, the best strategy for subject i is full-appropriation as his action can not guarantee resource survival. Finally, whenever $X_{T-1}^{up} - X_{T-1}^{-i} > e$, the best strategy of subject i is again full-appropriation as the survival of the resource stock is already guaranteed.

However, appropriation decisions are simultaneous and, therefore, X_{T-1}^{-i} depends on the expectations of subject i about the behavior of others. In fact, whenever $X_{T-1}^{up} < ne$, the community faces a coordination game that has different coordination equilibria that preserve the resource and guarantee future payoffs.[5] In any other situation, the best individual strategy is full-appropriation.

We can now calculate the best individual decision for round $(T-2)$ and so on back to the initial round. Backward induction implies that the resource will be exhausted up to his minimal survival level in the shortest possible time. After this number of rounds, subjects will use strategies to keep the resource stock above 0. The minimum duration of any game, $t_{\min}$, is $t_{\min} = [F_0/cne] + 1$ if $[F_0/cne] < F_0/cne$ and $t_{\min} = [F_0/cne]$ if $[F_0/cne] = F_0/cne$,[6] where $[x]$ represents the integer part of x. Subjects will choose full-appropriation till round $(t_{\min} - 1)$. Thereafter, subjects face a coordination game.

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[4] Let $[x]$ represent the integer part of x. The maximum appropriation that guarantees resource survival is $x_{i(T-1)} = [X_{T-1}^{up} - X_{T-1}^{-i}]$ if $[X_{T-1}^{up} - X_{T-1}^{-i}] < X_{T-1}^{up} - X_{T-1}^{-i}$ and $x_{i(T-1)} = [X_{T-1}^{up} - X_{T-1}^{-i}] - 1$ if $[X_{T-1}^{up} - X_{T-1}^{-i}] = X_{T-1}^{up} - X_{T-1}^{-i}$.

[5] Whenever the community members are able to coordinate and $X_{T-1} < X_{T-1}^{up}$, they guarantee resource preservation and future payoffs.

[6] Maximum appropriation in round t is $X_t = ne$. Consequently, the common resource decreases by cne points in that round. The fastest way of exhausting a common resource is full-appropriation in each round. The common resource will be zero in $t_{\min} = F_0/cne$.

Let us now find the best *social* investment decision. Again we use backward induction. First, we calculate the aggregate payoff in the final round T:

$$\Pi_T = \sum_{i=1}^{n} \pi_{iT} = w \sum_{i=1}^{n} x_{iT} + \alpha \sum_{i=1}^{n} (e - x_{iT}) + F_T \tag{6}$$

The first order condition for the maximization of this aggregate payoff is:

$$\frac{\partial \Pi_T}{\partial x_{iT}} = w - \alpha - c - g < 0 \tag{7}$$

The sign of expression (7) is negative, as we have assumed that $(w - c) < (\alpha + g)$, that is, that the aggregate marginal net benefit associated with project A, $(w - c)$, is lower than that associated with project B, $(\alpha + g)$. Thus, the best investment decision from the social point of view is to invest the entire endowment in project B, that is, non-appropriation $x_{iT}^{E} = 0$.

If we consider the next-to-last round, $(T - 1)$, we find that the first order conditions for aggregate payoff maximization are again those presented in (7), thus, project B is socially more efficient than project A. Repeating the procedure for every round back to the first, the best social strategy in every round is to invest the entire endowment in project B, that is, non-appropriation. If this strategy were followed by every community member, the common pool resource would grow gne points in each round.

The best individual strategy and the best social strategy describe the social dilemma of the commons: individual behavior, driven by the maximization of individual payoffs, leads to actions that are socially suboptimal. There are, however, other individual strategies that may be worth mentioning. For example, the *sustainable strategy*. An agent follows the sustainable strategy if his investment decision allows the stock size to remain unchanged from one round to the next. In such a case, the decrease in the resource stock caused by the investment of agent i in project A, cx_i, is offset by the growth of the stock due to his investment in project B, $g(e - x_{it})$. That is, if $cx_i = g(e - x_{it})$, the investment decision of agent i has no effect on the stock size. Therefore, the points invested in project A by agent i during round t must be $x_{it}^{S} = ge/(c + g)$.[7]

In addition, note that there are many other strategies that allow the experiment to be played out to the last possible round, T. The maximum accumulated appropriation that permits a community to reach round T, is equal to $\sum_{t=1}^{T} \sum_{i=1}^{n} x_{it} = \frac{F_0 + Tgne}{c+g}$ points,[8] which corresponds with a *maximum accumulated average appropriation* level per round equal to $x_{it}^{L} = \frac{F_0 + Tgne}{(c+g)nT}$. We refer to this strategy as the *limit strategy*.[9] Any behavioral strategy with an accumulated average appropriation level below x_{it}^{L} will permit the experiment to continue until round T. Note that to obtain the limit strategy we need to know the initial resource stock and the time horizon.

[7] In a community, the common pool resource remains unchanged if aggregate investment in project A equals $gne/(c + g)$.

[8] We determine this maximum accumulated appropriation from Eq. 2 assuming that $F_T = 0$. Note that round T can be reached with a slightly higher accumulated appropriation level than that proposed. In this event, however, the experiment will end up with a negative resource level. In fact, round T will be reached whenever $F_{T-1} > 0$, that is, whenever the remaining common pool resource, after the investment decisions of round $(T - 1)$, is positive. This happens if the accumulated appropriation at the beginning of round T remains below $\frac{F_0 + (T-1)gne}{c+g}$ points.

[9] Observe that, for any appropriation trend followed by a group of users, we can calculate the accumulated appropriation at any time t and the corresponding accumulated average appropriation. If this average exceeds the limit strategy, early extinction will occur sooner or later, unless the group is to restrain appropriation.

Table 1 Different treatments and strategies

Treatment	Characteristics			Strategies x_{it}			
	F_0	T	$t_{\min}$	Individual	Social	Sustainable	Limit
Abundance	2400	20	10	20 till $t = 9$ then coord. game*	0	4	12
Scarcity	1200	20	5	20 till $t = 4$ then coord. game*	0	4	8
Ext. Scarcity	600	20	3	20 till $t = 2$ then coord. game*	0	4	6

*In T, the best individual strategy is, again, 20

3 Experimental Design and Procedure

We implemented three different treatments, an abundance treatment, a scarcity treatment and an extreme scarcity treatment. Each subject took part in only one treatment, that is, we implemented a between-subjects study. In these three treatments, the common pool resource is shared by a community of $n = 4$ members, each of whom has an endowment of $e = 20$ experimental points for personal investment in each round. The marginal benefit from project A is $w = 2$, while the social cost associated with this investment is $c = 3$. The marginal benefit from project B is $\alpha = 1$. In addition, the resource growth associated with project B is $g = 0.75$ and the time horizon is $T = 20$. The only parameter that changes from one treatment to the other is the initial quantity of the common resource, which can be either $F_0 = 2400$ (abundance), $F_0 = 1200$ (scarcity) or $F_0 = 600$ (extreme scarcity) experimental points.

