

# Potential Disasters can Turn the Tragedy into Success

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**Abstract** This paper presents a novel experimental design that allows testing how users of a common-pool resource respond to an endogenously driven drastic drop in the supply of the resource. We show that user groups will manage a resource more efficiently when confronted with such a non-concave resource growth function, compared to groups facing a logistic growth function. Even among cooperative groups there is a significant behavioral difference, although theory predicts there should not be. We argue that effectiveness of communication is endogenous to the problem; the threat of reaching a critical tipping point, beyond which the growth rate will drop drastically, triggers more effective communication within the group, enabling stronger commitment for cooperation and more knowledge sharing, which together explains the results. We argue that the insights generated by this study can be seen as one of many, but nevertheless important, contributions towards an increased understanding of the interactions between human behavior and the environment in common-pool resource systems.

**Keywords** Common-pool resources · Laboratory experiments · User behavior · Renewable resources · Thresholds · Non-concave dynamics

## 1 Introduction

Many natural resources produced within ecosystems are common-pool resources (CPRs). Such resources, which are shared by a group of users, are often associated with over-

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exploitation, a *tragedy of the commons* (Hardin 1968), unless the user group finds a way to cooperate (Ostrom 1990). The collective behaviour of CPR users, for example, if, when and how they manage to cooperate or not, has been extensively studied but most of this research focuses on static and institutional aspects (such as wealth inequality, user heterogeneity, role of punishment and communication, etc.) and, hence, assumes, implicitly or explicitly, no or simple resource dynamics (see, e.g., Ostrom et al. 2002; Poteete et al. 2010 for overviews).

Natural goods and services stem from ecosystems with complex dynamics, including, for example, non-linearities and multiple stable states (Holling 1973; May 1977; Levin 1998). An increasing amount of empirical evidence suggests that if some critical threshold is trespassed (e.g., below some natural resource stock level), a large, dramatic transformation can interrupt smooth changes in the ecosystem, creating a *regime shift* (Scheffer et al. 2001; Biggs et al. 2012). A regime shift can lead to abrupt and potentially persistent changes in the system's function and structure and, hence, negatively influence the growth of natural resources that stem from the ecosystem. Case studies have documented regime shifts in many different types of ecosystems and at various scales, ranging from local to global (Folke et al. 2004; Rocha et al. 2015)<sup>1</sup>. There is, for example, scientific evidence suggesting that such changes may occur in the Barents Sea, a region hosting one of the most productive fish stocks in the world (ACIA 2005; Wassmann and Lenton 2012).

Expected large negative (in some cases even catastrophic) changes in aggregate human welfare and in its distribution are at stake (IPCC 2014). Human activities generate such shifts to an increasing extent, e.g., through resource extraction and pollution, and their frequency seems to be increasing (Steffen et al. 2015). Hence, it is important to study how resource users react to, and deal with such abrupt changes, which are triggered through their own actions, i.e., endogenously driven.

Our objective is to understand how users, sharing a CPR, make decisions in such a context. More specifically, when there is a critical stock threshold, below which the resource growth rate drops substantially, how will such a latent shift influence institutional arrangements that emerge, e.g., patterns of communication and cooperation? What implications will there be for individual exploitation and cooperation strategies over time and consequently overall resource management? For example, should we expect an increase or a decrease in the frequency of tragedies of the commons? The purpose of this study is to address exactly these questions, which is, to our knowledge, the first attempt.

In order to advance the understanding of patterns of behavior of resource users and communities facing regime shifts, we argue (in line with Ostrom 2006) that a multi-method approach is necessary. Such an approach would, for example, combine insights and predictions generated from theory and modeling with data collected through empirical and experimental methods. To our knowledge, however, there are no empirical studies that can complement existing theoretical work on behavioral responses to regime shifts (see Sect. 2).

It is very challenging to collect empirical field data on collective behavior with regards to regime shifts. Sufficient data (both ecological and socio-economic) must contain precise information about the resource and management situation before and after the shift for the studied system. This is hardly available (Walker and Meyers 2004). Another approach would be to collect relevant data from different case study sites along some biophysical gradient (in our case that could be the likelihood of a regime shift) to see if it correlates with a cooperation gradient. Such an endeavor would be very useful, but at the same time, extremely

<sup>1</sup> See also the Regime Shifts Database for an overview of case studies: [www.regimeshifts.org](http://www.regimeshifts.org).

time consuming (if at all possible). For these reasons, we chose to rely on the experimental method to generate data.

We performed a framed laboratory experiment and compared two experimental treatments. In both treatments, subjects played a dynamic CPR game, but whereas some groups faced a simple (a logistic type of) resource dynamics, other groups faced a more complex resource dynamics with an endogenously driven abrupt change.

Our experimental results show that such an endogenously driven abrupt drop in the resource renewal rate leads to less over-exploitation and more efficient resource management. We argue that the threat of reaching the resource stock threshold triggers more effective communication within the group. This enables commitment for cooperation and knowledge sharing about the resource dynamics, which leads to better performance.

## 2 Literature

Theoretical studies on optimal management of renewable resources show that management is challenging when regime shifts can occur because even marginal changes, in, e.g., resource extraction, can cause radical, potentially irreversible, ecosystem transformations (see [Crépin et al. 2012](#) for a review). The implications of a potential regime shift for optimal management depend, among other things, on whether the shift is endogenous, i.e., whether resource users' actions could trigger such a shift or whether it would happen due to external forces (exogenous). For example, if a natural catastrophe or disaster is the sole driver of a potential regime shift, resource users' actions have no impact on the likelihood of the realization of the shift and then we know from previous studies that this motivates more aggressive exploitation strategies to secure resources now rather than to risk losing them ([Polasky et al. 2011](#) and references therein). In contrast, if the regime shift is endogenous and would lead to a change in resource dynamics with negative welfare impacts, rather than a collapse of the resource, it is optimal to take precaution and lower the rate of exploitation ([Polasky et al. 2011](#)). We contribute to this literature by studying collective action around such resources rather than optimal management. We focus solely on the case when resource users' actions cause the regime shift (it is endogenous and there is no exogenous driver) and we study what kind of group behaviour this triggers.

