Can Violence Harm Cooperation? Experimental Evidence*

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Abstract

While folk theorems for dynamic renewable common pool resource games sustain cooperation at equilibrium, the possibility of appropriating violently the resource destroys the incentives to cooperate, because of the expectation of conflict when resources are sufficiently depleted. This paper provides experimental evidence that individuals behave according to the theoretical predictions. For high stocks of resources, when conflict is a highly costly activity, participants cooperate less than in the control group, and play non-cooperatively with higher frequency. This comes as a consequence of the anticipation that, when resources run low, the conflict option is used by a large share of participants.

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1 Introduction

The depletion of the world's renewable natural resources has become increasingly concerning and is reflected in the warnings of the scientific community (Homer Dixon 1999, Stern 2007). When such resources are commonly managed, they are prone to the *tragedy of the commons* problem, i.e. over-extraction resulting from inherent externality problems (Hardin 1968). The management of these resources is best described in a formal dynamic setting, which allows to capture the regenerative nature of resources through time. In a dynamic setting, cooperation on the efficient extraction of a renewable resource can be sustained among resource users by the threat of reverting to noncooperation in case of noncompliance to some agreed behaviour (Cave 1987, Dutta 1995, Sorger 2005, Dutta and Radner 2009).

More recently, the game theoretic predictions on the management of the commons have received extensive attention by experimental economists. The early experimental literature focused on testing the equilibrium behavior generated by repeated games (Palfrey and Rosenthal 1994, Dal Bó 2005), or finite dynamic games (Herr et al. 1997). In general, findings tend to concur with the theoretical predictions, suggesting that free riding and therefore inefficiencies do arise, and that dynamics help fostering the cooperative equilibrium through reputation mechanisms and the existence of latent punishment schemes.[1] Exploring whether cooperation can be sustained in dynamic games of resource exploitation is a more challenging question that has only been tackled recently (Frechette 2014). Since the cooperative extraction level can be sustained with several different subgame perfect punishments, experimental economists need to limit their experimental tests to a (some) specific strategie(s). Vespa (2014) shows that individuals tend to cooperate in a dynamic renewable common pool resource (CPR) game if given the possibility to "cooperate" or "defect" to the noncooperative Markovian strategy. Yet such cooperation is jeopardized when participants are offered the choice

[1]Scholars have also demonstrated a tendency of participants to use costly punishments against non-cooperators, even that leaves them materially worse-off (Fehr and Gaechter 2000, Casari and Plott, 2003).

of a “highly profitable” deviation. These findings therefore seem to suggest that individuals do cooperate under the threat of some punishment strategies.

The punishment strategies described above rely on the dynamic nature of the game. As a consequence, the picture changes if players are given the possibility to alter the nature of the game via their actions. Sekeris (2014) demonstrates that in a dynamic renewable CPR game, where individuals are given the choice to revert to violence at any point in time so as to claim ownership of the common resource, the efficient solution may not be sustainable at equilibrium. This follows from the players’ incentives to violently appropriate the CPR when the resource becomes scarce, which renders the non-cooperative punishments necessary to support cooperation not subgame perfect, and therefore invalidates the logic of Folk theorems. Given the important consequences that such reasoning may have with regards to the conservation of resources that are vital for sustainaining human life, such as fresh water, land and fossil fuels, it is crucial to inquire whether individuals do act as rational theory predicts.

A burgeoning experimental literature on conflicts has emerged lately.[2] While the initial contributions subjected to experimental validation static theories of conflict, the dynamic considerations we are focusing on have equally received attention by scholars more recently (Abbink and de Haan 2014, Lacomba et al. 2014, McBride and Skaperdas 2014). Yet, whereas all the contributions perceive conflict as an appropriation of private goods and/or production potential, our approach conceives the status quo as a CPR game. Cooperation in experimental conflict settings has equally received some attention, albeit the focus of the existing literature has been on alliance formation as opposed to cooperation in the production process (Ke et al. 2015, Herbst et al. forthcoming). Moreover, to conform to the theory of Sekeris that we are testing, we design a conflict experiment replicating an infinite-horizon game as in Vespa (2014).

In this paper, we therefore experimentally explore whether the possibility of costly appropriation of a

[2] see Dechenaux et al. (2014) for a recent review of the literature.

CPR modifies the incentives to cooperate. To that end, we develop a simplified version of the model in Sekeris (2014), which allows us to derive clear predictions with regards to the players' optimal strategies. In the absence of costly appropriation, the theory predicts that cooperation can be sustained at equilibrium. With the introduction of costly appropriation results change dramatically: individuals stop cooperating by opting for non-cooperation in the early stages of the game, and eventually resorting to costly appropriation. To experimentally evaluate the applicability of this theory, we design three treatments and compare cooperation rates across them. Each treatment involves 58 participants, for a combined total of 174 students from the University of York (UK).

In all treatments participants are randomly matched into pairs and then called to decide the amount of 'points' to extract from a pool of points at each 'round' of the game, and given a pre-defined regeneration rate of the CPR.

In the first treatment, which we label the 'chance' treatment, during each 'round' participants are given the possibility to extract either a 'low' level of points corresponding to the theoretical prediction of a cooperative extraction, or a 'high' level of points corresponding to the theoretical prediction of a non-cooperative (Markov-perfect) extraction. In addition to 'low' and 'high', participants are given the choice of opting for resource appropriation, denoted by 'chance', whereby the CPR is split equally between the two paired individuals, at some cost which is increasing in the stock of the CPR.[3] If at some time period chance is played, the optimal extraction path is imposed on participants from the subsequent time period and thereafter.

In the second treatment, which represents our first control treatment and is labelled the 'no-chance control' treatment, participants play the same game but without the 'chance' option. This control treatment allows us to directly test the theoretical predictions of the paper.

[3]We deliberately chose a neutral tag to denote the conflict action in our experiment to avoid any framing bias. In particular, had we named our resource appropriation 'conflict' or 'violence', changes in cooperation rates across treatments may have been the consequence of different moral/ethical values among participants.

Finally, we design an alternative control treatment named 'chance control'. This treatment is identical to the 'chance' treatment, except for the cost of opting for resource appropriation, which is substantially increased to make it theoretically suboptimal. In other words, we offer participants the same three options as in the 'chance' treatment (i.e. low, high extraction rates and chance), but if chance is chosen 60% of the CPR is destroyed, thus making that choice suboptimal for any level of resources.

To emulate the infinite horizon environment required for folk theorems to be applicable, we follow the methodology in Vespa (2014) which was first introduced by Roth and Murnighan (1978) and later applied by Cabral et al. (2011). The technique introduces an uncertain time horizon by allowing the software to terminate the game at any 'time period' with some predetermined probability. This practice - which in theory is equivalent to an infinite time horizon if individuals are risk neutral - has been shown not to be innocuous in practice (Dal bó 2005, Frechette and Yuksel 2014). Since both our control and treatment groups are subject to the same random termination rule, however, the validity of our experiment is not jeopardized.

Our experimental findings support the theory of Sekeris (2014). Under the chance treatment the level of cooperation is lower compared to both control treatments, and non-cooperation is higher. Both the magnitude of the coefficients and the level of significance are larger when compared to the non-chance control treatment, than when comparing to the costly chance control group. This signals higher levels of non-cooperation and lower levels of cooperation under the costly chance treatment than under the no-chance control group. Hence, the very possibility of using the chance option - even when it is costly - seems to incentivize participants to substitute cooperation by non-cooperation. The fact that cooperation is lower and non-cooperation larger in the chance treatment compared to the chance control treatment implies that the expectation of a higher likelihood of chance being played in later stages of the game reduces cooperation in favour of non-cooperation in the early stages of the game. Restricting the analysis to the early rounds of the game (or alternatively to high levels of CPR) confirms that participants tend to non-cooperate more in expectation of chance being potentially chosen in subsequent rounds.

In the following section we lay out a simplified version of Sekeris (2014), in Section 3 we describe the experimental design, in Section 4 we present our experimental results, and lastly Section 5 concludes.

2 Theory

We consider a dynamic common pool resource game featuring a renewable resource, r_t. Time is discrete and denoted by $t = \{0, 1 \ldots \infty\}$. Two players labeled 1 and 2 simultaneously decide at each time period the amount of resources to extract from the common pool of resources. The initial resource endowment is given by r_0 and the resource regenerates at some linear rate γ. Players costlessly invest effort in resource-use, so that player i's appropriation effort of renewable resources in time t is denoted by $e_{i,t}$, with $e_{i,t} \in [0, \bar{e}]$, $\bar{e} > r_0$. Player i's associated instantaneous consumption is given by $x_{i,t}$ such that:

$$x_{i,t} = \begin{cases} e_{i,t} r_t & \text{if} \quad e_{1,t} + e_{2,t} \leq r_t \\ \frac{e_{i,t}}{e_{1,t}+e_{2,t}} r_t & \text{otherwise} \end{cases} \tag{1}$$

The law of motion of resources is given by:

$$r_t = (1 + \gamma)(r_{t-1} - x_{1,t-1} - x_{2,t-1}) \tag{2}$$

The instantaneous utility of any player i in time t is given by:

$$u_{i,t} = \ln(x_{i,t}) \tag{3}$$

And the discounted life-time utility of player i in time period 0 equals:

$$U_{i,0} = \sum_{t=0}^{\infty} \delta^t \ln(x_{i,t}) \tag{4}$$

Where δ designates the common discount rate.

We denote a strategy for player i by $\mathbf{e_i} = \{e_{i,t}\}_{t=0}^{\infty}$.

2.1 Cooperation

The "cooperative" solution of this game consists in both players choosing extraction rates that internalize the negative externality of resource depletion on the opponent. Stated otherwise, the "cooperative solution" is the central planner solution which reads as:

$$\max_{e_1,e_2} \sum_{i=1,2} \sum_{t=0}^{\infty} \delta^t \ln(x_{i,t}) \tag{5}$$
$$s.t. \qquad (1) \text{ and } (2)$$

The solution to this problem, the details of which can be found in Appendix A.1.1, is such that:

$$e^c_{i,t} = \frac{1-\delta}{2} r_t \qquad i = \{1,2\} \tag{6}$$

where superscript c denotes the cooperative solution. Or, defining by s^c_i the (constant) optimal extraction share of player i at any time period t, we have $s^c_1 = s^c_2 = (1-\delta)/2$.