The three treatments have been designed to allow for *early extinction*. The minimum duration of the game, $t_{\min}$, is 10 rounds when $F_0 = 2400$ points, 5 rounds when $F_0 = 1200$ points and 3 rounds when $F_0 = 600$ points. Therefore, full-appropriation is the best individual strategy till round 9 in the abundance treatment and till rounds 4 and 2 in the scarcity and extreme scarcity treatments, respectively. From then on, the communities will face coordination games. In the three treatments, however, the best social strategy is non-appropriation, $x^* = 0$, and the best sustainable strategy is an appropriation of 4, $x^S = 4$, in any round. Finally, the limit strategy is an appropriation of 12 points in the abundance treatment, an appropriation of 8 points in the scarcity treatment and an appropriation of 6 points in the extreme scarcity treatment. Table 1 summarizes all these strategies.

The experiments were conducted in the computer rooms of the *Public University of Navarra* during the months of March and April 2003 using the z-tree program (Firschbacher 1999) and the participants were undergraduate students from different disciplines. *A* total of 96 subjects, 55 female and 41 male, participated in the different sessions. There were 32 participants (8 groups) in each treatment. In every session, subjects were randomly divided into matching groups of four members that remained unchanged for the whole session. The composition of the groups was not known by the participants.

On arrival, the subjects had to read the instructions[10] where it was emphasized that there would be no communication with other participants during the experiment. The instructions described the situation, the quantity available in the common pool, the exact size of each group, the personal endowment, the investment possibilities and the exact number of decision rounds. Instructions also described the possibility of early extinction. The participants also knew that, after each decision round, they would receive information about the average

[10] The instructions are in Appendix B.

appropriation of their particular group in that round, the variation (positive or negative) of the common resource, the points remaining in the common pool after the group's investment decisions and his/her corresponding gains in points. Furthermore, after reading the instructions, the participants had to answer a comprehension test. Before the experiment began, all answers were check to ensure that the participants had understood the structure of the game. Subjects were told that at the end of the experiment the points would be exchanged for cash, at a pre-specified exchange rate. Each session lasted about one hour and the average earnings per subject were about 11 Euros.

4 Results

Now we analyze the role of scarcity in the agents' appropriation strategies, in particular, and even though this is a difficult task, we attempt to distinguish between the roles of three types of scarcity, initial or *exogenous* scarcity, actual or *absolute* scarcity and the effects of the appropriation evolution or *endogenous scarcity*. In any dynamic setting such as ours, once agents have started the game these different types of scarcity become entangled, and their effects difficult to isolate. In the following subsections, we analyze the influence of these scarcity types on appropriation decisions.

4.1 The Role of Exogenous Scarcity

We compare agents' behavior under three different levels of initial resource stock $F_0 = 2400$, $F_0 = 1200$ and $F_0 = 600$. In Panel A of Fig. 1, we have depicted the average appropriation time series for each of the communities that participated in the abundance treatment. The solid line represents the abundant treatment average appropriation time series. Panel B and Panel C display the same data for the scarcity and the extreme scarcity treatments, respectively. In Panels A, B and C we have marked with a dot the communities that ended the game prematurely because of resource extinction. Finally, Panel D depicts and compares the evolution of the average appropriation under each treatment, round by round.

We observe in Fig. 1 that, under all treatments, half of the communities (4) fail to reach the last round, $T = 20$.[11] The data show that extinction is not always avoided. Surprisingly, an initially abundant resource stock does not increase the rate of resource survival. This necessarily implies that, in the extreme scarcity treatment, agents adopt a more careful appropriation strategy. The data in Panel 1D reveals that the scarcer the initial resource, the lower the average appropriation series. We can therefore make the following observations:

Observation 4.1 The rate of resource survival is not affected by initial resource scarcity.

Observation 4.2 Initial resource scarcity limits appropriation.

For a statistical analysis of these observations, we compare differences in the evolution of average appropriation under each treatment. In particular, we test the significance of the differences among each treatment average appropriation time series. To calculate a treatment average appropriation time series we need to combine community average appropriation time

[11] Resource extinction has been found in other experimental studies. Chermak and Krause (2002) show that 16% of the groups that participated in their overlapping generations experiment exhausted the resource before the terminal round. Mason and Phillips (1997) observe that one-third of the experimental industries drove the resource to extinction. Walker and Gardner (1992) find that, in general, equilibrium cannot be sustained and the resource is destroyed.

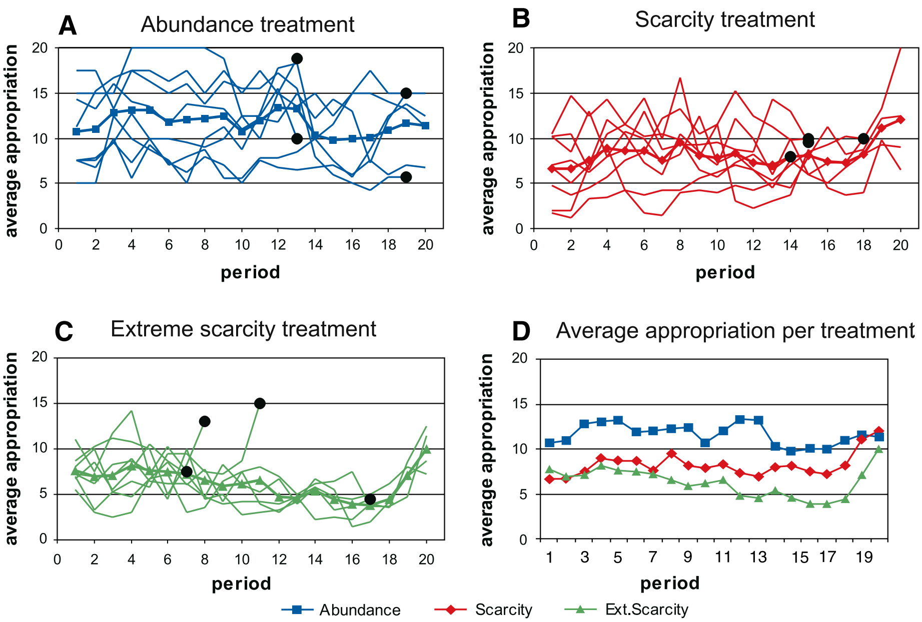

Fig. 1 Variability in average appropriation

series with different definition domains, because some communities do not reach period T due to early extinction. We use the *mean-padding* approach to solve this problem.[12] When the members of community j destroy the resource at period $t = t^*$, with $t^* < T$, the mean-padding approach imputes, for $t > t^*$, $\widetilde{X}_j(t) = 1/t^* \sum_{s=1}^{t^*} \bar{X}_j(s)$, where $\bar{X}_j(s)$ is community j average appropriation for round s. That is, after extinction, it imputes the community with an appropriation level equal to its average appropriation before extinction.