In a CPR system, theory suggests that an endogenously driven regime shift can magnify the externality associated with non-cooperation ([Mäler et al. 2003](#); [Kossioris et al. 2008](#)) or cause other kinds of suboptimal outcomes depending on parameter values and the initial state of the system ([Crépin and Lindahl 2009](#)). However, the outcomes of these CPR game theoretic settings depend very much on underlying behavioral assumptions: do users cooperate or not and how do users update their strategies and respond to changes in the resource stock? Theory alone cannot provide answers to these questions. To improve our understanding of these systems and to be able to speak to the optimal set of policies, we need empirical data. This study contributes to fill this research gap by showing how this particular resource dynamics can result in more cooperative outcomes.

The prevalence of CPRs and their often associated inefficiencies have given rise to an extensive literature aiming at identifying factors influencing management ([Bromley et al. 1992](#); [Ostrom et al. 2002](#)). Laboratory experiments have been proven valuable for gathering empirical data on drivers of human behavior in CPR systems (see, e.g., [Kopelman et al. 2002](#); [Ostrom 2006](#) for comprehensive overviews). Recently, studies have also demonstrated the advantage of using experiments for analyzing the potential impact of specific ecological

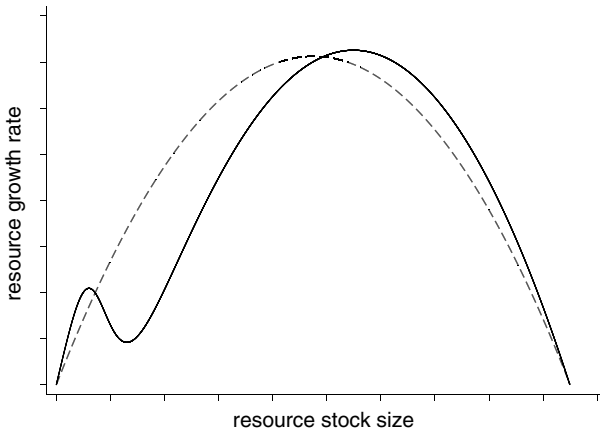
features in such systems, such as temporal or spatial dynamics (Moreno-Sánchez and Maldonado 2010; Poteete et al. 2010; Cardenas et al. 2013). Janssen (2010) and Janssen et al. (2010), for example, find that spatial resource dynamics can have a significant influence on the institutional rules that arise and that this element of complexity amplifies the importance of communication between resource users. Cardenas et al. (2013), Castillo et al. (2011) and Prediger et al. (2011) also introduce spatial variability. In their designs, field subjects choose where to harvest (two options) and the location with too high harvest pressure will degrade temporarily. They find that cultural and ecological context play a significant role in determining outcomes. Lindahl et al. (2015), introduce ecological complexity through two interdependent resources and asymmetric resource access; where the efficiency of management of one of the resources hinges upon how well the other resource is managed. They find that the need to gain a basic understanding of the complex dynamics overshadows potential tensions brought by the asymmetry. We contribute to this literature by considering a specific feature of ecological complexity previously understudied in this experimental literature, an endogenously driven drastic abrupt drop in the resource growth rate. It is quite challenging to transform a CPR problem, involving not only strategic elements but also a dynamic resource entailing a non-concave resource growth rate, into a comprehensible decision task for experimental participants. This paper introduces a novel experimental design that allows for precisely that.

Numerous case studies and experiments (including the studies mentioned above where communication is allowed) indicate that communication *per se* is important for determining whether groups will cooperate or not and, hence, prevent the tragedy of the commons (Pretty 2003; Ostrom 2006; Balliet 2010). However, this observation is mostly based on a comparison of experimental outcomes where the same group plays a CPR game without the opportunity to communicate in a first stage, and then, in a second stage of the experiment, with the opportunity to communicate (see, e.g., Ostrom and Walker 1991; Cardenas 2000). The difference between the two stages is then substantial and draws the participants' attention to communication. As a result, communication almost always takes place in the second stage leading to a significant increase in management performance. However, such a setting does not say very much about what triggers communication in the first place. In our experiment, all groups, regardless of treatment, are given the same opportunity to communicate from the beginning and there is no designated communication phase. Our study, thus, adds to the existing CPR literature by showing that just because resource users have the opportunity to engage in communication does not necessarily mean they will take it. As a matter of fact, our study demonstrates that the effectiveness of communication, i.e., to what extent people *do* communicate and to what extent this communication actually leads to agreements being made, which is a prerequisite for cooperation, can differ depending on specific characteristics of the resource dynamics.

## 3 Experimental Setup

### 3.1 Experimental Design

In the resource economics literature, the logistic growth function is often used to model resource growth (see, e.g., Clark 1990). This function is also our point of reference, as it has the advantage that one can easily capture resource dynamics with a threshold below a certain stock size by adding a sigmoid term, such as a “Holling-type” III predation term (Ludwig et al. 1978). Such a non-concave growth function can simulate the dynamics of relatively complex



**Fig. 1** Two types of resource dynamics: logistic-type resource dynamics (*dashed curve*) and resource dynamics involving an endogenous abrupt change (*solid curve*)

ecosystems, like forests, grasslands or coral reefs (Scheffer and Carpenter 2003; Crépin 2007; Graß 2012), and has already been used in the theoretical resource management literature (Crépin and Lindahl 2009) to analyze the implications of regime shifts for management. Figure 1 illustrates resource growth for different stock levels ( $x$ ) with a logistic growth function (dashed curved) and a resource growth as modeled in Ludwig et al. (1978) (solid curve)<sup>2</sup>.