The discounted expected utility of both players following the cooperative strategy forever can be shown to equal:

$$V^c_{i,t} = \frac{1}{1-\delta}\left[\ln\left(\frac{(1-\delta)r_t}{2}\right) + \frac{\delta}{1-\delta}\ln(\delta(1+\gamma))\right] \tag{7}$$

2.2 Non-cooperation

We next define as the non-cooperative strategy the Markov Perfect Equilibrium (MPE) strategy of this dynamic game. Denoting the associated strategies by nc, in time period t the maximization problem for player i therefore reads as follows:

$$\max_{e_i} \sum_{t=0}^{\infty} \delta^t \ln(x_{i,t}) \tag{8}$$
$$\text{s.t.} \quad (1) \text{ and } (2)$$

After optimizing, we obtain the equilibrium non-cooperative extraction levels:

$$e_{i,t}^{nc} = \frac{1-\delta}{2-\delta} r_t \qquad i = \{1,2\} \tag{9}$$

And, accordingly, the MPE strategy is given by the pair of vectors $\left\{\mathbf{e_i^{nc}}, \mathbf{e_j^{nc}}\right\}$.

Defining bys_i^{nc} the (constant) optimal non-cooperative extraction share of player i at any time period t, we have $s_1^{nc} = s_2^{nc} = (1-\delta)/(2-\delta)$.

This enables us to compute the discounted expected utility of the non-cooperative subgame perfect equilibrium (SPE):

$$V_{i,t}^{nc} - \frac{1}{1-\delta}\left[\ln\left(\frac{(1-\delta)r_t}{2-\delta}\right) + \frac{\delta}{1-\delta}\ln\left(\frac{\delta(1+\gamma)}{2-\delta}\right)\right] \tag{10}$$

2.3 Cooperative and non-cooperative equilibria

The cooperative strategy yields - by construction - a Pareto-dominant situation, and given the assumed symmetry it equally yields a higher discounted expected intertemporal utility for each player than any alternative equilibrium strategy for any given starting stock of resources. A strategy whereby players cooperate irrespective of the opponent's action cannot be an equilibrium strategy, however, since the instantaneous utility of deviating from the cooperative extraction rate is higher than the instantaneous utility of cooperating. To sustain cooperation, therefore, punishment strategies should be considered. A widespread strategy that supports the cooperative extraction path as a subgame perfect equilibrium, is the Grimm-trigger strategy, whereby any deviation from the cooperative action by either player implies that both players revert to the non-cooperative MPE forever after. One interesting route is therefore to derive the conditions that induce play of the cooperative path in equilibrium. For cooperation to be sustained as a SPE it is sufficient that the following condition be satisfied:

$$\ln\left(e_{i,t}^{dev}(e_{j,t}^{c})\right) + \delta V_i^{nc}\left((r_t - e_{i,t}^{dev}(e_{j,t}^{c}) - e_{j,t}^{c})(1+\gamma)\right) < V_i^c(r_t) \tag{11}$$

where the *dev* superscript designates the "deviation" instantaneous best response of player i to any extraction rate of player j. In the above expression, since we are inspecting the condition for the cooperative path of play to be an equilibrium, player i considers the deviation best response in time period t given player j's cooperative extraction level in time period t, and given the reversion to the MPE from period $t+1$ (i.e. Grimm-trigger strategy).

It is shown in Appendix A.1.2 that, after replacing for the appropriate terms, this expression can be written as:

$$\delta \ln(2-\delta) > (1-\delta)\ln(1+\delta) \tag{12}$$

which is true for any $\delta > 1/2$. We can therefore state the following result:

Proposition 1. *The cooperative extraction of resources is supported as a subgame perfect equilibrium by a Grimm-trigger strategy of reversion to the Markov Perfect Nash strategy for any* $\delta > 1/2$.

While this is not the only punishment supporting cooperation, it is a particularly convenient punishment for an experimental application.[4]

2.4 Cooperation and conflict

We now amend the standard tragedy of the commons framework by endowing the players with the capacity to revert to conflict at any stage of the game in order to appropriate part of the common resource and to manage the appropriated resource forever after as personal resource. We consider a very basic conflict technology that grants each player the control over half the resource stock from the time-period the conflict occurs onwards. In this paper we abstract from modelling the arming process and from thereby endogenizing the winning shares as in Sekeris (2014). Moreover, the arming process being disregarded, the intensity of

[4] In particular, the strategy of mutual full exhaustion of the resource is subgame perfect and constitutes the harshest possible punishment supporting the cooperative equilibrium for any (see Vespa 2014 and Sekeris 2014).

conflict cannot vary endogenously in this setting, and we instead impose that conflict may be destructive, so that the resource resilience to conflict is described by some function $\phi(r_t) \in [0,1]$, with $\phi(r_t)' \leq 0$, and such that $\exists \bar{\bar{r}} > \bar{r} > 0$, whereby $\phi(r) = 1, \forall r \leq \bar{r}$ and $\phi(r) = 0, \forall r \geq \bar{\bar{r}}$. The function $\phi(r_t)$ is continuous on the interval $]\bar{r}, \bar{\bar{r}}[$.[5] The modified timing of actions is now such that:

1. Both players decide simultaneously whether or not to declare conflict, in which case conflict ensues.

2. Both players decide their extraction efforts simultaneously.

Given this modified setting, if either player declares conflict in time period τ, the discounted expected utility of player i in time τ is given by:

$$U_i^{violence}(r_\tau) = \sum_{t=\tau}^{\infty} \delta^{t-\tau-1} \ln \left(\phi(r_\tau) x_{i,t} \left(\tilde{r}_t\right)\right) \tag{13}$$

With $\tilde{r}_\tau = r_\tau/2$, and the new law of motion of resources becomes:

$$\tilde{r}_t = (1+\gamma)(\tilde{r}_{t-1} - x_{i,t-1}) \tag{14}$$

Optimizing this expression with respect to $x_{i,t}$ yields:

$$x^*_{i,t} = (1-\delta)\frac{r_t}{2} \qquad \forall r_t \tag{15}$$

Thus implying that along the optimal consumption path, Expression (13) can be written as:

$$V_i^{violence}(r_t) = \frac{1}{1-\delta} \ln \left((1-\delta)/2\phi(r_\tau) r_\tau\right) + \frac{\delta}{(1-\delta)^2} \ln((1+\gamma)\delta) \tag{16}$$

To understand how the possibility of violent resource appropriation affects the game's equilibria, we proceed in two steps. We first demonstrate that eternal cooperation is not achievable because, through

[5] Notice that this set of simplifying assumptions about the conflict technology are meant to produce numerical results that can easily be mapped in the lab, while capturing the essence of Sekeris (2014) where the players' armaments and therefore the associated damage to the resource are endogenous.

the dynamic depletion of the resource, the game reaches a point where both players prefer deviating from cooperation to conflict. In a second step, we demonstrate that short-lived cooperation is not implementable either.

To demonstrate that eternal cooperation is not possible, it is sufficient to establish that the next inequality is verified for some r_t:

$$\ln\left(e_{i,t}^{dev}(e_{j,t}^{c})\right) + \delta V_i^{violence}\left(\left(r_t - e_{i,t}^{dev}(e_{j,t}^{c}) - e_{j,t}^{c}\right)(1+\gamma)\right) > V_i^{c}(r_t) \tag{17}$$

If player i deviates from the cooperative path of play in time period t, then $e_{i,t}^{dev} = \frac{(1+\delta)(1-\delta)}{2} r_t$. Combining this with $e_{i,t}^{c} = \frac{1-\delta}{2} r_t$, we deduce that, in this event, the stock of resources in the subsequent time period would equal $r_{t+1} = (1+\gamma)\delta r_t$. Replacing for the appropriate values in the above inequality therefore yields:

$$\begin{aligned}\ln\left(\frac{(1-\delta)(1+\delta)}{2} r_t\right) + \frac{\delta}{1-\delta}\ln\left(\frac{1-\delta}{2}\phi\left[(1+\gamma)\delta r_t\right](1+\gamma)\delta r_t\right) + \frac{\delta^2}{(1-\delta)^2}\ln\left((1+\gamma)\delta\right) \\ > \frac{1}{1-\delta}\ln\left(\frac{(1-\delta)r_t}{2}\right) + \frac{\delta}{(1-\delta)^2}\ln\left((1+\gamma)\delta\right)\end{aligned}$$

After simplifying, this inequality can be reduced to:

$$\ln(1+\delta) + \frac{\delta}{1-\delta}\ln\left(\phi\left(r_{t+1}\right)\right) > 0 \tag{18}$$

where $r_{t+1} = (1+\gamma)\delta r_t$. For any $r_{t+1} \leq \bar{r}$, $\phi(r_{t+1}) = 1$ and the above inequality is then satisfied for any value of δ. For any $r_{t+1} \geq \bar{\bar{r}}$, $\phi(r_{t+1}) = 0$, and the inequality is then violated for any value of δ. Moreover, since $\phi(r_t)$ is continuously defined on $]\bar{r}, \bar{\bar{r}}[$, there exists a $\hat{r} \in [\bar{r}, \bar{\bar{r}}]$ such that the inequality is satisfied for any $r_{t+1} < \hat{r}$.

Having shown that cooperation cannot be sustained forever, we now demonstrate that cooperation is not sustainable in the short run either and that the game's unique equilibrium involves non-cooperative behaviour for high stocks of resources, as well as conflict for low stocks of resources. To establish this, we exploit the previous result according to which cooperation is not sustainable forever, together with the fact that for low levels of resources, violence is better than the discounted expected utility of non-cooperation. The latter result is proven by establishing that there exist values of r_t, which satisfy the following inequality:

$$V_i^{violence}(r_t) > V_i^{nc}(r_t) \tag{19}$$

Replacing for the appropriate values and simplifying yields:

$$(1-\delta)\ln(\phi(r_t)/2) + \ln(2-\delta) > 0 \tag{20}$$

Replacing r_t by $\bar{r}$ implies that the condition is satisfied for any δ.

Defining by $\hat{r}$ the maximal value of resources satisfying inequality (20), we show that for any resources $r_t > \hat{r}$ players will play non-cooperatively. Assume that in period τ we expect conflict to be the preferred option if both players expect each other to cooperate. Then in $t = \tau - 1$, should one's opponent play cooperatively, it is optimal to play the non-cooperative best response. Hence, in $t = \tau - 1$, both players will play non-cooperatively. This mutual non-cooperation is due to the fact that in time τ players have no punishment scheme to support cooperation. Applying the argument backwardly implies that players never cooperate, which leads to the following proposition.