The evolution of each treatment average appropriation time series using the mean-padding approach is depicted in Fig. 2a. To asses the statistical significance of the differences between treatments, we use the test suggested by Cuevas et al. (2004).[13] Appropriation differences under the three treatments prove significant ($p < 0.002$).

These significant differences between treatments discard the social strategy and the sustainable strategy as good predictors for appropriation. Both strategies predict equal appropriation levels in the different treatments and the data clearly refutes this point. However, the individual strategy and the limit strategy predict different appropriation strategies between treatments. The question is whether the differences we have found can be explained by any of these strategies. First, we consider the individual strategy. Recall that the individual strategy predicts full-appropriation in the first and in the last rounds, a behavior that seems far from the observed data. This strategy also predicts that subjects will face coordination games during the experiment. However, as subjects do not choose full-appropriation in the first rounds, the

12 There are several ways to solve the problem of combining functional data with different definition domains (see, for example, Ramsay and Silverman 1997; Ramsay and Li 1998). One simple approach is to replace the missing values with zeros. However, this approach is not valid in the present setting, as zero-appropriation when the resource has been destroyed does not have the same implications as zero-appropriation when the resource survives.

13 See Appendix A for a detailed analysis of the statistical method.

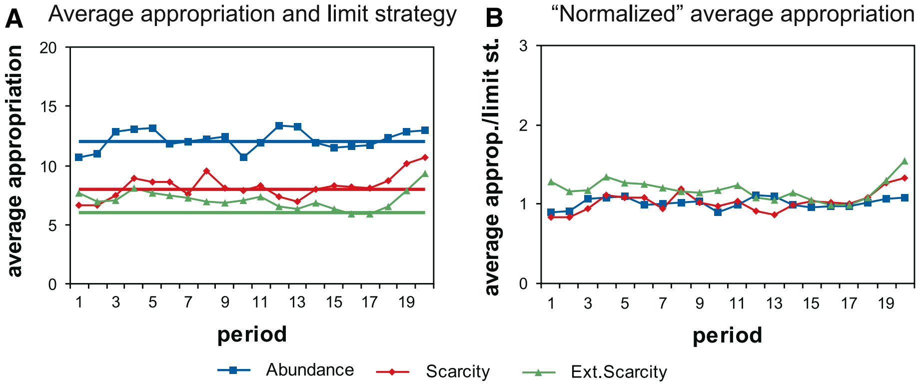

Fig. 2 Mean-padding

coordination game appears later than predicted. It is in period 5 that the first community faces a coordination game in the extreme scarcity treatment and not in round 2, as it was predicted by the individual strategy. Similarly, in the scarcity treatment, the first coordination game appears in round 10 and, in the abundance treatment, in round 12 instead of the predicted rounds 4 and 9, respectively.

Observation 4.3 All groups succeed in reaching the coordination game later and therefore preserving the resource longer than $t_{\min}$.

Remarkably, all groups succeed to escape the resource destruction predicted by the individual strategy benchmark, although they do not uniformly succeed to preserve the resource until the last round. Not all the communities that reach a coordination game are able to avoid the destruction of the common resource. For example, in the scarcity treatment, seven communities face a coordination game during the experiment and only three of them reach the final round. In the scarcity treatment, six communities face a coordination game and only two reached the final round. Finally, in the abundance treatment four communities face a coordination game and none of them reach the final round.

The other benchmark is the limit strategy. In Fig. 2a the average appropriation time series oscillates around the corresponding limit strategy (represented with straight lines). In fact, if we "normalize" these average appropriation time series by dividing average appropriation in each round by the corresponding limit strategy (i.e., $\bar{X}(s)/x^L$), the previously observed differences between treatments are washed out ($p > 0.69$).[14] The "normalized" average appropriation is depicted in Fig. 2b. Therefore, we make the following observation.

Observation 4.4 The limit strategy is a good predictor of average appropriation.

Furthermore, note that there are substantial differences in the initial levels of common resources between treatments but, after the appropriation rounds, the average level of common resources left is quite similar between treatments. These can be observed in the data depicted in Fig. 3a. In fact, the evolution of the normalized resource, F_t/F_0, is quite similar in the three treatments, especially in the abundance and the scarcity treatments, as can be seen in Fig. 3b. When comparing the evolution of the available common resource, we find

[14] As before, we use the above mentioned Cuevas et al. (2004) test.

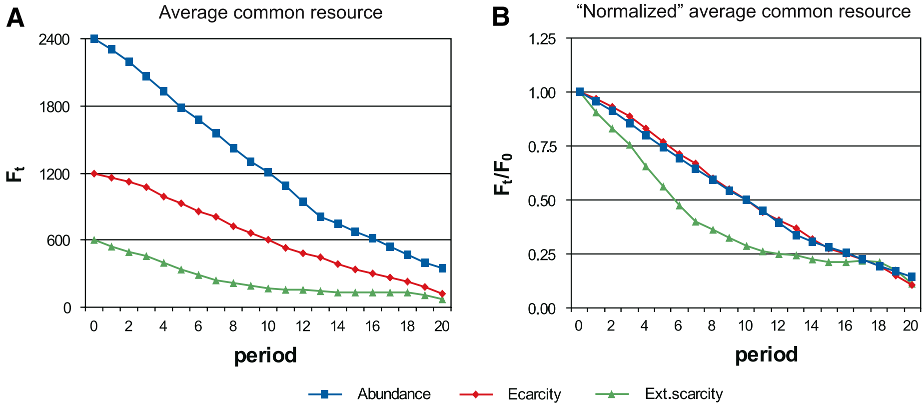

Fig. 3 Average evolution of the common resource

significant differences ($p < 0.000$) between treatments. For the normalized resource we find no statistical difference ($p > 0.73$).[15]

Therefore, there exist a significant differences in appropriation due to initial resource scarcity. However, the restriction on average appropriation is not enough to prevent early extinction. Moreover, cases of early extinction appear in all three settings, that is, subjects are not fully able to adapt and modify their appropriation strategies to restore the resource stock.