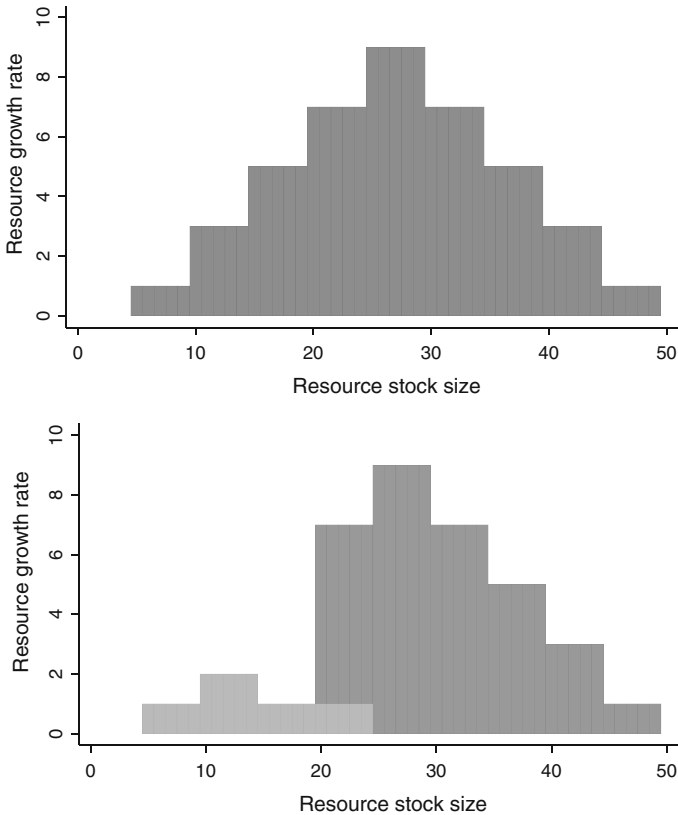
Figure 1 is based on Eq. (1), which represents the dynamics of a stock  $x$  that changes with time  $t$ , with growth rate  $r$  and carrying capacity  $K$ . In the “Holling type” III predation term,  $b$  denotes the maximum uptake rate,  $a$  half saturation, and exponent  $\theta$  introduces the non-convexity. The term  $h$  represents exploitation and can be controlled.

$$\frac{dx}{dt} = rx \left( 1 - \frac{x}{K} \right) - b \frac{x^\theta}{a^\theta + x^\theta} - h \tag{1}$$

A model where resource users maximize an objective under the constraint of a logistic growth function typically has one unique interior stable solution and one boundary solution where the stock gets extinct, which is unstable (Clark 1990). A model with an endogenously driven regime shift may have up to three interior solutions of which two are stable and one unstable (Graß 2012). In such a model, there are also critical thresholds (bifurcation points) at which the system dynamics change abruptly; at such a point, a marginal change in exploitation may shift the system into another stable domain, where resource growth differs significantly from the previous stable domain. The critical threshold leading from one stable domain to another often differs from the critical threshold for going back to the original stable domain once the system has shifted. This is called hysteresis, and results from the presence of internal feedback loops that maintain the system state, making it difficult to reverse (Biggs et al. 2012).

To our experiment subjects, we presented the two above described resource growth models as discrete versions, whereby each model represented one treatment. Figure 2 shows the resource dynamics of the logistic type model treatment (upper graph) and the threshold model (lower graph) respectively. As we can see in Fig. 2, for both treatments, the minimum resource stock size allowing for possible reproduction is five units, and the maximum resource

<sup>2</sup> The figure is simulated based on the following parameter values: Logistic, no threshold model:  $r = 0.6$ ;  $K = 9.5$ ;  $h = 0$ . Threshold model:  $r = 1$ ;  $K = 11$ ;  $a = 1$ ;  $b = 1.3$ ,  $h = 0$  and  $\theta = 4$ .



**Fig. 2** Graphical illustration of resource dynamics as presented to the experiment subjects. The *upper graph* represents the resource dynamics of the no threshold treatment and the *lower graph* the resource dynamics of the threshold treatment

stock size is set to 50 units. The maximum sustainable yield is nine resource stock units, and the resource growth rate changes by steps of five units.

As Fig. 2 shows, at 20 resource stock units and above, the resource dynamics of both treatments are identical. For the threshold model (lower graph of Fig. 2), if the resource stock size falls below the threshold (set at 20 resource stock units), the regeneration drops dramatically, from a regeneration rate of 7 to a rate of 1. There is also hysteresis: to recover a high growth rate once the resource stock size is below 20 units, the resource stock must be rebuilt up to 25 units, or more, to recover to a high resource growth rate. From now on, we refer to our two treatments as the ‘threshold treatment’ (lower graph of Fig. 2) and the ‘no threshold treatment’ (upper graph of Fig. 2). In the experiment, in both treatments, groups started with the maximum resource stock size (50 units) and over a number of periods, which was unknown to them, they extracted resource stock units.

Because the main focus of this study is to analyze group behavior in respect to endogenous changes in the resource dynamics, we kept the institutional setting of the experiment simple, i.e., rules and norms could only be self-imposed and were not costly. Our experimental design stems from our intention to mimic the field as well as possible: we provided our subjects with a real resource problem description under approximation of an indefinite time horizon and allowed for face-to-face communication, as it has been observed that communities dealing

with CPRs keep up frequent face-to-face communication (Pretty 2003). In these respects, one can classify our experiment as a “framed laboratory experiment” (see Harrison and List 2004 for a classification of experiments).

### 3.2 Experimental Procedure

We recruited 150 subjects from Stockholm University Campus. Subjects were recruited with the help of a show-up fee of SEK 100–150 (SEK 1 corresponds to approximately 0.11 Euros or 0.13 US dollars) and were randomly assigned to a group of four subjects<sup>3</sup>. Each experimental session (one group at a time) lasted approximately one and a half hours and each subject participated only once and in one treatment only. We gathered 20 groups for the threshold treatment and 21 groups for the no threshold treatment. Summary statistics describing the subject pool are presented in Table 1.