Proposition 2. *In a renewable resource exploitation game, where players can revert to violence to appropriate the common pool resource, the equilibrium is such that players exploit the resource non-cooperatively if $r > \hat{r}$ and they declare conflict if $r \leq \hat{r}$.*

3 Experimental design

3.1 Parametrization

For the experimental game, we fix the parameters of the model such that (i) cooperation is supported as a SPE in the conflict-free version of the game, and (ii) conflict is the players' preferred option when resources are sufficiently depleted in the conflict version of the game, therefore verifying Proposition 2.

The unique sufficient condition for (i) to hold is that $\delta > 1/2$. We accordingly set the discount rate in the lab to $\delta = 0.7$, and the values of s^c and s^{nc} are thus respectively fixed at 0.15 and 0.23. The associated value of the non-cooperative best response to cooperation, $s^{dev} = \frac{(1-\delta)(1+\delta)}{2}$, is equal to 0.255.

We set the initial stock of points to be $r_0 = 40$ and the regeneration rate $\gamma = 0.3$.

Lastly, we give some structure to function $\phi(r_t)$ to be able to simulate payoffs. To keep figures simple, while satisfying the requirements of the model, we impose:

$$\phi(r_t) = \begin{cases} 1 & \text{if } \; r_t < 25 \\ 2 - 0.04 r_t & \text{otherwise} \end{cases} \tag{21}$$

which implies that the threshold value of the CPR below which conflict is theoretically optimal is given by $\hat{r} = 29.15$.

3.2 Design

The experiment was programmed in zTree and participants where recruited among students of the University of York using hroot (Bock et al. 2014). We conducted three different treatments, each involving 58 participants. Each treatment consists of one supergame, in which participants play 20 identical games (10 practice games and 10 "real" games with a lottery payment of two out of the 10 "real" games).[6] For each game, participants are randomly matched into pairs, whereby each game runs for a randomly determined number of rounds. Random rematching at the end of each game occurs using zTree's matching-stranger option. To implement an infinitely dynamic game in the laboratory, we follow the methodology of Vespa (2014), building on Roth and Murninghan (1978) and the recent application of Cabral et al. (2011). Like Vespa (2014),

[6]This payment method was chosen to prevent participants from adapting strategies with regards to cumulated payoffs obtained during earlier games.

we impose that the first six rounds of each game are played with unit probability but the earned payoff is discounted at a constant rate of 0.7. From round 7 onwards, the software randomly terminates the game with a probability of $(1-\delta) = 0.3$. The rationale for adopting such a hybrid termination rule is that, without such a rule in place for the entire game (i.e. such that at each round the game would terminate with probability 0.3), the average length of a game would approximately equal 3.3 periods, thus potentially inducing players not to cooperate despite the Pareto-superiority of cooperation. Indeed, *if both players were to always cooperate*, cooperation would start dominating non-cooperation after round 5, as shown in Figure 1, where we depict cumulated payoffs under mutual cooperation and mutual non-cooperation, respectively. Imposing 6 rounds of certain play increases the average number of rounds played to 9.3, without affecting players' expected payoffs.

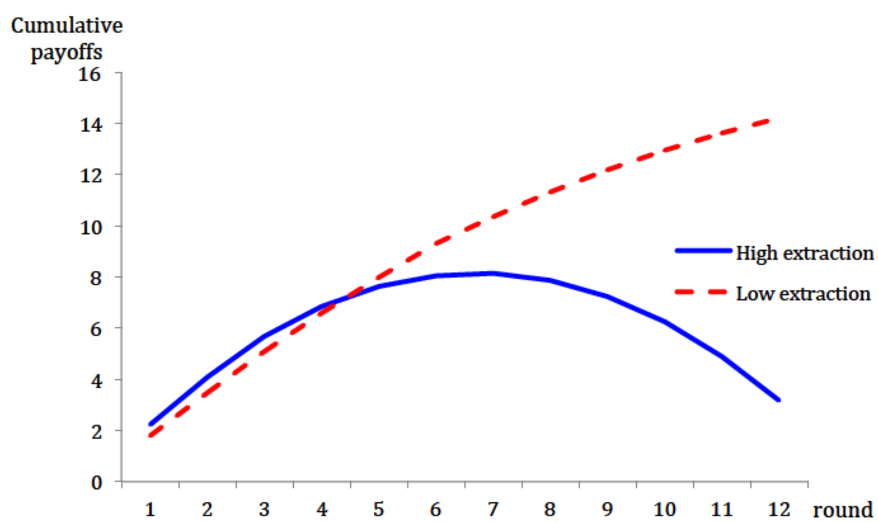


Figure 1: Cumulated payoffs under mutual cooperation and mutual non-cooperation

In all treatments, participants begin each game with a common pool of 40 'points'. In our first control treatment, denoted 'no-chance control', participants are given two extraction choices, either a 'high' extraction rate or a ‘low’ one. To capture the prisoners’ dilemma nature of the game, we respect the payoff structure of the theoretical model so that the (constant) shares of points that are extracted for each combination of choices of paired participants are given as follows:

- If both players play ‘high’, each extracts 23% of the remaining points.
- If a player opts for ‘low’, he/she extracts 15% of the remaining points, irrespective of the other player’s extraction.
- If a player plays ‘high’ and his/her match plays ‘low’, he/she extracts 25.5% of the remaining points.

Our actual treatment - denoted ‘chance’ treatment - offers participants the same choices as the ones described above, and additionally these participants can opt for ‘chance’ at any round of the game. If chance is selected, the CPR is subjected to a loss described by function (21), and the remaining stock of points is shared equally among both players, who are from then on imposed the (optimal) ‘low’ level of extraction for the current and all subsequent rounds. Consistent with the theoretical findings, we expect that, when confronted with this treatment, participants should play less cooperatively and more non-cooperatively in a game’s early rounds, while chance should be selected after the stock of points drops below 29.15 (i.e. when inequality (20) is satisfied).

The two treatments described above differ not only in the options given to the participants, but also in the number of choices offered. It could therefore be argued that, when presented with an additional option in the ‘chance’ treatment, the level of cooperation will naturally decrease, *ceteris paribus*, if chance is to be played for any reason compatible or not with our theory. In order to curb such potential criticisms we implemented a second control treatment, denoted by ‘chance control’. In the latter treatment, players are confronted with the same three choices as in the ‘chance treatment’, with the sole difference that the cost of playing chance in terms of CPR losses equals 60% of the stock, irrespective of the amount of points that remain. The 60%

figure guarantees that choosing chance is never optimal from a theoretical perspective for participants.

In addition to the instructions that were handed out to participants (see Appendix A.2), the screen indicated the amount of points that would be available in the next time period for each potential choice participants could make, and for all respective choices of the opponent. This information was available during each round of the game. Participants could pre-select an option, in which case a red frame would appear around their choice. They then had to confirm their selection be pressing "OK", which let them proceed to the next round. A screenshot of the 'chance' treatment is provided in Figure 2. It illustrates the functionality of the software.

Figure 2: Screenshot of 'chance' treatment with 28 points

Each experimental session lasted approximately 120 minutes. We paid a show-up fee of £3, and given our two-out-of-ten rounds lottery the average payment per participant was £17.56 with an earnings' variance of £1.20.

4 Empirical analysis

Before presenting the empirical results, some descriptive statistics may prove useful in grasping the participants' behaviour. In Figure 3 we depict the cumulated share of participants opting for cooperation across the three treatments. There is a marked difference between treatments, with cooperation being played at a higher rate - at any given round - in the no-chance treatment (top discontinuous curve) - , and with cooperation being chosen less often in the chance treatment (bottom continuous curve). This very preliminary result concurs with our theoretical expectations: the anticipation of chance being played in either the chance-control or the chance treatments reduces players' propensity to opt for cooperation. Moreover, with chance-control being sub-optimal, it is reasonable to expect that players anticipate chance to be played more frequently in the chance treatment, and therefore to cooperate even less in the latter treatment.

Our theoretical predictions suggest that cooperation should be substituted by non-cooperation when the CPR is relatively abundant. To see that this is indeed the case, consider Figure 4, where we have plotted the cumulated share of participants that opt for non-cooperation across the three treatments. Interestingly, we observe a trend, which seems to mirror the cooperation rates in the game's initial rounds, so that it is the participants in the chance treatment who are least cooperative in all rounds (followed by the chance control treatment, and then by the no-chance-control treatment).

To convince the reader of this preliminary evidence, we have plotted the proportion of participants playing chance for the two treatments where chance is permitted in Figure 5. This Figure shows that the differences between the cooperative and non-cooperative behaviour are intimately linked to the participants' propensity to resort to chance during later rounds of the game. There is a marked difference in the proportion with which chance is being played in the chance (continuous curve) and the chance-control (dotted curve) treatments. In the former treatment, participants are more willing to play chance during any round of the game, but perhaps more importantly, there is a striking difference between the chronological evolution depicted in the separate curves. In the chance treatment we observe a sharp increase in round 3, which corresponds to the round where the level of points is - on average - in the range where chance becomes optimal in theory. Since chance is never optimal in the chance-control treatment, we should expect no similar pattern in the latter treatment, which seems to be confirmed by Figure 5. Under both treatments we do, however, observe an increase in the proportion of participants that play chance in later rounds. This behaviour may be due to several reasons. One could be that participants resort to some sort of protection mechanism by attempting to put an end to the depletion of the CPR. Other psychological mechanisms could be invoked to explain these observations, but irrespective of the cause of this behaviour, the only explanation for the higher rate of non-cooperation in the game's early rounds must be the expectation of such behaviour in the future.