4.2 The Role of the Actual Level Scarcity

The initial resource stock, the evolution of the resource stock and the time horizon together determine the actual scarcity faced by subject i in community j in any round t. All else being equal, a given resource level would be considered more abundant the fewer rounds were left to be played. In order to measure this *absolute scarcity* we construct an *scarcity index* (SI_{ijt}), that we define as,

$$SI_{ijt} = \frac{F_{j(t-1)}}{T-(t-1)} \tag{8}$$

where $F_{j(t-1)}$, represents the remaining resource stock at the end of the previous round in community j, and $T-(t-1)$ the number of rounds to go (including t) before reaching the time horizon T. Furthermore, the scarcity index is an easy-to-calculate indicator of the abundance of the resource. In each round, a player has information about the remaining resource stock (F_{t-1}), the actual round (t) and the time horizon (T). The index is a straightforward way to measure the resource stock that can be consumed in each round. These two characteristics of the game, the actual level of stock and the appropriation horizon, fully define the absolute scarcity level faced by any community j in any round t.[16] Two individuals facing the same SI_{ijt} face the same absolute scarcity but may be enjoying different levels of resource stock, have a different number of remaining rounds to play and their communities can belong to different treatments. Therefore, using this index we mixed exogenous and endogenous

[15] To make these comparisons we also use the statistical method described in Appendix A.

[16] Note that each agent i in community j faces the same scarcity index in round t.

Table 2 Scarcity index and average appropriation

Treatment	Scarcity Index				
	[20,30)	[30,40)	[40,50)	[50,60)	[60,70)
Abundance	14.08	13.75	11.81	17.83	14.50
Scarcity	7.73	8.32	9.13	9.93	7.34
Extreme Scarcity	6.86	6.15	5.20	3.33	4.42

Note: Initial Scarcity Index: $SI_1^A = 120$; $SI_1^S = 60$; $SI_1^{ES} = 30$
where *A*: abundance; *S*: scarcity; *ES*: extreme scarcity

scarcity because the same SI_{ijt} amount could be reached through many different ways, for example, through different combinations of treatments and agent behaviors.

As this index normalizes the resource stock size by the amount of playing time remaining, it makes different situations comparable, between communities, between treatments and between rounds. *A* large SI_{ijt} would suggest that a large stock was left and then agents could appropriate larger amounts before pushing the resource to extinction; a small SI_{ijt} would suggest that a more restrictive appropriation was necessary to keep the resource away from extinction. If agents' actions were guided only by the absolute level of scarcity, we should expect those facing the same scarcity index to behave similarly. The evidence does not support this hypothesis, however. This is illustrated in Table 2. For each treatment, we have calculated the average appropriation level associated to different scarcity indexes. It can be easily seen that, for a given scarcity index, the highest appropriation levels always correspond to the abundance treatment.

4.3 The Role of Endogenous Scarcity

Furthermore, as the investment rounds progress, the scarcity faced by each community is determined by the appropriation strategies followed by their community members. In each round, the resource stock can increase (if $(c + g)\sum_{i=1}^{n} x_{it} < gne$) or decrease (if $(c + g)\sum_{i=1}^{n} x_{it} > gne$). In order to test whether this variation of the resource stock influences players' strategies, we study the determinants of individual appropriation through a regression analysis. Our dependent variable is the appropriation of agent *i* in community *j* during round *t*, x_{ijt}. We include two independent variables to capture the effect of this *endogenous* resource variation.[17] The first captures the *positive* variation in the resource stock, if any, which is represented by PV_{ijt}. It measures the increment in the resource stock size in community *j* during the previous round and is defined as $PV_{ijt} = gne - (c+g)\sum_{i=1}^{n} x_{ijt-1}$ whenever $(c + g)\sum_{i=1}^{n} x_{ijt-1} < gne$ and 0 otherwise, where *i* represents all agents belonging to community j.[18] If the regression coefficient of this variable is positive and significant it will imply that an increase in the resource stock size is followed by an increase in appropriation decisions. That is, an increase in PV_{ijt} is followed by an increase in x_{ijt}. Agents' behavior will tend to erode the increase in resource stock size in the previous round. If the estimated regression coefficient of PV_{ijt} turns out to be negative and significant, however, it will imply that an increase in the resource stock size is followed by a reduction in appropriation

[17] When scarcity is generated by the community members' decisions we call it endogenous.

[18] All agents *i* in community *j* and in round *t* face the same PV_{ijt}.

decisions taken in the next period. Agents will tend to preserve and sustain the increasing trend of the resource stock.

Similarly, we define NV_{ijt}, as the variable that captures the *negative* variation of the resource stock, if any. It measures the decrease in the resource stock size during the previous round. It is equal to $NV_{ijt} = |gne-(c+g)\sum_{i=1}^{n} x_{ijt-1}|$ whenever $(c+g)\sum_{i=1}^{n} x_{ijt-1} > gne$ and 0 otherwise. If the regression coefficient of this variable is positive and significant, it will imply that a reduction in the resource stock size is followed by an increase in the average appropriation decisions taken in the next round. Agents' behavior will tend to exacerbate the previous reduction in the resource stock size. If, however, it turns out to be negative and significant, it will imply that a reduction in the resource stock size will be offset by a reduction in appropriation decisions in the following round.

The results from observation 4.2 indicate that initial scarcity conditions affect appropriation strategies. Therefore, to identify and isolate the effect of initial scarcity conditions, we introduce as explanatory variables two dummy variables. First, we introduce variable DA_i, which takes a value of 1 if agent i belongs to a community with an initial resource of 2400 units (abundance treatment) and zero otherwise.[19] Secondly, we introduce variable DS_i, which takes a value of 1 if the agent i belongs to a community with an initial resource of 1200 units (scarcity treatment) and zero otherwise. We expect both coefficients to be positive with the coefficient of DA_i being higher than that of DS_i.