Upon arrival, the subjects were seated around a table; they signed a consent form and were given the experiment instructions to read (the instructions can be found in the supplementary material—online resource) after which there was time for clarifying questions. The subjects were told that each of them represented a resource user, and that, together with the other participants in the group, they had access to a common renewable resource stock from which they could harvest units, each worth SEK 5, over a number of periods. To keep individual harvest decisions anonymous, subjects indicated their individual harvest on a protocol sheet, which the experimenter collected after each decision-making period. The experimenter calculated the sum of the individual harvests as well as the new resource stock size and communicated (written and orally) this new resource stock size to the group. Since face-to-face communication was allowed (but not forced) at each step of the experiment (there was no designated communication phase), subjects could discuss their individual harvest rates<sup>4</sup>; however, what the subjects actually wrote down in each round was kept anonymous. Subjects were told that the experiment would end either when they depleted the resource stock or when the experimenter decided to end it, but the exact end-period was unknown to them<sup>5</sup>. If the group’s total harvest was equal to or exceeded the number of available resource units in one period ( $X_t$ ), the experiment ended. The payment ( $p_{it}$ ) of subject ( $i$ ) in that period  $t$  was based on her harvest share ( $h_{it}$ ) of the group’s total harvest in period  $t$ ,  $n$  denoting group size (see Eq. 2).

$$p_{it} = \frac{h_{it}}{\sum_{i \in n} h_{it}} X_t \quad (2)$$

After the experiment, the subjects filled in a questionnaire specifically designed to identify and analyze individual and group attributes. We asked the subjects to state their age, gender, and educational background. We also asked them to indicate on a five-level Likert scale (Likert 1932), ranging from strong disagreement (scale value 1) to strong agreement (scale value 5), (1) if they understood the resource dynamics, (2) if their group communication was effective (where effective communication was defined as being able to reach agreements) and (3) if their group managed to cooperate (where cooperation was defined as being able

<sup>3</sup> We aimed for four subjects, but performed the experiment also with three subjects in those cases where one of them did not show up. We also had to increase the show-up fee from SEK 100 to SEK 150 to increase the number of sign-ups. In our regression analyses, we control for these variables (group size and show-up fee) but they are not significant. As a matter of fact, the model tests show an improvement when we remove these variables from the regressions (see also Sect. 5.2).

<sup>4</sup> It is worth mentioning that it was neither suggested by the instructions nor the experimenter to discuss individual harvest decisions. Most groups, however, made use of this possibility.

<sup>5</sup> To ensure an unknown time horizon, we varied the end-time between groups.

**Table 1** Summary statistics of subject pool and comparison of treatment proportions and averages

	N	No threshold	Min	Max	N	Threshold	Min	Max	t test	p values Pearson's Chi-square
Proportion of females in group	21	0.571			20	0.600				0.721
Proportion of groups with four subjects	21	0.714			20	0.7				0.446
Proportion of tragedies (over-exploitation)	21	0.571			20	0.200				0.015
	N	Min	Max	N	Min	Max	t test	MWU test		
Average age	77	29.896 (10.760)	17	66	73	28.233 (9.906)	18	62	0.327	0.276
Average individual earnings, excluding show up fee (SEK)	77	146.753 (55.554)	35	240	73	176.644 (45.179)	35	265	0.000	0.000
Average efficiency <sup>a</sup>	21	0.508 (0.368)	0	1	20	0.837 (0.226)	0	1	0.000	0.000
Average cooperation index <sup>a</sup>	21	3.896 (1.518)	1	5	20	4.534 (1.094)	1	5	0.004	0.002
Average knowledge index <sup>a</sup>	21	4.90 (1.002)	1	5	20	4.493 (0.784)	1	5	0.484	0.791
Average communication index <sup>a</sup>	15	4.196 (1.102)	1	5	15	4.768 (0.713)	1	5	0.002	0.000

There were 77 subjects in 21 groups in the no threshold treatment and 73 subjects in 20 groups in the threshold treatment. N = number of observations. Values in parentheses display standard errors. MWU stands for Mann-Whitney U test. <sup>a</sup> These variables display mean group values. The indices are derived from the questionnaire



to reach agreements and where these agreements were followed by all group members). In the following, we refer to these three variables, which display mean group values, as ‘group knowledge index’, ‘group communication index’, and ‘group cooperation index’ respectively. To complement the self-reported variables collected through the questionnaires, the experimenters also took notes on these matters. At the end, subjects were paid privately, one by one.

## 4 Formulating Hypotheses

The purpose of this section is to derive hypotheses (based on theory) that can guide our empirical analysis rather than giving all theoretical details of the model. To this end, we provide the intuition here. For a more formal treatment we refer the reader to the supplementary material (online resource).

To formulate hypotheses, we rely on methods from repeated game theory. We assume an indefinite time horizon (Carmichael 2005) to mimic the experimental setting, which implies that the discount factor represents the probability that the game will continue to the next period (Fudenberg and Tirole 1998). To mimic the experiment, we also assume that the players receive an update on the stock level  $X_t$  at the beginning of each period, which implies that they can deduce information on the other players’ actions. For example, they know if someone has deviated from an agreed cooperative strategy. They can thereby condition their strategies on current and past stock sizes. In fact, we assume that they condition their strategies *only* on this piece of information, i.e., they use Markov strategies (Maskin and Tirole 2001). There are many types of equilibrium outcomes in this game, but for our purpose—to derive hypotheses—we do not need to consider them all. We only consider equal sharing equilibrium outcomes and focus on pure strategies<sup>6</sup>.

The first observation we can make is that each stock size of the game,  $X \in \{5, 6, 7, \dots, 50\}$ , can be sustained as an equal sharing Markov Perfect Equilibrium if the discounted value of one resource unit is large enough for each player  $i$  in the game (i.e., the players believe the game will continue to the next period with a relatively high probability). If the discount factor,  $\delta_i$ , for one (or more) of the players falls below some critical value  $\hat{\delta}(X)$ , the equilibrium cannot be sustained any longer. This critical value varies with the growth rate and consequently stock size. For example, for a stock size with a high growth rate, the critical value  $\hat{\delta}(X)$  is relatively low (the stock size can relatively easily be sustained in an equilibrium) compared to a stock size where the growth rate is low. If the growth rate is high, the incentive to deviate and deplete the resource is low because the discounted value of the sum of future payoffs is also high. Following, we observe that the critical value  $\hat{\delta}(X)$  is the same for both treatments for those stock sizes where the growth rate is the same. However, for the stock sizes where the growth rates differ, i.e., for  $X \in \{10, 11, 12, \dots, 19\}$ , the critical value is higher in the threshold treatment because the growth rate is lower.