The patterns presented in Figures 3-5 are consistent with our mechanism. Visual correlations alone, however, cannot be interpreted as causal evidence. We therefore turn now to regression analysis and we estimate the following model:

$$Cooperation_{igt} = \alpha + \beta\, Game_i + \gamma\, Round_{ig} + \delta\, Chance_i + X_i'\zeta + \epsilon_{igt} \tag{22}$$

where $Cooperation_{igt}$ is a dummy variable capturing whether participant i in game g and round t opted for the efficient extraction of points. $Game_i$ is the number of 'real' games played by participant i, whereas $Round_{ig}$ captures the number of rounds played by participant i in the current game. Both controls are meant to capture potential trends or learning effects across and within games. $Chance_i$ is a dummy variable equal to one for all participants of the chance treatment.[7] The vector X_i' controls for individual characteristics and includes

[7] We do not include the stock of points left in our empirical model as it is endogenous to cooperation levels and highly collinear with

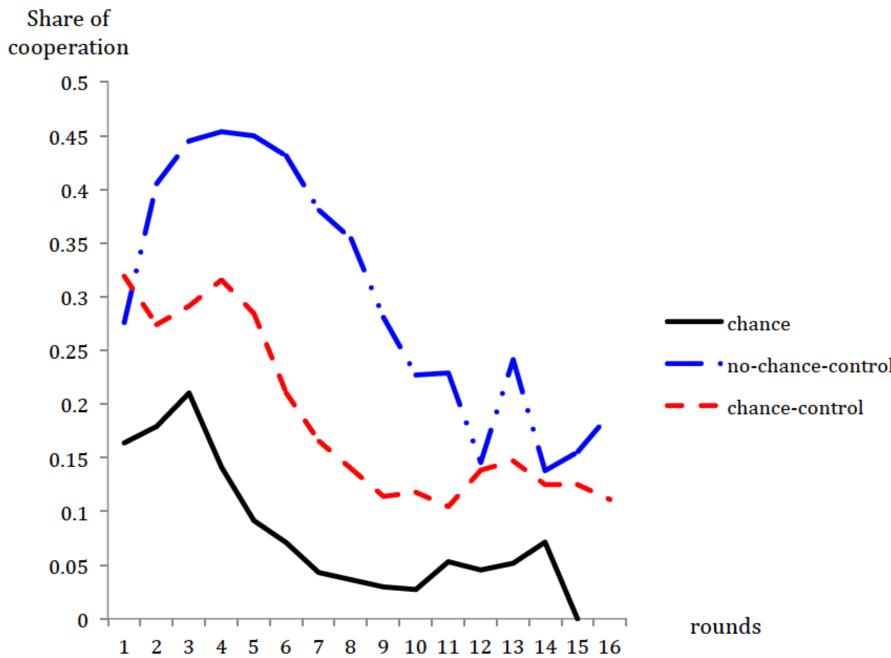


Figure 3: Share of participants opting for cooperation

study subject and gender. Regarding study program, we create two dummies for hard sciences (*science*) and social sciences (*social*), with the residual group being humanities. As for gender, since it may influence the attitude of participants, both towards cooperation and towards the chance option, we include a dummy variable for *male*. Finally, ϵ_{igt} is the standardized error term clustered at the individual level. The coefficient of interest is δ, which captures the impact of having the 'chance' option on the level of cooperation.

We then estimate equation (22) by replacing the dependent variable by a dummy $\textit{Non-cooperation}_{igt}$ equal to one when the participant chooses the non-cooperative extraction level.

the variable Round. Substituting Round with the level of stock of points produces qualitatively identical results.

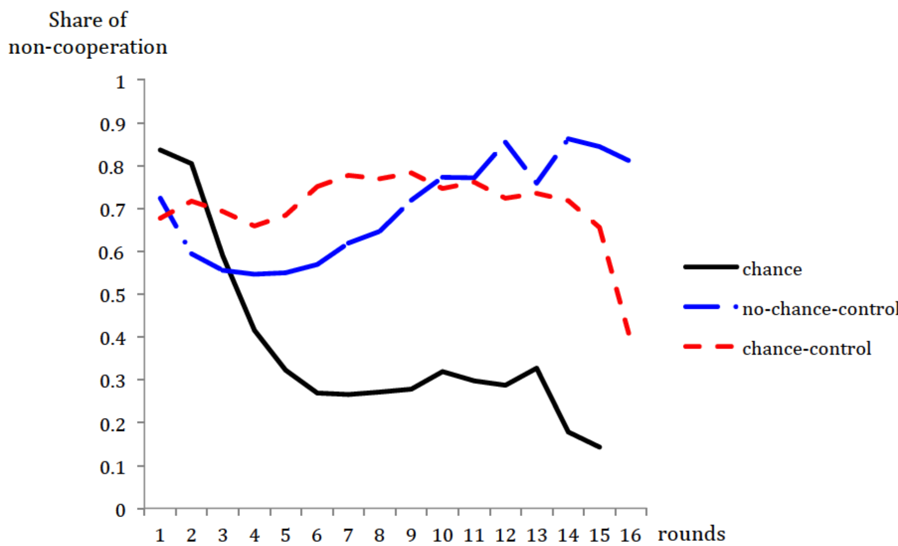


Figure 4: Share of participants opting for non-cooperation

4.1 Baseline results

In Table 2 we report the results of estimating model (22), where the control group is restricted to the no-chance control treatment only.[8] In other words, we are comparing the behaviour of a participant having only two choices (low and high extraction rates) with the behaviour of participants having three options (low, high, and chance). The first column of Table 2 reports the results of the benchmark specification and as shown all coefficients are statistically significant at the 1% level. Compared to the no-chance control, participants in the chance treatment tend to cooperate by 23.6 percentage points less on average, thus lending support to our theoretical findings. Given that the average level of cooperation in the no-chance-control treatment equals 37%, this implies that the introduction of the chance option reduces the likelihood of cooperation by 63.7%. Consistently with previous findings, the *Game* coefficient, which captures the learning effect across

[8] All model specifications are estimated by OLS. Replicating our estimates by a probit estimation does not affect our results qualitatively.

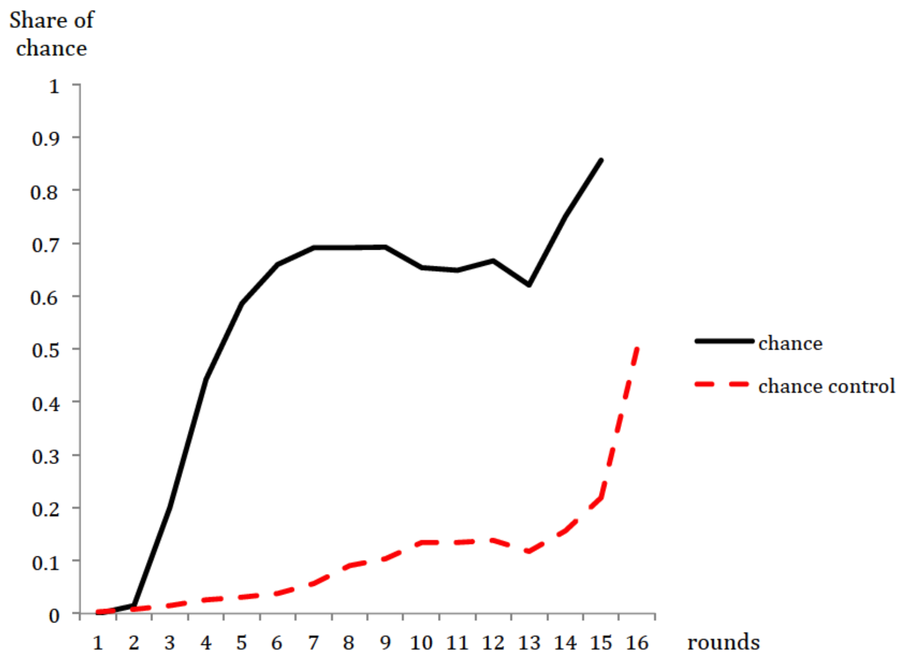


Figure 5: Share of participants opting for chance

games, implies that the level of cooperation decreases on average by 0.4 percentage points from one game to another (Dal Bó and Fréchette 2011). Moreover, cooperation is decreasing on average by 1.6 percentage point from one round to another within a game. As will become clear later, the latter result is mainly driven by participants' increasingly frequent choice of chance, on the one hand, and by the participants' increasingly frequent reversion to non-cooperation when the stock of points start to run very low. Lastly, the gender and studies coefficients take signs compatible with earlier findings: male participants tend to cooperate less (Eckel and Grossman 1998), and the same holds true for non-humanities students (Frank et al. 1993).

The negative effect on cooperation of allowing participants to use the 'chance' option does not necessarily map onto an increase of non-cooperation to the extent that the effect may be driven by an increase in the use of the third option which is unavailable in the no-chance-control group. Our main theoretical finding, which is summarized in Proposition 2, stipulates that for high levels of the stock of points (i.e. $r > 29.15$ given our parametrization) the optimal decision is to choose the non-cooperative extraction rate, with the chance option being used only when the stock of points is sufficiently depleted ($r \leq 29.15$). To verify therefore that we indeed observe a substitution of cooperation by non-cooperation, we restrict our estimation in multiple ways. In column 2 of Table 2, we restrict the sample to $r > 29$ to see whether for high stock of points - where chance is unlikely to have been chosen - cooperation does decrease. Compared to the benchmark estimation (Column 1), the coefficient is smaller but still negative and significant at the 5% level, thus implying that cooperation decreases as compared to the no-chance-control treatment, when resorting to chance is theoretically sub-optimal. Given, however, that the stock of points is endogenous to the extraction rates of participants, in columns 3 and 4 we equally exclude the rounds where 'chance' has been played, and in Column 4 we further restrict the sample to the first 6 rounds of play, where the random termination rule has not yet kicked in. The rationale for excluding the rounds where '*chance*' has been played, is to restrict the comparison of the no-chance treatment to rounds where the treated group opted for cooperation or non-cooperation alone. The results further confirm a substitution away from cooperation to non-cooperation in the chance treatment. Lastly, in column 5 of Table 2, we restrict the analysis to the first two rounds. Given that all games begin with a stock of 40 points, the stock of points would equal 28 in round 2, even if both players played 'high' in the game's first rounds, making participants roughly indifferent between playing 'chance' and not. Cooperation is significantly lower under the chance treatment by 14.7 percentage points, further confirming our expectations.

In Table 3 we present the results of the same specifications as in Table 2 by replacing the dependent variable by *non-cooperation*. The benchmark regression yields a negative coefficient, which is significant at the 1% level: adding the 'chance' option reduces non-cooperation on average by 20.3 percentage points compared to the no-chance-treatment. One may be tempted to conclude that the inclusion of the 'chance' option leads to a reduction of *both* cooperation and non-cooperation in favour of 'chance', thus possibly contradicting Proposition 2. Such an interpretation would be mistaken, however, since the benchmark model captures the average effects of the introduction of chance in a standard CPR exploitation game, while Proposition 2 clearly identifies two distinct optimal choices depending on the stock of points: where points are abundant non-cooperation should increase, whereas where points are scarce chance is the optimal choice. We therefore proceed in columns 2-5 with the same sample restrictions as in Table 2. If Proposition 2 is to be verified, we should expect non-cooperation to increase only when the stock of points is abundant, or alternatively in the early rounds of the game. Our results confirm this prediction: according to the results reported in column 5, non-cooperation increases by 14.2 percentage points in the game's first two rounds compared to the no-chance control treatment. Hence, the possibility of reverting to 'chance' induces participants to substitute cooperation with non-cooperation when the stock of points is sufficiently large.