Moreover, to confirm whether appropriation strategies are affected by the actual scarcity level, we introduce the scarcity index, SI_{ijt}, presented above. We know that the same SI_{ijt} can be reached through many different appropriation patterns and combinations of initial resource levels and agents behavior. Therefore, if SI_{ijt} is significant in explaining an agent's appropriation behavior, we could conclude that agent's behavior depend on the actual measurement of scarcity, and not only on how it is reached, since it could be reach through different behavioral strategies. This index does not capture whether the scarcity is improving or deteriorating—it only captures the actual level. Therefore, if SI_{ijt} is non-significant and this lack of significance is accompanied by significant coefficients on PV_{ijt} or NV_{ijt}, we could conclude that the evolution of the resource is more relevant than the actual scarcity level in determining appropriation attitudes. Further, to analyze whether the differences in appropriation responses to resource scarcity observed in Table 2 are significant, we introduce two additional variables, $DASI_{ijt}$ and $DSSI_{ijt}$, such that $DASI_{ijt} = SI_{ijt} \times DA_i$ and $DSSI_{ijt} = SI_{ijt} \times DS_i$. If the estimated coefficient of $DASI_{ijt}$ is negative it would indicate that the reduction in appropriation due to resource scarcity is smaller the larger the initial amount of resource stock. The contrary would hold if it is positive. A similar analysis can be done for $DSSI_{ijt}$.

An alternative specification for representing the resource scarcity is to introduce, as an explanatory variable, the level of the resource stock left from the previous round $F_{ij(t-1)}$. Agents knew this amount before making appropriation decisions each round. When we introduced $F_{ij(t-1)}$ in the regression equation we drop SI_{ijt} as both variables represent actual scarcity faced by agents. Similarly, in order to distinguish if the appropriation response to resource scarcity was different among treatments, we introduced two more variables $FA_{ij(t-1)}$ and $FS_{ij(t-1)}$, such that $FA_{ij(t-1)} = F_{ij(t-1)} \times DA_i$ and $FS_{ij(t-1)} = F_{ij(t-1)} \times DS_i$. The interpretation of these variables is similar to the interaction terms of the scarcity index in the preceding paragraph. For example, a negative coefficient for $FA_{ij(t-1)}$ will

[19] We drop subindex t because these variables are constant through time, and subindex j because agents remain in the same community though out the game.

suggest that the reduction in appropriation due to resource scarcity is smaller in the abundant treatment.

Finally, in order to investigate whether appropriation is affected by time evolution, we introduce a set of time index dummies. We define the time index variables as a set of variables Ts_t so that $Ts_t = 1$ if $t = s$ and zero otherwise. Note that the introduction of these time dummies, Ts_t, allowed us to distinguish the patterns of appropriation between time periods. That is, it allows to test if appropriation in one period significantly differed from that in any other period. Recall that DA_i (or DS_i) estimated coefficients allows us to distinguish the appropriation among treatments, now with the addition of this time index we could also distinguish the pattern of appropriation between periods.[20]

Moreover, to isolate any systematic group characteristics we defined a set of dummy variables, Dj_i, to distinguish and compare the behavior of agents across communities, where $Dj_i = 1$ if $i \in j$, that is, if agent i is in community j. We included this set of variables in our estimated regressions but they were non-significant, and therefore we dropped them. In addition, we introduced two variables that represent agents' characteristics: gender (G_i) and undergraduate major in economics (E_i). However, they were also non-significant.[21] Finally, we introduce an explanatory variable representing the appropriation of all other community j members but i. This variable was also non-significant as it introduced multicollinearity in the model and we dropped it.

Together with the decision of which variables to include, we had several estimation approaches to choose among. Our data set has the characteristics of panel data and we could account for this characteristic through a fixed or a random effects model (FE and RE, respectively, onwards). Greene (1993, p. 479) and Wooldridge (2002, p. 247) argue that if unobserved effects are uncorrelated with the set of explanatory variables the RE model is more appropriate; otherwise a FE model would be preferable because it maintains the property of consistency of the estimated coefficients. However, the RE model makes estimate all the parameters of the model possible, whereas the FE model only allows estimates of the parameters of the time changing variables. We estimated the correlation between the unobserved effect and the explanatory variables and it was equal to 0.2. That is, positive but quite low. In fact, spurious correlation between variables often reache this value, (see Novales 1993, p. 344). Additionally, the results of the Hausman test allowed us to accept the null hypothesis of absence of differences between these two approaches. We present the estimations of the RE and the FE models in the first and second column, respectively, of Table 3 when we used SI_{ijt} as an explanatory variable, and in the first and second column of Table 4 when we used $F_{ij(t-1)}$ as an explanatory variable. In these models, idiosyncratic errors are assumed to be gaussian. It seems more prudent to rely in the FE estimators as they are less vulnerable to the existence of correlation between unobserved effects and explanatory variables.[22]

[20] Note, however, that with this specification the appropriation differences between periods are restricted to being the same in the three treatments. In order to allow these appropriation differences to be distinct between treatments, we introduce a set of interaction terms. We construct a set of interaction terms with the abundant treatment as the product $Ts_t \times DA_i$, and we did the same for the scarcity treatment. We estimated a regression with all these variables, and the time index variables were mostly significant. However, the interaction terms were never significant. Therefore we dropped the interaction terms from our model. Similarly, we introduced the interaction terms $Ts_t \times FA_{ij(t-1)}$ and $Ts_t \times FS_{ij(t-1)}$ as explanatory variables in the regression equations where we used $F_{ij(t-1)}$ as an explanatory variable, and they were also non-significant.

[21] Gender differences have been analyzed, among others, by Andreoni and Vesterlund (2001) and a reference to differences due to subjects knowledge of economy can be found in Dawes and Thaler (1988).

[22] We choose to present the RE estimators, despite the possible estimation problems associated with the existence of correlation, for two reasons. First, because we were able to accept the null hypothesis of the Hausman test, and second, to show the parameter estimates of the time constant variables. Note that, in our

Table 3 Determinants of individual appropriation (A)