Equilibrium outcomes that can be sustained are equally likely and for these groups there is a coordination problem. However, although there may be several possible equilibrium outcomes, there is only one, which is optimal. The optimal outcome of the game is the one where the group is able to maximize joint earnings. This outcome is obtained if the group harvests 25 units in the first period, and then, in each subsequent period, harvests the maximum

<sup>6</sup> We choose to focus on equal-sharing equilibrium outcomes (if an equilibrium is sustained, it is based on equal shares of the stock size) because this is actually consistent with the observed behavior in the experiment. Whereas some of these equal-sharing groups shared the harvest equally in each period, others used a rotating scheme to share the harvest equally over time.

sustainable yield, here 9 units, as long as the discount factor for each group member is high enough (i.e., higher than the critical value,  $\hat{\delta}(X)$ ). This is true for both treatments. If, for some reason, the stock falls below 25 units, the optimal strategy is to let the resource recover until it reaches 34 units (most rapid approach) and then harvest 9 units for the subsequent periods. We define over-exploitation (tragedies) as exploitation above the optimal (and vice versa for under-exploitation). Efficiency is measured as the share of actual joint earnings over the maximum possible.

Between stock sizes of 10 and 19 (the region where we find over-exploitation according to the definition), the incentive to deviate from an equilibrium is higher in the threshold treatment because the growth rate (and, hence, the incentive to play according to the equilibrium) is lower. Thus, equilibrium outcomes for stock sizes between 10 and 19 are harder to sustain in the threshold treatment. For the other stock sizes,  $X \in \{5, 6, 7, 8, 9\} \cup \{20, 21, 22, \dots, 50\}$ , where the growth rate of both treatments is identical, equilibrium outcomes are equally hard/easy to sustain. As a result, we expect fewer cases of over-exploitation in the threshold treatment than in the no threshold treatment. This leads to our first hypothesis.

**Hypothesis 1** We expect less over-exploitation in the threshold treatment compared to the no threshold treatment.

If players in this game make full use of the communication opportunity and cooperate then the rational tactic for the group is to follow the optimal group strategy and stay at the maximum sustainable yield, regardless of treatment. Of course it can be debated whether cooperative groups will really reveal this type of behavior (group rationality). This is exactly what we want to test. We define a cooperative group as one where the group is able to reach agreements for the entire duration of the experiment, and that these agreements are also being followed by all group members.

**Hypothesis 2** We expect cooperative groups to follow the optimal strategy and be equally efficient in their management of the resource regardless of treatment.

The intuition behind Hypothesis 2 stems from this latter idea that both treatments are identical for all remaining stock sizes and from the fact that the game starts with the maximum possible resource stock. Thus, the optimal outcome can be obtained as a Markov Perfect Equilibrium regardless of treatment if the expected discounted value of one resource unit is large enough for all players  $i$  in the game<sup>7</sup>. So just to remind the reader: whereas the first hypothesis relates to all groups, the second relates only to cooperative groups.

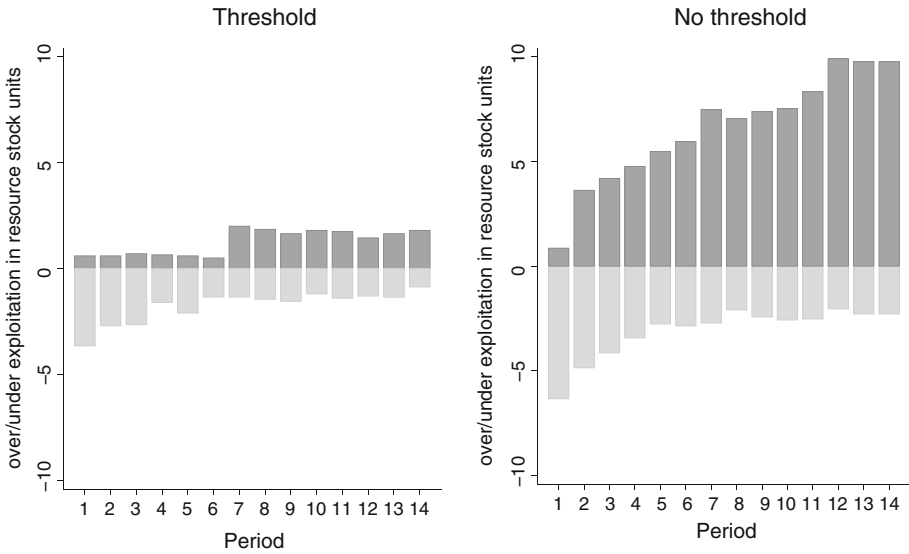
## 5 Experiment Outcome

### 5.1 Statistics

For the statistical analysis we use STATA 12. Because experiments often lead to skew distributions (which was also the case here<sup>8</sup>), we report significance levels from non-parametric Mann-Whitney U tests along with standard independent  $t$  tests. To compare proportions

<sup>7</sup> Note that to be able to derive hypotheses, we need to invoke two assumptions: (1) that the *critical values* for the discount factors belong to a subset of the range of the *actual* subjective discount factors and (2) that the range of *actual* subjective discount factors is independent of treatment. See the supplementary material (online resource) for a more elaborate discussion.

<sup>8</sup> According to a Shapiro-Wilk test, we can reject the normality assumption at the 5 %-level for all continuous variables of Table 1.



**Fig. 3** Average over- and under-exploitation in resource stock units for both treatments in each period. Data points above zero indicate over-exploitation and data points below zero under-exploitation

across the two treatments, we use a Pearson’s Chi-square test (D’Agostino et al. 1988). All reported *p* values are two-sided and displayed in italics. In the regressions we let \* denote significance at the 10-percent level, \*\* on the 5-percent level and \*\*\* on the 1-percent level. Because we can reject normality, we bootstrap the standard errors for all our regressions (Goncalves and White 2005).