To provide additional evidence of this mechanism, in Figure 5 we report the cumulative share of participants opting for 'chance'. Consider the solid line, describing the share of participants choosing 'chance' in the chance treatment. Firstly, it clearly reveals that virtually no participant opts for 'chance' in the first 2 rounds of the game. Secondly, we observe a surge of 'chance' being chosen in rounds 3 to 6, rising from it being played by 1.5% to 66% of the pairs. This coincides roughly with our expectation that chance becomes optimal when the stock of points drops below 29, since the *average* stock of points in rounds 2 and 3 is equal to 29 and 21.1 points, respectively. Combined with the results of Tables 2 and 3, we can confidently state that the introduction of a resource appropriation option in an experimental game of renewable CPR exploitation induces participants to become more non-cooperative in the presence of abundant resource stocks, thus precipitating their depletion, and eventually opting for the partition of the resource.

One potential criticism we ought to consider at this stage is that the no-chance control treatment and the chance treatment do not feature the same number of choices. One could argue that the very existence of a third option, whether relevant or not, increases the likelihood of that option being played (possibly even by mistake), thereby triggering more non-cooperation in the chance treatment. Even though participants seem to opt for the ‘chance’ option when that option becomes optimal, comparing the two options with the three options game may hide other mechanisms driving our results. To address this potential concern, we designed an additional chance-control treatment where participants have the same three choices, namely ‘low’, ‘high’, and ‘chance’, but where the cost of chance is purposefully kept at a level which makes it suboptimal throughout the game. In Tables 4 and 5 we re-estimate Tables 2 and 3 after substituting the chance-control group for the no-chance-control group.

All the results obtained with the no-chance control treatment remain qualitatively true when using the chance-control group as the control treatment. The magnitude of all the relevant coefficients is, however, smaller: while cooperation decreases by 14.7 percentage points (Table 2) and non-cooperation increases by 14.2 percentage points in the game’s two first rounds with the no-chance control as the control treatment group, these coefficients both drop to 11.9 percentage points with the chance-control as the control treatment group. Once more, using Figure 5 - where we compare the proportion of participants opting for chance across treatments and rounds - can help clarifying the reasons behind the observed drop. Notice that even though ‘chance’ is very costly and suboptimal in the chance-control treatment, participants do choose it especially in the game’s late rounds. While in round 3 around 1.5% of the participants opted for ‘chance’, this share increases sharply after round 13, eventually reaching the 50% figure. The puzzling fact that ‘chance’ is chosen despite it being sub-optimal could have various explanations. By the time participants reach these late rounds of the game, the difference in their marginal payoffs becomes relatively small, reducing the incentive to carefully plan a playing strategy. Irrespective of the actual reason behind participants’ irrational choice of playing ‘chance’, what matters is that, when the game lasts many rounds, the ‘chance’ option is chosen with increasing frequency. Anticipating this, and in line with our theoretical mechanism, participants decrease cooperation and increase non-cooperation in the game's early rounds, thereby reducing the difference in cooperation and non-cooperation rates with respect to the chance treatment.

A marked difference in cooperation rates across the chance and chance-control treatments, however, remains. Even though participants in the control-chance treatments do expect chance to be played with some probability, they also probably realize (i) that the probability of the game lasting long enough is very low[9] and (ii) that even then, the share of participants who choose chance is moderate. This strongly contrasts with the patterns in the chance treatment. As reported in Figure 5 (solid line), about 70% of participants play 'chance' by round 6, which occurs with certainty.

4.2 Exploring the mechanism: the expectation of chance

To further convince the reader that it is indeed the expectation of chance being played that triggers non-cooperation in the game's early rounds, we propose two additional sets of tests. First, if participants decide to use the chance option at some stage of the game, it is reasonable to assume that they plan their earlier rounds' strategy accordingly. We can test whether among participants in the chance treatment, individuals who played 'chance' in a specific game (defined 'attackers') are more likely to choose the non-cooperative extraction level in early rounds of that same game. In other words, when restricting the sample of the chance treatment to 'attackers', we expect the difference in cooperation and non-cooperation rates (with respect to our control treatments) to be more marked compared to the results of Tables 2 and 3, where the entire chance treatment sample is considered.

The results of this test are reported in Table 6, where the first 4 columns replicate on this trimmed sample the specifications in columns 2 – 5 of Table 2, and the last 4 columns replicate the specifications in columns

[9]The probability of a game reaching round 13 for instance is 0.082.

2 – 5 of Table 3. Interestingly, all coefficients for chance in columns 1 – 4 are negative and significant at the 1% level. The magnitude is always larger than the corresponding coefficients of Table 2, hence supporting our intuition. Similarly, the coefficients for chance in columns 5 – 8 of Table 6 are larger in magnitude than the corresponding coefficients in Table 3, confirming that participants, who eventually revert to chance within a specific game, are more likely to extract the non-cooperative amount of points in that same game.

The second set of tests explores the difference in behaviour across participants with a different past experience in the game. If the substitution of cooperation by non-cooperation observed in the early rounds of the chance treatment rests in the expectation of 'chance' being played, we should expect participants who choose 'chance' ('attackers'), and those matched with them ('victims') in the previous game, to increase their expectation for chance to be played. This, in turn, implies that past attackers or victims should more markedly reduce their cooperation and increase their non-cooperation in the early rounds of a game. To implement this test we create two additional variables: a dummy capturing whether a participant has played chance in the previous game (*lagged attacker*) and another dummy capturing whether a participant was matched with an attacker in the previous game (*lagged victim*). We then reestimate our models, including these two additional controls.

Table 7 reports the results of this test. More specifically, in the 4 first columns of Table 7 we replicate the estimations reported in columns 2-5 of Table 2, whereas columns 5-8 replicate the specifications of columns 2-5 in Table 3 with the two additional controls. The results in column 1 suggest that, when the stock of points is higher than 29 points, previous game attackers cooperate by 10.4 percentage points less than the average participant in the chance treatment. The equivalent figure for victims in the previous game equals 8.7 percentage points. This considerable difference between participants who did not experience chance in the previous game, and those who did, further supports that the expectation of chance is the mechanism driving the drop in cooperation rates. Results in columns 2-4 follow a similar pattern, thus further strengthening our interpretation.

In the last 4 columns of Table 7, we assess the impact of experiencing chance in the previous game on the likelihood of extracting the non cooperative level of points. According to the results in column 5, the non-cooperation rate increases by 7.5 percentage points among *lagged attackers*, though the coefficient is not statistically significant, and by 8.7 percentage points among *lagged victims* compared to the average participant in the chance treatment. Again, extending the analysis to alternative sample restrictions in columns 6-8, leaves the results qualitatively unaffected.

Finally we replicate the same exercise but restricting the analysis on participants in the chance treatment. We therefore test whether participants that experience 'chance' in the previous game, as an attacker or as a victim, are more likely to extract the non-cooperative share of points and less likely to cooperate in the early periods of the game. The results, reported in Table 8 broadly confirm our previous results. We can thus confidently deduce that participants who have experienced 'chance' in the previous game are more likely to expect 'chance' to be chosen in the current game, therefore substituting cooperation by non-cooperation in the game's early rounds.

5 Conclusion

Folk theorems permit cooperation to arise in equilibrium in dynamic common pool renewable resource games, both theoretically and experimentally. Allowing the players to revert to violence to split the resource (and to thereafter manage efficiently what has become a private resource) disrupts the logic of Folk theorems. In our theoretical section we propose a simple version of the CPR management model of Sekeris (2014), where players can opt for potentially costly conflict to share resources. In such settings, infinite horizon dynamic games may endogenously become finite horizon strategic games up to the moment when conflict emerges, after which the problem stops being strategic and instead becomes decision-theoretic. In this paper we inquire experimentally whether participants respond to such incentives that should lead to (i) less cooperation in the presence of high stocks of resources, and to (ii) conflict after the resource stock is sufficiently depleted. We find a strong and highly significant effect of the introduction of conflict (labelled 'chance' to minimise framing effects) as a potential choice in addition to the two choices of cooperation and non-cooperation. In the early rounds of the game (i.e. the first two rounds), participants reduce their cooperation by 14.7 percentage points and increase non-cooperation by 14.2 percentage points. Given that the average rates of cooperation and non-cooperation in the game's two first rounds are around 34% and and 66%, respectively, this equates, to a 43.2% decrease of cooperation, and to a 21.5% increase of non-cooperation.

To exclude the possibility that our results are driven by the fact that our participants had one option less in the control treatment compared to the conflict scenario, we additionally compare our results to a treatment featuring the same three options as in the conflict scenario, but with the difference that we impose a (theoretically) prohibitive cost of conflict. The results remain the same in qualitative terms: in the early rounds of the game in the treated group, cooperation decreases by 11.9 percentage points and non-cooperation increases by the same percentage points. We attribute the reduced magnitude of the coefficients to the fact that, in this control group where conflict is prohibitively costly, participants nevertheless did resort to conflict in an (irrational) attempt to halt the degradation of resources when the stock of resources ran very low. The expectation of conflict therefore pushed participants to lower their levels of cooperation, but to a lesser degree than in the main conflict treatment where conflict is played both more frequently and in earlier rounds of the game.

This contribution constitutes the first evidence that the fear of - possibly distant - conflicts over shared resources can hamper cooperation in the short run, and can thereby accelerate the depletion of the resources. Our findings may help comprehend the failure to reach agreements over such matters as the conservation of the environment. This in turn would imply that one crucial dimension for promoting cooperation would be the strengthening of institutions and international bodies able to contain such violence.