	RE	FE	AR(1) FE	FE IV
Constant	4.762 (1.185)	7.639 (0.497)	7.713 (0.780)	7.563 (0.506)
DA_i	2.211 (0.843)			
DS_i	0.340 (0.602)			
PV_{ijt}	−0.048 (0.016)	−0.044 (0.023)	−0.038 (0.025)	−0.064 (0.090)
NV_{ijt}	0.032 (0.005)	0.030 (0.003)	0.012 (0.003)	0.021 (0.008)
SI_{ijt}	0.013 (0.002)	0.014 (0.004)	0.016 (0.005)	0.014 (0.005)
$DASI_{ijt}$	−0.011 (0.002)	−0.012 (0.004)	−0.011(0.005)	−0.011 (0.004)
$DSSI_{ijt}$	−0.001 (0.005)	0.001 (0.005)	−0.001 (0.006)	−0.000 (0.005)
G_i	1.426 (0.978)			
E_i	1.956 (1.391)			
$T2_t$	−2.219 (0.429)	−2.109 (0.720)	−1.012 (0.834)	−1.426 (0.978)
$T3_t$	−1.203 (0.700)	−1.100 (0.726)	−0.059 (1.021)	−0.391 (1.050)
$T4_t$	−0.823 (0.582)	−0.770 (0.728)	0.559 (1.075)	0.067 (0.992)
$T5_t$	−1.454 (0.618)	−1.293 (0.742)	0.185 (1.064)	−0.429 (1.055)
$T6_t$	−1.845 (0.612)	−1.686 (0.736)	−0.276 (1.102)	−0.878 (1.001)
$T7_t$	−1.955 (0.494)	−1.812 (0.732)	−0.514 (1.105)	−1.025 (1.015)
$T8_t$	−1.153 (0.765)	−1.014 (0.738)	0.170 (1.109)	−0.247 (1.024)
$T9_t$	−1.845 (0.571)	−1.682 (0.746)	−0.346 (1.113)	−0.916 (0.988)
$T10_t$	−2.351 (0.720)	−2.194 (0.740)	−0.976 (1.115)	−1.484 (0.949)
$T11_t$	−1.265 (0.787)	−1.128 (0.732)	−0.085 (1.115)	−0.484 (0.921)
$T12_t$	−1.654 (0.630)	−1.503 (0.748)	−0.242 (1.116)	−0.786 (0.981)
$T13_t$	−1.949 (0.759)	−1.799 (0.755)	−0.552 (1.114)	−1.032 (1.039)
$T14_t$	−1.975 (0.877)	−1.813 (0.766)	−0.704 (1.118)	−1.117 (0.971)
$T15_t$	−2.225 (0.794)	−2.067 (0.778)	−0.970 (1.117)	−1.367 (0.998)
$T16_t$	−2.373 (1.005)	−2.231 (0.798)	−1.193 (1.114)	−1.601 (0.990)
$T17_t$	−2.437 (0.996)	−2.317 (0.806)	−1.312 (1.090)	−1.652 (1.080)
$T18_t$	−1.800 (0.809)	−1.697 (0.820)	−0.734 (1.042)	−1.098 (1.013)
$T19_t$	−0.717 (0.951)	−0.640 (0.862)	0.509 (0.900)	−0.030 (1.025)
$T20_t$	−1.638 (1.428)	−1.634 (1.061)		−0.793 (1.308)
	$N = 1636$	$N = 1636$	$N = 1540$	$N = 1636$

Note: Standard errors in parenthesis

The estimated covariance matrix of these models is robust to cross-sectional heteroskedasticity and serial correlation.[23] The robust estimation assured that the estimated regression coefficients were consistent, but not that they were efficient.

Moreover, we tested for the presence of an AR(1) structure in the errors and estimated a $\hat{\rho} = 0.303$. This result showed the existence of an AR(1) structure in the error term

Footnote 22 continued
case, it is not overly relevant as all time constant variables but DA_i are not significant and therefore our comments will mainly focus on the FE models.

[23] We used the xtreg STATA procedure. We used the cluster option to adjust standard errors for intra-group correlation. In our regressions each community of 4 members was a group.

Table 4 Determinants of individual appropriation (B)

	RE	FE	AR(1) FE	FE IV
Constant	1.560 (1.673)	2.539 (1.089)	9.239 (0.612)	2.703 (1.236)
PV_{ijt}	−0.052 (0.023)	−0.045 (0.023)	−0.411 (0.025)	−0.047 (0.089)
NV_{ijt}	0.037 (0.003)	0.035 (0.003)	0.016 (0.003)	0.026 (0.008)
$F_{ij(t-1)}$	0.0062 (0.001)	0.008 (0.001)	0.010 (0.003)	0.008 (0.002)
$FA_{ij(t-1)}$	−0.004 (0.001)	−0.005 (0.001)	−0.007 (0.002)	−0.006 (0.001)
$FS_{ij(t-1)}$	−0.003 (0.001)	−0.004 (0.001)	−0.006 (0.002)	−0.004 (0.001)
G_i	1.478 (0.978)			
E_i	2.192 (1.334)			
$T2_t$	−2.315 (0.716)	−2.140 (0.719)	−6.175 (1.058)	−1.507 (0.960)
$T3_t$	−1.075 (0.724)	−0.852 (0.728)	−6.440 (1.288)	−0.226 (1.022)
$T4_t$	−0.517 (0.732)	−0.182 (0.739)	−5.963 (1.292)	0.535 (0.945)
$T5_t$	−0.921 (0.758)	−0.472 (0.769)	−6.081 (1.236)	0.355 (0.994)
$T6_t$	−1.020 (0.769)	−0.489 (0.783)	−6.151 (1.173)	0.289 (0.951)
$T7_t$	−0.837 (0.786)	−0.250 (0.802)	−5.982 (1.121)	0.468 (0.967)
$T8_t$	0.184 (0.805)	0.820 (0.824)	−4.964 (1.084)	1.495 (0.977)
$T9_t$	−0.339 (0.829)	0.378 (0.851)	−5.219 (1.042)	1.072 (0.968)
$T10_t$	−0.604 (0.845)	0.166 (0.871)	−5.526 (1.008)	0.800 (0.963)
$T11_t$	0.732 (0.861)	1.535 (0.889)	−4.307 (0.984)	2.077 (0.957)
$T12_t$	0.488 (0.887)	1.343 (0.918)	−4.250 (0.964)	1.930 (0.999)
$T13_t$	0.389 (0.911)	1.291 (0.944)	−4.296 (0.946)	1.895 (1.038)
$T14_t$	0.440 (0.932)	1.392 (0.969)	−4.266 (0.945)	1.967 (1.038)
$T15_t$	0.406 (0.959)	1.403 (0.998)	−4.257 (0.942)	1.964 (1.064)
$T16_t$	0.482 (0.979)	1.486 (1.017)	−4.209 (0.956)	1.986 (1.069)
$T17_t$	0.650 (0.993)	1.667 (1.032)	−4.051 (0.950)	2.163 (1.100)
$T18_t$	1.639 (1.013)	2.694 (1.056)	−3.054 (0.927)	3.158 (1.099)
$T19_t$	3.279 (1.047)	4.404 (1.093)	−1.107 (0.827)	4.944 (1.154)
$T20_t$	3.543 (1.128)	4.833 (1.181)		5.755 (1.324)
	$N = 1636$	$N = 1636$	$N = 1540$	$N = 1636$

Note: Standard errors in parenthesis

($dw = 1.394$). We present the AR(1) FE panel data estimator in the third column of Table 3.[24] When we introduced $F_{ij(t-1)}$ as an explanatory variable we estimated a $\hat{\rho} = 0.295$. We present the estimated results in the third column of Table 4. Our estimates should be efficient. However, the properties of the estimated coefficients depend on the estimated covariance matrix.