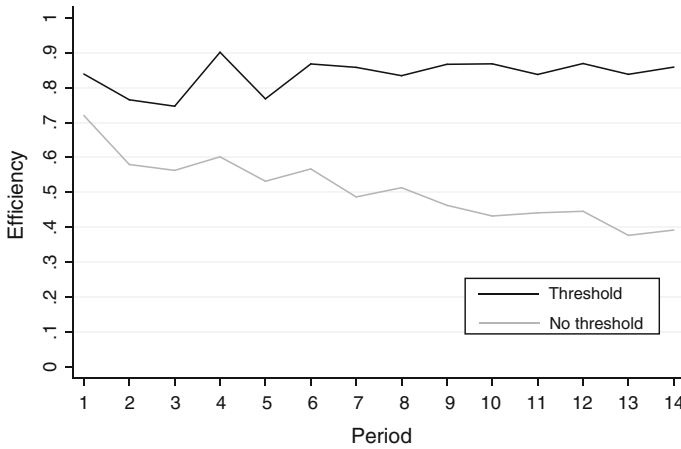
### 5.2 Results

We first look at the overall picture of the data, comparing means and proportions of the threshold with the no threshold treatment. Table 1 illustrates that there are indeed significant differences between both treatments; threshold treatment groups cooperate more, report more effective communication, achieve a higher efficiency, experience fewer tragedies and, hence, earn more money on average than groups in the no threshold treatment. There are no structural differences with respect to the individual variables age and gender, nor to group size.

In Fig. 3, we illustrate the average amount of over- and under-exploitation for both treatments in each period. From this figure, it is obvious that, on average, the threshold treatment implies less over- and under-exploitation in each period compared to the no threshold treatment.

Figure 4 clearly demonstrates the significant difference in average efficiency (see Table 1) between the two treatments; the no threshold treatment is associated with less efficiency compared to the threshold treatment. It is not that surprising to see that efficiency decreases over time for the no threshold treatment. Once there is a depletion case, efficiency drops to zero for that group, bringing down the average efficiency. From Fig. 3 we can also deduce that most inefficiencies in the threshold treatment stem from under-exploitation.

**Result 1** Based on Table 1 and Figs. 3, 4, we cannot reject Hypothesis 1. We find more cases of over-exploitation in the no threshold compared to the threshold treatment. Moreover, the average obtained efficiency in the no threshold treatment is significantly lower.



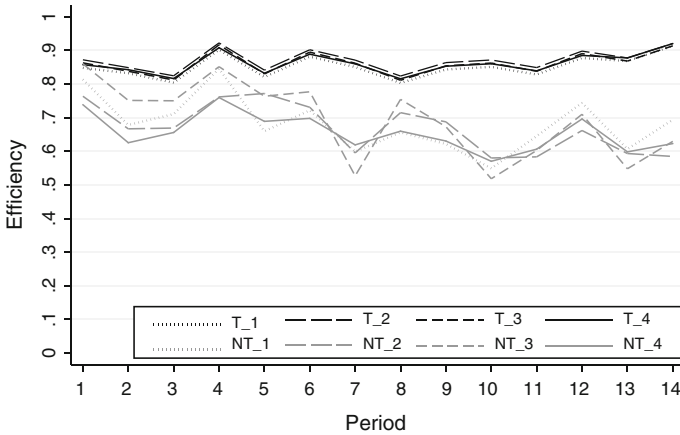
**Fig. 4** Average efficiency given current stock size over time (14 periods) of both treatments, including all groups

**Table 2** Number of cooperative groups and associated average efficiency by treatment and category

Treatment	Category 1: fulfilling criteria (i)	Category 2: fulfilling criteria (ii)	Category 3: fulfilling criteria (i) and (ii)	Category 4: fulfilling criteria (i) or (ii)
<b># Cooperative groups</b>				
Threshold	15	15	14	16
No threshold	10	9	7	13
<b>Average efficiency</b>				
Threshold	0.851 (0.200)	0.870 (0.198)	0.860 (0.201)	0.860 (0.196)
No threshold	0.682 (0.277)	0.669 (0.296)	0.694 (0.290)	0.655 (0.293)
<b>p value of equal means (MWU)</b>				
	0.000	0.000	0.000	0.000

Values in parentheses display standard errors. MWU stands for Mann-Whitney U test. Criteria (i) indicates an average Gini coefficient <0.01 and (ii) indicates an average cooperation index of five

To test Hypothesis 2, we look into the behavior of cooperative groups. We want to identify groups that were able to reach agreements that were being followed by all group members for the entire experiment. One way of classifying a group as cooperative is to use the average cooperation index (see Sect. 3.2). However, since this variable is self-assessed, one might argue that it is not reliable. Another way of classifying groups is according to the distribution of the earnings, i.e., a Gini coefficient of zero could indicate that the group is a cooperative group because earnings are shared equally. We noticed in the experiment, however, that some groups used a rotating scheme in order to optimize harvest, which implies that one or two subjects in a specific group could earn one resource unit more or less over the entire duration of the experiment, resulting in a slightly higher Gini coefficient (but still lower than 0.01). We use four cooperation categories based on fulfilling only one (either (i) or (ii)), both, or one of the two criteria: (i) groups with a Gini coefficient less than 0.01, (ii) an ‘average cooperation index’ of 5 (maximum possible). The four categories are presented in Table 2.



**Fig. 5** Average efficiency given current stock size over time (14 periods) of both treatments, only cooperative groups (the different curves refer to the four different cooperation categories, see Table 2)

If we look at Fig. 5, where we illustrate average efficiency over time for cooperative groups (specified for the different cooperation categories) for the two treatments separately, we see that the efficiency of no threshold groups (NT) is now closer to the efficiency obtained by threshold groups (T) (compare Figs. 4, 5).

Table 2 indicates some significant differences though between the threshold and the no threshold treatment; the average efficiency for cooperative groups lies between 0.85 and 0.87 for the threshold treatment and between 0.66 and 0.69 for the no threshold treatment. Mann-Whitney U tests reveal that the differences between the treatments are significant on the 1-percent level regardless of cooperation classification. Depending on classification, there are 14 to 16 cooperative groups in the threshold treatment and 7 to 13 in the no threshold treatment. According to a Pearson’s Chi square test, however, there is no significant difference between the classifications with respect to the number of groups (*p* value 0.7216).

**Result 2** We reject Hypothesis 2. From Fig. 5, it is clear that cooperative groups do not follow the optimal management strategy (which would correspond to an efficiency of 1). We also note that there is a significant difference between the treatments for cooperative groups.