Tables

Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
cooperation	15812	0.2393119	0.426677	0	1
non-cooperation	15812	0.6014419	0.4896169	0	1
chance	15812	0.1592461	0.365917	0	1
# games	15812	5.457627	2.890105	1	10
round	15812	5.356438	3.19872	1	16
male	15812	0.4280293	0.4948088	0	1
stock of points	15812	16.89136	11.58028	0.1206	40
science	15812	0.1795472	0.383822	0	1
social	15812	0.4538958	0.4978856	0	1

Table 2: Effect of 'chance' on cooperation (no chance control)

Dependent variable:	cooperation				
	(1)	(2)	(3)	(4)	(5)
chance	-0.236***	-0.137**	-0.162***	-0.150***	-0.147***
	(0.039)	(0.055)	(0.046)	(0.047)	(0.051)
round	-0.016***	0.195***	-0.012***	0.021***	0.072**
	(0.003)	(0.023)	(0.003)	(0.007)	(0.029)
# game	-0.004	-0.013***	-0.003	-0.007**	-0.014***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
male	-0.099***	-0.092	-0.118***	-0.124***	-0.096*
	(0.036)	(0.056)	(0.045)	(0.047)	(0.051)
science	0.112**	0.105	0.139**	0.146**	0.068
	(0.052)	(0.081)	(0.058)	(0.066)	(0.074)
social	-0.000	0.063	-0.002	-0.010	0.012
	(0.046)	(0.061)	(0.055)	(0.057)	(0.057)
stock>29		✓			
chance excluded			✓	✓	
rounds 1-6				✓	
rounds 1-2					✓
Observations	10,520	1,658	8,255	5,855	2,320
R-squared	0.128	0.117	0.066	0.080	0.065

Notes: Standard errors clustered at the individual level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Control group includes participants on the no chance treatment only.

Table 3: Effect of 'chance' on non-cooperation (no chance control)

Dependent variable:	non-cooperation				
	(1)	(2)	(3)	(4)	(5)
chance	-0.203***	0.128**	0.162***	0.150***	0.142***
	(0.041)	(0.056)	(0.046)	(0.047)	(0.052)
round	-0.020***	-0.208***	0.012***	-0.021***	-0.080***
	(0.005)	(0.025)	(0.003)	(0.007)	(0.028)
# game	-0.008**	0.013***	0.003	0.007**	0.014***
	(0.003)	(0.004)	(0.003)	(0.003)	(0.003)
male	0.062	0.081	0.118***	0.124***	0.091*
	(0.041)	(0.058)	(0.045)	(0.047)	(0.053)
science	-0.148***	-0.102	-0.139**	-0.146**	-0.067
	(0.050)	(0.081)	(0.058)	(0.066)	(0.075)
social	-0.026	-0.069	0.002	0.010	-0.017
	(0.048)	(0.061)	(0.055)	(0.057)	(0.058)
stock>29		✓			
chance excluded			✓	✓	
rounds 1-6				✓	
rounds 1-2					✓
Observations	10,520	1,658	8,255	5,855	2,320
R-squared	0.060	0.117	0.066	0.080	0.061

Notes: Standard errors clustered at the individual level in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Control group includes participants on the no chance treatment only.

Table 4: Effect of ‘chance’ on cooperation (chance-control)

Dependent variable:	cooperation				
	(1)	(2)	(3)	(4)	(5)
chance	-0.121***	-0.140***	-0.071*	-0.074*	-0.119**
	(0.030)	(0.053)	(0.038)	(0.041)	(0.048)
round	-0.019***	0.106***	-0.015***	-0.003	-0.015
	(0.003)	(0.030)	(0.004)	(0.007)	(0.028)
# game	-0.012***	-0.019***	-0.014***	-0.015***	-0.015***
	(0.002)	(0.004)	(0.003)	(0.003)	(0.003)
male	-0.034	0.017	-0.038	-0.019	0.002
	(0.029)	(0.055)	(0.037)	(0.042)	(0.049)
science	-0.085**	-0.239***	-0.103*	-0.135**	-0.213***
	(0.042)	(0.064)	(0.053)	(0.059)	(0.055)
social	-0.057*	-0.038	-0.070*	-0.095**	-0.077
	(0.033)	(0.060)	(0.041)	(0.046)	(0.056)
stock>29		✓			
chance excluded			✓	✓	
rounds 1-6				✓	
rounds 1-2					✓
Observations	10,464	1,708	7,946	5,784	2,320
R-squared	0.071	0.099	0.035	0.033	0.058

Notes: Standard errors clustered at the individual level in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Control group includes participants on the chance-control treatment only.

Table 5: Effect of 'chance' on non-cooperation (chance-control)

Dependent variable:	non-cooperation				
	(1)	(2)	(3)	(4)	(5)
chance	-0.273***	0.132**	0.071*	0.074*	0.119**
	-0.035	-0.056	-0.038	-0.041	-0.049
round	-0.025***	-0.117***	0.015***	0.003	0.004
	-0.005	-0.031	-0.004	-0.007	-0.027
# game	0.005	0.017***	0.014***	0.015***	0.014***
	-0.003	-0.004	-0.003	-0.003	-0.003
male	-0.006	-0.025	0.038	0.019	-0.004
	-0.035	-0.057	-0.037	-0.042	-0.051
science	0.044	0.243***	0.103*	0.135**	0.217***
	-0.045	-0.064	-0.053	-0.059	-0.056
social	0.04	0.032	0.070*	0.095**	0.07
	-0.039	-0.061	-0.041	-0.046	-0.057
stock>29		✓			
chance excluded			✓	✓	
rounds 1-6				✓	
rounds 1-2					✓
Observations	10464	1708	7946	5784	2320
R-squared	0.099	0.098	0.035	0.033	0.055

Notes: Standard errors clustered at the individual level in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Control group includes participants on the chance-control treatment only.

Table 6: Cooperation and non-cooperation rates among attackers

Dependent variable:	cooperation				non-cooperation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
chance	-0.171***	-0.215***	-0.180***	-0.181***	0.147**	0.215***	0.180***	0.165***
	(0.060)	(0.052)	(0.052)	(0.056)	(0.069)	(0.052)	(0.052)	(0.061)
round	0.201***	-0.013***	0.025***	0.083**	-0.218***	0.013***	-0.025***	-0.094***
	(0.028)	(0.004)	(0.009)	(0.036)	(0.029)	(0.004)	(0.009)	(0.034)
# game	-0.010**	0.001	-0.003	-0.013***	0.009*	-0.001	0.003	0.012***
	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.004)	(0.004)	(0.004)
male	-0.087	-0.117**	-0.128**	-0.098	0.076	0.117**	0.128**	0.093
	(0.064)	(0.054)	(0.057)	(0.060)	(0.065)	(0.054)	(0.057)	(0.061)
science	0.155*	0.195***	0.211***	0.125	-0.152*	-0.195***	-0.211***	-0.123
	(0.091)	(0.063)	(0.073)	(0.082)	(0.090)	(0.063)	(0.073)	(0.083)
social	0.117	0.045	0.044	0.073	-0.124*	-0.045	-0.044	-0.080
	(0.072)	(0.071)	(0.072)	(0.068)	(0.072)	(0.071)	(0.072)	(0.069)
stock>29	✓				✓			
chance excluded		✓	✓			✓	✓	
rounds 1-6			✓				✓	
rounds 1-2				✓				✓
Observations	1,190	6,048	4,147	1,614	1,190	6,048	4,147	1,614
R-squared	0.125	0.060	0.082	0.074	0.123	0.060	0.082	0.066

Table 7: The impact of experiencing chance in the past (full sample)

Dependent variable:	cooperation				non-cooperation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
chance	-0.087	-0.143***	-0.125**	-0.090	0.087	0.143***	0.125**	0.092
	(0.063)	(0.050)	(0.055)	(0.061)	(0.063)	(0.050)	(0.055)	(0.062)
lagged attacker	-0.104**	-0.098**	-0.085*	-0.097*	0.075	0.098**	0.085*	0.076
	(0.050)	(0.040)	(0.047)	(0.049)	(0.063)	(0.040)	(0.047)	(0.056)
lagged victim	-0.087**	-0.019	-0.036	-0.083***	0.087**	0.019	0.036	0.083***
	(0.034)	(0.025)	(0.025)	(0.030)	(0.034)	(0.025)	(0.025)	(0.030)
round	0.194***	-0.012***	0.021***	0.076**	-0.210***	0.012***	-0.021***	-0.084***
	(0.026)	(0.003)	(0.008)	(0.030)	(0.027)	(0.003)	(0.008)	(0.028)
# game	-0.013***	-0.002	-0.007*	-0.013***	0.012***	0.002	0.007*	0.013***
	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)
male	-0.098*	-0.120***	-0.129***	-0.099**	0.089	0.120***	0.129***	0.095*
	(0.054)	(0.045)	(0.047)	(0.050)	(0.055)	(0.045)	(0.047)	(0.051)
science	0.100	0.137**	0.142**	0.071	-0.096	-0.137**	-0.142**	-0.068
	(0.081)	(0.059)	(0.067)	(0.074)	(0.081)	(0.059)	(0.067)	(0.074)
social	0.069	-0.000	-0.007	0.017	-0.074	0.000	0.007	-0.022
	(0.060)	(0.055)	(0.057)	(0.056)	(0.061)	(0.055)	(0.057)	(0.057)
stock>29	✓				✓			
chance excluded		✓	✓			✓	✓	
rounds 1-6			✓				✓	

Table 8: The impact of experiencing chance in the past among participants in the chance treatment

Dependent variable:	cooperation				non-cooperation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lagged attacker	-0.097**	-0.053	-0.062	-0.083*	0.068	0.053	0.062	0.062
	(0.048)	(0.036)	(0.040)	(0.046)	(0.059)	(0.036)	(0.040)	(0.052)
lagged victim	-0.080**	-0.008	-0.026	-0.077***	0.080**	0.008	0.026	0.077***
	(0.034)	(0.022)	(0.022)	(0.029)	(0.033)	(0.022)	(0.022)	(0.029)
round	0.072	-0.010*	0.007	0.015	-0.126**	0.010*	-0.007	-0.033
	(0.046)	(0.006)	(0.011)	(0.038)	(0.052)	(0.006)	(0.011)	(0.034)
game	-0.015***	-0.011***	-0.013***	-0.014***	0.014***	0.011***	0.013***	0.014***
	(0.005)	(0.003)	(0.004)	(0.004)	(0.005)	(0.003)	(0.004)	(0.004)
male	-0.061	-0.088*	-0.076	-0.056	0.043	0.088*	0.076	0.048
	(0.068)	(0.048)	(0.054)	(0.058)	(0.073)	(0.048)	(0.054)	(0.063)
science	-0.101	-0.138**	-0.144*	-0.134**	0.115	0.138**	0.144*	0.144**
	(0.074)	(0.065)	(0.073)	(0.061)	(0.076)	(0.065)	(0.073)	(0.065)
social	0.023	-0.083	-0.085	-0.042	-0.030	0.083	0.085	0.033
	(0.083)	(0.058)	(0.063)	(0.071)	(0.083)	(0.058)	(0.063)	(0.073)
stock>29	✓				✓			
chance excluded		✓	✓			✓	✓	
rounds 1-6			✓				✓	
rounds 1-2				✓				✓