Furthermore, our model does not satisfy the assumption that all explanatory variables are strongly exogenous due to the introduction of PV_{ijt} and NV_{ijt} to the regression. These variables include in their definition the one-period delayed value of the dependent variable $x_{ij(t-1)}$. To solve the exogeneity issue, we used a two-stage, least squares, instrumental variables (IV) FE estimator. We use, as an instrument of PV_{ijt}, the variable $PV3_{ijt}$ that was constructed taking into account appropriation decisions of all community members

[24] We used the xtregar STATA procedure.

but agent i. That is, $PV3_{ijt} = 3ge - (c+g)\sum_{k=1}^{n} x_{kt}$ where k represents all agents belonging to community j but i. Note that we do not include delayed but contemporaneous appropriation levels—neither $x_{ij(t-1)}$ nor $x_{kj(t-1)}$—in the definition of $PV3_{ijt}$, to assure that our instruments are strictly exogenous. We did the same for NV_{ijt}.[25] The results of these estimations are presented in the fourth column of Tables 3 and 4. More importantly, note that the value of the estimated parameters of both, the AR(1) and the IV FE models are almost always included in the confidence interval of the robust models, showing that the differences among these three methodologies are minimal and that all of them present similar results.

Looking at the results in Tables 3 and 4, we observe that the resource variation, represented by PV_{ijt} and NV_{ijt}, is statistically significant in the determination of individual behavior. The negative sign of PV_{ijt} suggests, as we said earlier, that an increase in resource stock size is followed by a reduction in appropriation decisions. Individuals tend to preserve and sustain the increasing resource stock trend. Agents with low appropriation levels do not switch behavior. *A* similar interpretation can also be made with respect to the positive sign of the NV_{ijt} coefficient. *A* decrease in resource stock size causes an increase in average appropriation levels. Agents' behavior tends to exacerbate the previous reduction in resource stock size. Again, the effect is similar but in the opposite direction; individuals with high appropriation levels find it difficult to switch behavior. The endogenous variation determined by the appropriation pattern has a significant effect on appropriation strategies. Agents do not counteract the appropriation strategies of previous rounds but follow the appropriation trend, with either an increasing or decreasing effect on the resource stock.

The absolute scarcity, SI_{ijt}, is significant and positive in all regression equations in Table 3, that is, a lower resource stock level reduces appropriation. Moreover, there are significant differences between the abundant and the other treatments as the coefficient of $DASI_{ijt}$ is negative and significant, that is, the reduction in appropriation due to increased scarcity is smaller the larger the initial amount of resource stock. Similar conclusions are obtained from the estimated results presented in Table 4. The estimated coefficient of $F_{ij(t-1)}$ is also significant and positive, confirming that lower levels of resource stock reduce appropriation. Moreover, the estimated coefficients of both, $FA_{ij(t-1)}$ and $FS_{ij(t-1)}$ are negative and significant; further note that the estimated parameters of $FA_{ij(t-1)}$ are always larger in absolute value than the estimated parameters of $FS_{ij(t-1)}$, corroborating the results obtained with $DASI_{ijt}$, that the reduction in appropriation due to increased scarcity is smaller the larger is the initial resource stock.

Therefore, the regression analysis reveals that agents respond to scarcer resources by reducing appropriation (the effect of SI_{ijt} or $F_{ij(t-1)}$) and that this reduction is limited by the initial scarcity level (the effect of $DASI_{ijt}$ or $FA_{ij(t-1)}$). The reduction in appropriation is smaller the larger the initial resource stock. Moreover, this concern for resource scarcity is not enough to prevent the destruction of common resources. Endogenous resource variation (the effect of PV_{ijt} and NV_{ijt}) is also significant in determining individual strategies. The negative sign of PV_{ijt} and the positive sign of NV_{ijt} show that agents do not counteract the appropriation strategies of previous rounds but follow the appropriation trend and therefore resource destruction is possible. High appropriation levels are followed by further high appropriation levels. They are unable to offset the reduction in stock size. Concern for resource preservation is therefore not enough to prevent the destruction of common property resources, that is, to avoid the tragedy of the commons.

Finally, the pattern of signs and significance levels of all the regressions indicates that the 19th and 20th periods present a larger appropriation level. The estimated coefficients

[25] We used the xtivreg STATA procedure.

corresponding to these two dummies present a distinctive pattern of appropriation. Individual appropriation is greater in these final periods of the game when the threat of early extinction has vanished. On the other hand, recall that we also constructed a set of interaction terms,[26] the lack of significance of these interaction variables suggests that, even if we could establish differences in appropriation levels associated with time periods, the time evolution of the appropriation pattern was the same in the three treatments.

5 Conclusions

The results obtained in this dynamic setting capture the role of abundance and scarcity in the appropriation strategies of subjects interacting in a common pool resource setting. They highlight that scarcity, in general, limits appropriation. However, this restriction in appropriation strategies is not enough to avoid the depletion of the common property resources. Moreover, we observe that resources that are initially more abundant do not have a greater survival rate. The level of initial resource scarcity is important in determining initial appropriation strategies, particularly by inducing more caution in appropriation strategies than resource abundance.

However, in this setting, the level of actual scarcity is determined by both the initial resource scarcity and the agents' behavior. That is, the level of scarcity is a combination of environmentally induced scarcity and human-induced scarcity. Although disentangling the effects of both factors in appropriation strategies is a difficult task, a deeper analysis of the results shows that agents react to actual scarcity, and we observe that the scarcer the resource, the lower the appropriation. Further, for a given level of resource scarcity, the restriction on appropriation is greater when the resource was initially scarcer. In addition, our subjects were also highly reluctant to alter their appropriation trend. Resource scarcity is not enough to restrain appropriation when the resource variation trend features high exploitation levels. Environmental and human-induced scarcity act as independent forces that counteract each other; which one will be stronger depends on each particular situation.