To summarize, the different treatments produce a significant difference in group behavior (as we predicted in Hypothesis 1). However, the effect is even stronger than predicted (in Hypothesis 2). We explore the experimental results further to gain some insights and understanding about why this could be the case. Table 3 illustrates the results from three linear regressions. We use efficiency as the dependent variable. The first regression is with all groups, the second only with cooperative groups, and the third only with non-cooperative groups (in Table 3 we present the regressions based on cooperation category 1<sup>9</sup>). To capture potential within group correlation, we employ a random effects structure.

The models presented in Table 3 are chosen among several alternative specifications based on their performance with respect to model test (Wald Chi-square) and explanatory power. The alternative specifications show that neither average age in the group, group gender distribution, nor group size can significantly explain the variation of observed efficiency<sup>10</sup>.

<sup>9</sup> For the other three cooperation classifications, we get similar results; the same variables show up significant irrespective of classification (these regressions are provided upon request).

<sup>10</sup> The other specifications are provided as upon request.

**Table 3** Random effects linear regression models

	All groups efficiency	Cooperative groups (category 1) efficiency	Non-cooperative groups (category 1) efficiency
	Coefficient (St. error) <i>p</i> value	Coefficient (St. error) <i>p</i> value	Coefficient (St. error) <i>p</i> value
Constant	-0.125 (0.201) 0.535	-0.204 (0.506) 0.688	0.361 (0.417) 0.386
Treatment: Threshold = 1; No threshold = 0	0.267*** (0.058) 0.000	0.201*** (0.066) 0.002	0.391*** (0.099) 0.000
Average group knowledge index	0.085* (0.048) 0.076	0.197* (0.107) 0.066	0.025 (0.094) 0.795
Average group cooperation index	0.085*** (0.029) 0.000		
Period	-0.009* (0.005) 0.078	-0.004 (0.006) 0.483	-0.017* (0.010) 0.079
Rho (fraction of variance due to $u_i$ )	0.362	0.356	0.328
Model test: Wald Chi square	58.62*** 0.000	14.26*** 0.002	19.16*** 0.000
N (unbalanced panel)	568	361	207

Standard errors are bootstrapped (500 repetitions)

The first regression in Table 3 (where these insignificant variables have been excluded from the model) reveals instead that groups playing the threshold treatment, cooperative groups and groups with a higher ‘group knowledge index’ are associated with a higher average efficiency. We can also identify differences in behavior between cooperative and non-cooperative groups. For example, efficiency decreases with the number of periods played for non-cooperative groups but not for cooperative groups. This is not surprising, as we typically find over-exploitation and depletion among non-cooperative groups. The treatment is significant for both groups. According to the theoretical predictions, it should not have any effect for cooperative groups, thus, validating our rejection of Hypothesis 2. The ‘group knowledge index’ also plays a role for cooperative groups but not for non-cooperative groups.

Besides the treatment, whether a group manages to cooperate or not seems to play a crucial role in explaining how the group performs with respect to efficiency. If the group has on average a good knowledge of the resource dynamics also seems to influence achieved efficiency. But what triggers cooperation and what lies behind the knowledge variable?

A linear regression, with the ‘group cooperation index’ as dependent variable shows that groups with effective communication are more likely to cooperate (see Table 4, regression 1). No other variables, including the treatment, can significantly explain how well a group

**Table 4** Four regression models

	(1) Group cooperation index (OLS)	(2) Group knowledge index (OLS)	(3) Group communication index (OLS)	(4) Group cooperation index (2SLS)
	Coefficient (St. error) <i>p</i> value	Coefficient (St. error) <i>p</i> value	Coefficient (St. error) <i>p</i> value	Coefficient (St. error) <i>p</i> value
Constant			4.221*** (0.182) 0.000	
Treatment: Threshold = 1; No threshold = 0	0.045 (0.385) 0.906	-0.400* (0.227) 0.077	0.566*** (0.199) 0.004	
Average group communication index <sup>a</sup>	1.173*** (0.301) 0.000	1.121*** (0.137) 0.000		0.672** (0.334) 0.016
Average group knowledge index	-0.236 (0.301) 0.431			0.277 (0.344) 0.420
Average group cooperation index		-0.102 (0.134) 0.447		
Model test: Wald Chi square	1509.75*** 0.000	2923.31*** 0.000	8.09*** 0.005	546.95*** 0.000
N	41	41	41	41

Standard errors are bootstrapped (500 repetitions). <sup>a</sup> In the 2SLS (4), predicted values from reg. (3) are used

manages to cooperate<sup>11</sup>. Recall that we define effective communication as communication where the group takes advantage of the communication possibility and, moreover, they are able to reach agreements<sup>12</sup>.

Table 4 (regression 2) reveals that the most influential variable for the ‘group knowledge index’ is the ‘group communication index’. The threshold treatment is, as we know from Table 1, associated with poorer understanding of the resource dynamics, which also becomes evident here (although only at the 10-percent level). How effective the group was at communicating can explain how well they cooperated and how well they understood the resource dynamics, which in turn can explain the variation of efficiency observed. So which groups are more likely to be associated with a higher ‘group communication index’? Table 4 (regression 3) shows that the treatment is the only influential variable. Threshold groups communicated more effectively. It seems that the effectiveness of communication is endogenous to the problem, which in turn suggests that ‘group communication index’ is a “bad” control. To capture the causal effect of communication we, therefore, use a two stage least

<sup>11</sup> Table 3 presents the best (with respect to model test and explanatory power) models. Other model specifications are provided upon request.

<sup>12</sup> We have information on communication for about 75 % of the observations (30/41). Together with the experimental notes, it is then possible to replace missing variables based on averages from threshold respectively no threshold groups (see Table 1).

square (2SLS) regression where we use predicted values from regression 3 in regression 1. Regression 4 in Table 4 presents these results. Effective communication is then associated with a higher level of cooperation. Based on our results we propose the following linkage:

**Result 3** The threat of reaching a critical tipping point triggers more effective communication within the group, which in turn enables not only stronger commitment for cooperation but also knowledge sharing, which can explain why threshold groups managed the resource more efficiently, even when we only consider cooperative groups.

## 6 Discussion

The purpose of this study was to experimentally assess the effects of endogenously driven, abrupt and persistent changes in the growth rate of a CPR on resource users' management. We find that the existence of such shifts significantly influences resource users' strategies for cooperation and resource exploitation. We observe more cooperative outcomes and more efficient resource management.