A Appendix

A.1 Proofs

A.1.1 Derivation of the cooperative extraction rate

We denote by $V^c(r_t)$ the value function of this problem given the resource stock r_t, meaning that the indirect aggregate utility can be expressed as a Bellman equation:

$$V^c(r_t) = \arg\max_{e_{1,t},e_{2,t}} \left[\sum_{i=1,2} \ln\left(x_{i,t}\right) + \delta V^c\left(r_{t+1}\right) \right] \tag{23}$$

Given the assumed regeneration rule, the above expression can be written as:

$$V^c(r_t) = \arg\max_{e_{1,t},e_{2,t}} \left[\sum_{i=1,2} \ln\left(x_{i,t}\right) + \delta V^c\left(\left(1+\gamma\right)\left(r_t - x_{1,t} - x_{2,t}\right)\right) \right] \tag{24}$$

Differentiating (24) with respect to the two decision variables, $e_{1,t}$ and $e_{2,t}$, we obtain the following system of equations:

$$\begin{cases} \frac{\partial V^c(r_t)}{\partial e_{1,t}} = \frac{1}{x_1^c(r_t)} - \delta(1+\gamma)\sum_{i=1,2} V_i^{c'}\left((1+\gamma)\left(r_t - x_1^c\left(r_t\right) - x_2^c\left(r_t\right)\right)\right) = 0 \\ \frac{\partial V^c(r_t)}{\partial e_{2,t}} = \frac{1}{x_2^c(r_t)} - \delta(1+\gamma)\sum_{i=1,2} V_i^{c'}\left((1+\gamma)\left(r_t - x_1^c\left(r_t\right) - x_2^c\left(r_t\right)\right)\right) = 0 \end{cases} \tag{25}$$

Where these equations hold because the constraint $e_{1,t} + e_{2,t} \leq r_t$ will never be binding, as $\lim_{r_t \to 0} V_i^{c'} = +\infty$.

From (25) we deduce that $x_1^c(r_t) = x_2^c(r_t) = x^c(r_t)$. To derive the efficient equilibrium, we inquire whether $x^c(r_t)$ may be a linear function of its argument so that $x^c(r_t) = s^c r_t$. This assumption implies that the stock of resources in time period $t+1$ can be expressed as $r_{t+1} = (1+\gamma)(1-2s^c)\, r_t$. Replacing in V_i^c, together with using the regeneration rule gives us:

$$V^c(r_t) = 2\left[\ln(s^c r_t) + \delta \ln(s^c(1+\gamma)(1-2s^c)r_t) + \delta^2 \ln\left(s^c(1+\gamma)^2(1-2s^c)^2 r_t\right) + \ldots\right] \tag{26}$$

Rearranging the terms of (26) gives us:

$$V^c(r_t) = \frac{2\ln(s^c r_t)}{1-\delta} + 2\sum_{\tau=0}^{\infty} \delta^\tau \ln((1+\gamma)^\tau (1-2s^c)^\tau) \tag{27}$$

Thus implying that $V^{c'}(r_t) = \frac{2}{(1-\delta)r_t}$. Substituting in (25) for $V^{c'}(.)$ yields:

$$\frac{1}{s^c r_t} - \frac{2\delta(1+\gamma)}{(1-\delta)(1+\gamma)(1-2s^c)r_t} \Rightarrow s^c = \frac{1-\delta}{2}$$

A.1.2 Derivation of expression (12)

We first need to compute the deviation extraction rate in time period t. This extraction rate is determined by maximizing player i's intertemporal payoff, by imposing that in time period t player j chooses his cooperative extraction rate, while from period $t+1$ onwards both players choose their (Markov perfect) non-cooperative extraction rates. Player i's optimization problem therefore reads as:

$$\max_x \ln(x) + \delta V^{nc}\left(\left(r_t - x - \frac{1-\delta}{2}\right)(1+\gamma\right)$$

Replacing for the appropriate values and optimizing yields the optimal extraction rate x^{dev} given by:

$$x^{dev} = \frac{(1-\delta)(1+\delta)}{2} \tag{28}$$

Replacing in the regeneration rate implies that:

$$r^{t+1} = \frac{\delta(\delta+1)(1+\gamma)}{2}$$

Replacing in expression (11) yields:

$$\ln\left(\frac{(1-\delta)(1+\delta)}{2}r_t\right)+\frac{\delta}{1-\delta}\ln\left(\frac{(1-\delta)(1+\gamma)\delta(1+\delta)}{2(2-\delta)}r_t\right)+\frac{\delta^2}{(1-\delta)^2}\ln\left(\frac{\delta(1+\gamma)}{2-\delta}\right)$$
$$<\frac{1}{1-\delta}\ln\left(\frac{1-\delta}{2}r_t\right)+\frac{\delta}{(1-\delta)^2}\ln\left(\frac{1-\delta}{2}\right) \tag{29}$$

Simplilfying yields:

$$(1-\delta)\ln(1+\delta)+\delta\ln\left(\frac{1}{2-\delta}\right)<0$$

which straightforwardly gives expression (12).

A.2 FOR ONLINE PUBLICATION - Instructions to the chance treatment

In this section we present the instruction handed to the chance treatment alone. The chance-control group received the same instructions, with the difference that the cost of chance was maintained equal to 60% of the resources throughout, while the no-chance-treatment was presented with the two choices ‘low’ and ‘high’ alone.

Welcome,

You are about to participate in an experiment on decision-making. You will be paid for your participation in cash, privately, at the end of the session. What you earn depends partly on your decisions, partly on the decisions of others, and partly on chance.

Please turn off all electronic devices now.

The entire experiment will take place through computer terminals. Please do not talk or in any way try to communicate with other participants until everybody has been told that the experiment is over and that you can leave the room.

We will now give you some time to carefully read the following instructions. If you have any questions, please raise your hand and your question will be answered so everyone can hear.

Overview & Payment

In this experiment you will play **the same game 20 times**. Each time you play, the computer will randomly pair you up with someone else in the room (but you don't know with whom). So, in each game you are paired with a random person in the room. The **first 10 games** you play will be for **practice**. The **remaining 10 games will be for real**.

Each game lasts for at least 6 rounds. After the 6^{th} round, you will enter each next round with a probability of 70% (so with a 30% probability the game ends). So, if you happen to enter round 7, there is a 70% share that you will enter round 8 and so on and so forth.

When you have played the game 10 times, each game lasting 6 or more rounds, you will be paid. Your payment has two components, an **initial endowment of** £5 and **a payment of** £1.50 **per point won**. To establish how many points you have won, we will randomly **draw 2 of the last 10 games (the for-real games)** you played and pay you according to the amount of points you won in those games. So, your final payment will be ***your initial endowment*** plus ***your points payment***.

Here is an example:

Say, the random draws were games 4 and 6, and you won **5.6 points** and **2.4 points** in those games respectively. Then your final payment would be: **3 + (5.6 + 2.4) x 1.50 = £15**.

Depending on how you play and for how many rounds the game continues, it is possible that you will get negative points, though this is unlikely.

Here is another example:

Say, the random draws were games 4 and 6, and you got **-2.4 points** and **1.2 points** in those games respectively. Then your final payment would be: **3 + (-1.2 + 2.4) x 1.50 = £4.80**.

So, to conclude, the choices you make really matter.

Playing a game

At the beginning of each game, you and your opponent both start with a joint stock of 40 points. Each round, you can choose how much of this stock of points you want to take. Whatever you and your opponent choose each round will affect how much stock there will be left next round.

The game continues like this. In the second round you choose how much to take of the remaining stock and that will affect how much stock will be left in round 3, and so on and so forth, until the game ends.

So, there are two things to understand: **choice** and **stock**.

Your choices are:

- **Low**
- **High**
- **Chance**

Low:

If you choose **low** and your opponent chooses **low** too, you **each take 15%** of the points in stock (e.g. 15% of 40 points = 6 points).

If you choose **low** and your opponent chooses **high**, **you take 15%** of the points (**e.g. 15% of 40 points = 6**) and your **opponent takes 25.5%** of the points (25.5% of 40 points = 10.2).

If you choose **low** but your opponent chooses **chance**, then you are in **chance mode**. What this means is described below.

High:

If you choose **high** and your opponent chooses **low**, **you take 25.5%** of the points (25.5% of 40 points = 10.2) and **your opponent takes 15%** of the points (15% of 40 points = 6).

If you choose **high** and your opponent chooses **high** too, you **each take 23%** of the points (23% of 40 points = 9.2 points).

If you choose **high** but your opponent chooses **chance**, then you are in **chance mode** (described below).

Chance:

If either **you <u>or</u> your opponent pick chance**, then **both of you** will be in **chance mode**.

If one of you has played **chance**, (so that you are both in **chance mode**) you will each take **15% of the stock** in all of the remaining rounds. As explained more in detail below, the total number of points you will collect is entirely left to *chance* under this scenario since you will not be making any more decisions after picking this option.

Playing **chance** is **costly**. Once chance is chosen, a cost will be taken away from your joint stock. The **cost** is a **one-off loss of points**, so it will **only be applied once** when you enter chance mode, but not in subsequent rounds of chance mode. Depending on the size of the current stock, this is how much playing chance would cost:

Stock:	40	39	38	37	36	35	34	33	32	31	30	29	28	27	26	25	24	…	0
Cost:	24	21.8	19.8	17.8	15.8	14	12.2	10.6	9	7.4	6	4.6	3.4	2.2	1	0	0	…	0

There is more to know about your choices:

The **points that you take** from the current stock each round are not exactly the **points that you get to keep**. There is a **formula**, which describes how many points you get to keep each round.

This will involve some mathematics, i.e. the natural logarithm. If you don't like maths, don't worry about understanding what logarithm means. All you need to know is that the **natural logarithm** of ***something*** is quite a bit **less** than that ***something***.