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Appendix

A Statistical Methods

To compare the appropriation series through time we apply a test based on Cuevas et al. (2004). We have a set of time series $\bar{X}_j(t)$ where t runs along the time range (from 1 to 20 in our case) and j identifies the community. We group communities by treatment. Let K be the number of treatments ($k = 1 \dots K$) ($K = 3$ in our case), and let m_k be their sizes ($m_k = 8$, for all k, in our case). Then we may write our data as $\bar{X}_{kj}(t)$ where k indexes the treatment

[26] See footnote 20.

and $j = 1 \dots m_k$ the community. In such cases, the comparison statistic will be based on the treatment average

$$\overline{\overline{X}}_{k\cdot}(t) = \sum_{j=1}^{m_k} \bar{X}_{kj}(t).$$

To assess the statistical significance of the grouping induced by the treatment, we use a technique similar to the one-way ANOVA for numbers, but here applied to curves (see Cuevas et al. (2004)). The statistic used to measure the *between-group* variability is

$$V = \sum_{\substack{k,\, j = 1 \\ k < j}}^{K} m_k ||\overline{\overline{X}}_{k\cdot}(t) - \overline{\overline{X}}_{j\cdot}(t)||^2 \tag{9}$$

where $|| \cdot ||$ denote the $\mathcal{L}^2$ norm

$$||Z||^2 = \int Z(t)^2\, dt$$

that in our case is computed by

$$||Z||^2 = \sum_{t=1}^{T-1} \frac{Z(t+1)^3 - Z(t)^3}{3(Z(t+1) - Z(t))}.$$

Using this statistic, we test the null hypothesis that the distribution of the appropriation series (and payoff series) is the same for all treatments. Cuevas et al. (2004) compute the asymptotical distribution of the V-statistic under the null hypothesis of equality of means without assuming homoscedasticity across groups. In our case, however, this asymptotical distribution is not appropriate, because the corresponding covariance matrix cannot be safely estimated given the small size of our treatments. To avoid this problem we use the permutation distribution (see, for example, Muñoz et al. (2002)). We compare the value V observed in our treatments with the empirical distribution of V obtained by permuting all communities in K groups of sizes m_k. If the observed V-value is in the top 5% of the distribution, we reject the hypothesis of equal distribution for the groups.

The algorithm we use for testing the null hypothesis is as follows.

Given F_i, $(i = 1 \dots N)$ time series grouped in K groups of sizes m_k, choose a simulation size B (for our data sizes a simulation size of some thousands is usually enough).

1. Compute the observed value V^* according to (9).
2. With $b = 1 \dots B$ do
   (a) Form a random permutation $\{F_{i_j}\}$ of the given series and split it sequentially in K groups of sizes m_k.
   (b) Compute the value V_b according (9) for these groups.
3. Estimate the p-value as the proportion of the computed V_b that are greater than V^*. That is, the rejection region is the right tail of the permutation distribution.

B Instructions for the Dynamic Game

Welcome to the experiment

During the experiment communication with other participants is not allowed. Should you have any questions please ask us. We will answer your questions personally.

This experiment studies decision making in an economic environment. In these instructions you will find information about the decisions you can take and about the consequences of such decisions.

Depending on your decisions you can earn money that you will receive in cash at the end of the experiment. During the experiment, we will speak in terms of points rather than Euros. At the end of the experiment, the total number of points you have earned will be converted into Euros at the following rate:

65 points = 1 Euro

The experiment

The experiment is divided into **20 periods**. In each period you have to make an investment.

You are a member of a **group of 4**, that is, you are in a group with three other participants. The members of your group are the same for the 20 periods although you will not know who they are. The earnings of your investment decisions will depend on your own decisions as well as on the decisions of the rest of your group.

Investment decisions

At the beginning of the first period, your group receives a pool of **2400 points**. Your investment decisions can affect this pool. If the pool is reduced to zero or a negative value, the game is finished. If you reach the last period, period 20, and there is a positive quantity in the pool, it will be divided equally among the 4 members of the group.

Furthermore, at the beginning of each period you receive **20 points**. We call these points **your endowment**. You have to decide how many of these points you wish to invest in project *A* and how many you want to put in project B. Investment in project *A* plus investment in project B must sum 20.

On the screen, you will have to enter the number of points you are investing in project A. You can put any integer number between 0 and 20. The rest of your endowment points (20-investment in A) are automatically invested in project B.

1. *Income from project A*: for each point that you invest in project A, you get 2 points. This investment also decreases the pool of your group by 3 points.

1 point in *A* = 2 points for you

1 point in *A* = 3 points less in the pool

2. *Income from project B*: for each point that you invest in project B, you get 1 point. This investment also increases the pool of your group by 0.75 points.

1 point in B = 1 point for you

1 point in B = 0.75 points more in the pool

Your income at the end of each period depends on these investment decisions: it is the sum of the payoff you get from project *A* and the payoff you get from project B. That is,

Income at the end of the period:

$2 \times$ investment in A + $1 \times$ investment in B

The income of each participant is calculated in the same way.

At the end of each period, the pool varies depending on the investments of the whole group in project *A* and project B.

Change in the pool at the end of each period

$0.75 \times$ investment in B $- 3 \times$ investment in A

Information at the end of each period. At the end of each period, you will obtain the following information in the screen:

- Your investment in project A.
- The average investment of your group in project A.
- The change in the pool: positive (increment) or negative (reduction).
- Quantity available in the pool for the next period.
- Your income of the period.

At the beginning of each **new period**, you receive a new endowment of **20** points and the opportunity to invest in project *A* and project B. You also obtain information about the available points in the pool. Remember that if the pool droops to a negative or zero value, the game is finished.

Your total income at the end of the experiment is the sum of the income that you have obtained in every period you play plus an equal share in the pool if your group reaches period 20.

Total income if the game does not reach period 20

Income from the periods played

Total income if the game reaches period 20

Income from the 20 periods played $+ \frac{\text{remaining pool}}{4}$

Comprehension questions. The following examples will help you to understand the experiment. They are not relevant for your final earnings.

1. Neither you nor any of the other members of your group invests in project A.
   - Increase in the pool _ points
   - Decrease in the pool _ points
   - Change in the pool _ points
   - Your income from project *A* _ points
   - Your income from project B _ points
   - Your total income in the period _ points
2. Each group member (including you) invests 20 points in project A.

   (same questions)
3. Total group investment in *A* is 48 points. 5 of these points have been invested by you.
   - Average investment of the group in *A* _ points
   - Increase in the pool _ points
   - Decrease in the pool _ points
   - Change in the pool _ points
   - Your income from project *A* _ points
   - Your income from project B _ points
   - Your total income in the period _ points
4. Total group investment in *A* is 48 points. 17 of these points have been invested by you.

   (same questions)

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