Our result that the resource users are likely to be able to avoid a disaster, is consistent with some other experimental and theoretical findings on collective action. For example, Santos and Pacheco (2011) show, by using an evolutionary dynamics approach, how decisions within small groups facing the threat of substantial monetary losses significantly raises the chance of coordinating actions and escaping such losses. Similarly, in one-shot public good games with thresholds, theoretical and experimental results show that avoiding disaster is possible when it is in the interest of each individual player (disaster is severe enough compared to the cost of avoiding it) to coordinate and contribute accordingly (Barrett and Dannenberg 2012; Barrett 2013).

So what is the value-added of this study? First, in the studies mentioned above, the common threat transforms the social dilemma problem into a coordination problem, with one clear focal point, and where it is in the interest of each individual user to coordinate on that focal point. In our study, by introducing temporal (and complex) resource dynamics, the focal point to coordinate on in order to avoid a regime shift changes over time and is path-dependent. Moreover, the incentive to deviate from an agreement increases with each period played (the focal point becomes 'weaker' with every time period). Such aspects make cooperation and coordination more difficult. This is demonstrated experimentally by, for example, Herr et al. (1997) who introduce path-dependency and resource scarcity in a CPR experiment, which trigger a race-to-the bottom. In their study, however, there is no feedback on the current resource state. Osés-Eraso et al. (2008) similarly introduce path-dependency and provide their experimental participants with feedback on the current resource stock. They find that users respond to scarcity with caution but are, nevertheless, not able to avoid resource extinction.

It is important to note that these latter studies do not involve communication. Communication has been identified as one of the most influential variables to ensure cooperative outcomes in CPR settings (see overviews in Sally 1995; Ostrom 2006; Balliet 2010). Group discussions enhance group identity and solidarity, which reduce social uncertainty and foster commitments to cooperate (Dawes et al. 1990; Kopelman et al. 2002). In our experiment, all groups that manage to avoid the threshold (in that treatment) engage in communication, which confirms the importance of communication. But on the other hand, all groups that communicate do not perform equally well with respect to efficient resource management—how come? Theory suggests they should.



In our experimental design we let communication arise spontaneously. As a result, we do not observe the same level of communication and cooperation across the groups. We show (through our 2SLS approach) that the extent to which groups communicate and the extent to which communication actually leads to agreements (the *effectiveness* of communication) is endogenous to the treatment. Such a causal link has, to our knowledge, not been established before. Numerous theoretical and experimental results highlight the importance of communication for cooperation and coordination, but usually nothing is said on when we should expect communication (or not). Our results can, thus, directly inform theory. Moreover, policy recommendations for successful commons management often centers on how we can enhance and support arenas for communication and conflict resolutions (Ostrom et al. 2002). Our results suggest that the actual problem that a group faces (and how it is perceived) also matters for the success of collective management.

So what are the empirical implications? For example, are there today any empirical cases that support our claim and can provide some guidance for future research directions? More and more attention in the empirical literature on the commons is directed towards understanding how different contextual factors influence emergence and dynamics of cooperation (Ostrom 2007; Dietz and Henry 2008) but, as far as we understand, relatively little attention has been directed towards understanding the specific influence of ecological factors, although there are exceptions. Araral (2013), for example, explore if variations in geography, including ecological factors, can explain variations in institutions, such as cooperative arrangements, by comparing geography and institutions of ancient irrigation systems in three sites in the Northern Philippines from the same ethnic linguistic group (thus controlling for production system, time and culture). He concludes that the needs to maintain ecological integrity and to avoid risks such as flooding and drought lead to specific cooperative institutional arrangements that mitigate these risks.

There are also some relevant framed field experiments that look (at least implicitly) at the role of ecological context. Prediger et al. (2011), for example, explore experimentally the differences in cooperative behavior between communal farmers in Namibia and South Africa, who share the same ethnic origin but have different historical and ecological constraints. They present evidence that the relevant ecosystems (grasslands) in Namibia are more sensitive to over-grazing and more likely to become irreversibly degraded. At the same time the authors also note that Namibian resource users have a longer experience of cooperative resource management and intact traditional norms. This is also reflected in their experimental results: Namibian resource users behave more cooperatively in a CPR game than resource users from South Africa. Similarly, Gneezy et al. (2015), compare experimental outcomes in two different fishing societies. The authors observe that in one of the regions, the ecological constraints favor more cooperative activities (to avoid and coordinate over risky activities). They observe higher levels of cooperation in the experiments in that region.

These studies show that ecological factors and past experiences of such *do* influence the behavior of resource users and should be included in the set of contextual factors to explore further in CPR research. Our experiment and our design can be seen as one attempt to approach this research gap. There are, of course, many critical questions left for future research. For example, in order to isolate the effect of an endogenously driven abrupt shift on users' strategies, we abstract away from exogenous drivers; the probability of a shift is driven positively and *solely* by the users' actions. This implies, of course, that there are no other uncertainties (but strategic) in our model. We know from related experimental studies that uncertainty about the location of a critical threshold, at which huge welfare losses are to be expected, can have substantial effects on public good contribution and that uncertainty about the resource stock size uncertainty or regeneration rate in commons dilemmas (where

subjects cannot communicate) can increase individual requests (Budescu et al. 1990; Barrett and Dannenberg 2012). How will uncertainties related to the tipping point in our commons dilemma, where users can communicate, influence our results? We have to leave this question for future research.

A significant contribution of this paper is that we manage to introduce and evaluate an experimental design that is comprehensible for the subjects while still allowing for a high degree of complexity of the underlying resource function. This design could thus be adopted and used for similar studies, both in the lab (e.g., as pilots before going into the field) and in the field with real resource users. By combining different types of experiments with ecological, historical and socio-economic data, we may then slowly progress towards a more realistic situation and learn which factors are of ultimate interest for advancing the understanding of the role of ecological context. Thus, we argue that the results we have obtained here can be seen as *one* piece (but nevertheless a crucial one) of the much bigger puzzle of understanding the interaction between human behavior and the environment in CPR systems.

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