Anyway, the following table shows how this works. In **round 1** you **get to keep the natural logarithm of the points you decide to take**. In **round 2** you get **70%** of the **natural logarithm of the points you take**. In round 3, you get to keep **70% of 70%** of the natural logarithm of the points you took, and so on and so forth. (Note that "ln" just means natural logarithm.)

Round	**Points you get to keep**
1	ln(points you take)
2	70% × ln(points you take)
3	70% × 70% × ln(points you take) =49% × ln(points you take)
4	70% × 49% × ln(points you take) =34% × ln(points you take)
5	70% × 34% × ln(points you take) =24% × ln(points you take)
4	70% × 24% × ln(points you take) =17% × ln(points you take)

Here are two examples:

Suppose you are in round 1, where your current stock is 40. If you both chose **low**, the points you would take would be 15% of 40 points (i.e. 6 points) each. But you would only get to keep ln(**points you take)**, which is ln(**6**) ≈ **1.79**.

Suppose again that you are in round 1, where your current stock is 40. If you chose **low** and your opponent chose high, you would again take 15% of 40 points (i.e. 6 points) and your opponent would take 25.5% of 40 points (i.e. 10.2 points). Here you would only get to keep ln(points you take), which is $\ln(6) \approx 1.79$ and your opponent would get to keep $\ln(10.2) = 2.32$.

Now, if you remember, **after round 6 there is only a 70% probability** of getting into each subsequent round. To be precise, at the end of each round **after round 6** the computer software will roll a virtual, 100-sided dice and will end the game if a number higher than 70 comes up on that virtual dice.

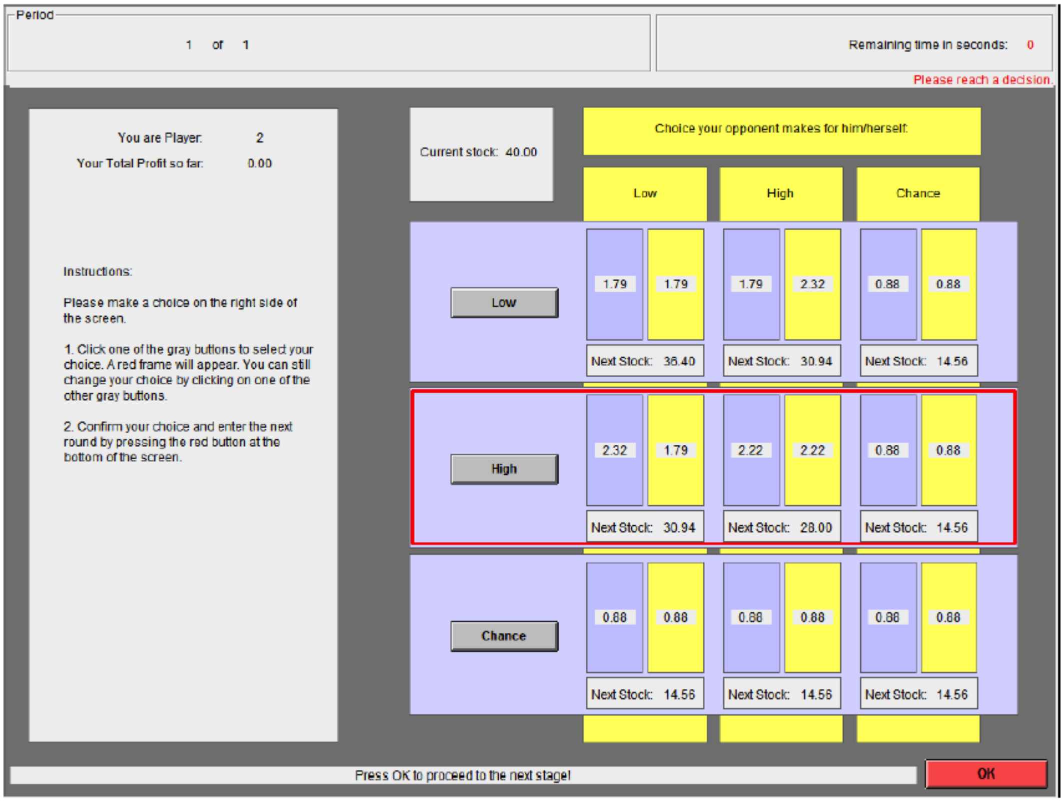
This has an **effect on** the **points you get to keep from round 7 onwards**. From Round 7 onwards, you and your opponent can make the same choices as previously but now **you continuously get to keep 17% of the natural logarithm of the points you take** for each additional round played. The following table illustrates this:

Round	**Shares of playing the round**	**Points you get to keep**
7	70%	=17% × ln(points you take)
8	70%	=17% × ln(points you take)
9	70%	=17% × ln(points you take)
10	70%	=17% × ln(points you take)
11	70%	=17% × ln(points you take)
…	…	…

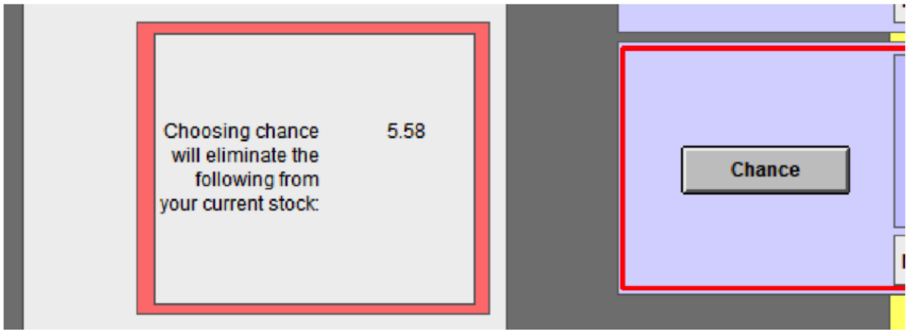
This is what your screens look like:

The following picture shows you what your first screen will look like. The **grey buttons** are your **choices**. The **purple boxes** display the **points you get to keep**, the **yellow boxes** display the **points your opponent gets to keep**. The **little grey boxes** show you what your **next stock** will be if you were to make that choice. The **big grey boxes** show you what either player **would get** if you were to choose chance.

If you click a **choice button**, a red frame will appear around the choice that you have picked (see image).



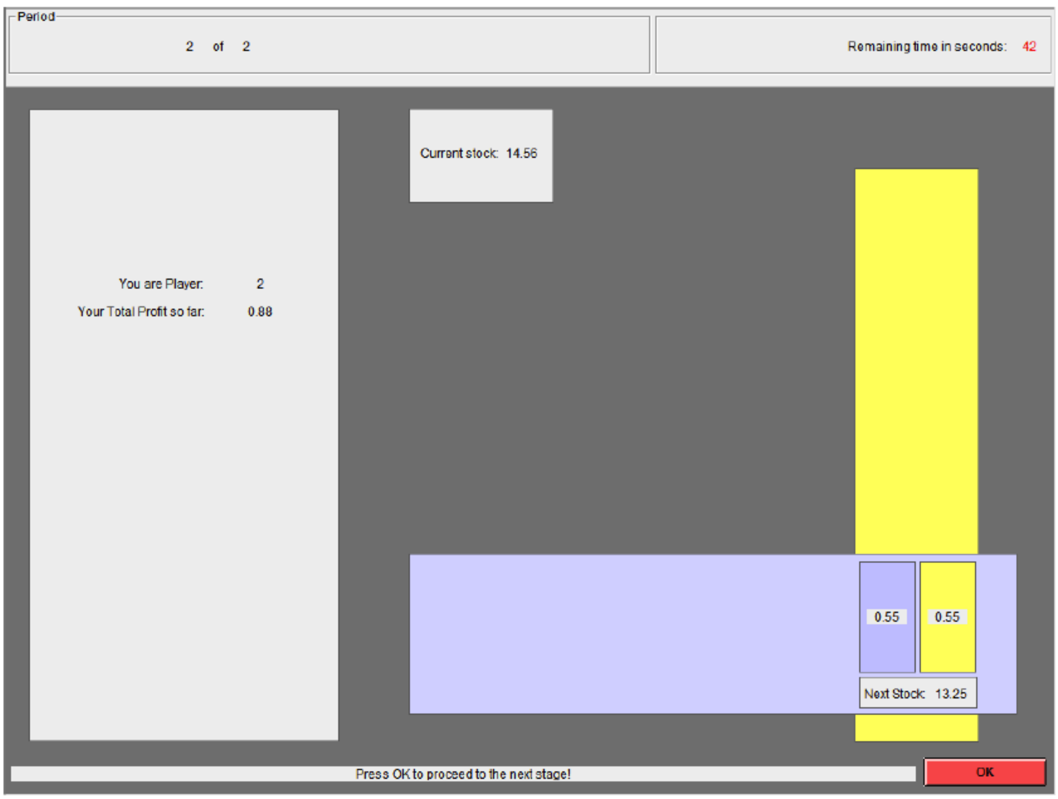
If you click on the **"chance" choice-button**, a **box will appear** next to it. It tells you what the **cost of choosing chance** would be, if you chose it in your **current round**. The following screenshot gives an example:



Of course, you do not know what your opponent?s choice will be until the next round, so do not wait for him/her.

At the bottom of the screen there is a **red OK button**. You ought to **press it** in order to **confirm your choice and enter the next round**.

Finally, the following picture shows the screen you would get if either of you were to choose chance; it shows you what **chance mode** looks like:



Stock:

Now, there is a little more to know about the stock of points. First, depending on the choices made, the stock decreases in size. But second, it also replenishes. It regrows by 30% each round. This is how the next stock of points is calculated:

1. Current stock - points you take - points opponent takes = remaining stock

2. Remaining stock + 30% = next stock

Here are two examples:

Suppose the **current stock** is **40** and **you choose low** and your **opponent chooses high**. Then we calculate: (**40** – **6** – **10**.**2**) × **1**.**30** = **30**.**94** points.

Suppose the **current stock** is **40** and **you choose low** and your **opponent chooses chance**. Then we calculate: (**40** – **24** – **3**.**2** – **1**.**6**) × **1**.**3** = **14**.**56** points. Here the 24 is the cost of playing chance, if you remember from above.

This picture highlights your **current stock** and **next stock** if **you choose low** and if **your opponent** chooses either **high** or **chance**:

This is it. Good luck!

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