# Does an increased risk of climate shocks affect individual resource extraction behaviour? *

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**Preliminary – please do not quote**

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**Abstract**

This study investigates how the increased risk of climate shocks influences individual resource extraction behavior in a common pool resource context. Conducted at the BonnEconLab using OTree, we simulated a resource extraction game under two scenarios: high (80%) and low (20%) risk of climate shocks, against a no-risk baseline. Our analysis employed parametric and non-parametric tests alongside a survey to assess additional factors influencing behavior. Results revealed significant increases in extraction rates under high risk compared to both low risk and baseline. This highlights a distinct behavioral shift towards greater extraction in anticipation of climate shocks, diverging from existing literature focused on incentivizing pro-environmental behavior. Moreover, we found evidence that self-assessed environmental attitudes correlate to lower extraction rates but only in a no-shock scenario.

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# 1 Experimental Procedure, Design and Behavioural Prediction

## 1.1 Experimental Procedure

We conducted our lab experiment on January 2024 at the BonnEconLab to study the effect of climate shock on human extraction behaviour, particularly in the context of common pool resource. The experiment took place in three separate sessions, in each session 24 carefully selected participants took part in our lab experiment. Participants were chosen based on specific criteria: they had to be registered members of the BonnEconLab, proficient in German, and aged between 18 and 30 years. A crucial aspect of the selection process was also ensuring that these participants had not previously taken part in similar experiments. Since our study involves study with human subjects, our study has been pre-registered and approved for ethical review by the Institutional Review Board of the University of Bonn (Gesellschaft für experimentelle Wirtschaftsforschung (GfeW)) prior to conducting this experiment.

Each of the three experimental session we conducted lasted approximately 45 minutes, and was divided into two main segments: a game followed by a comprehensive questionnaire, details of which are provided in the subsequent section. The design of our game segment follows the design of the forestry game by Janssen et al. (2013).To build our instrument, we used O-tree, a Python-based software for experimental economic researchChen, Schonger, and Wickens (2016). No deception were done in our experiment, because complete instructions of the game were fully communicated through on screen display in the lab (see Appendix A).

The game was divided into three parts: the baseline game as the control group, the anticipation treatments and the scarcity treatment. One part lasted five rounds, so the game lasted 15 rounds in total. Each participant played each part and was told in advance how many rounds the parts would last. Before the experiment began, each participant drew a number from 1 to 24 face down when they registered. This number indicated the participant's cabin number for the experiment. We assigned the participants to groups of three depending on their cabin number, i.e. the participants with the numbers one to three were one group, the participants with the numbers four to six were one group and so on up to 24. During the experiment the participants were not permitted to communicate with each other, and they were unaware of the group members to whom they had been assigned. The group assignments remained fixed throughout the experiment.

All participants in each session of our study began by participating first in our Baseline game, followed by Anticipation game, Scarcity game and ended the experiment with a survey in which the order remain the same for all participants. Furthermore, in each game parts before participants began round 1 of each game, they were given a complete on screen instructions and subsequently asked to complete comprehension questions to ensure that participants fully understood the given instructions.

### 1.2 Experimental Design

The game segment in our experiment consists of 3 parts, namely Baseline game, Anticipation game and Scarcity game, where the last two are the treatments in our experiment. The baseline game is the standard forestry extraction game following Janssen et al. (2013). The anticipation game follows a similar protocol to that in the baseline adjusted to a setting where there are risks of climate shock to occur and destroy the existing shared resources. In the scarcity game, subjects were put in a situation where the resource stock available is reduced significantly.

We employed between and within subject design in our experiment game. Our within subject design is through the linear successions of the game parts, and between game design is employed under Anticipation game only, where subjects were randomly assigned to high or low probability group treatments. We designed the game as such in order to observe any behavioural changes that occurs between Baseline against the Anticipation game. By comparing the observed behavior between the two, we can observe how subject's behaviour might change in the presence of exogenous risk of climate shock. This risk presents uncertainty to the subjects individually and as a group, which consequently induces a lower expected value of the shared resource, providing incentives for subjects to harvest more now rather than later. Such design for the first two parts of our game will allow us to test our first hypothesis.

> ***H1****: An increased risk of climate shocks, that induces a lower expected future value of the resource, leads to an increase in harvest rates and a decrease in the stock of the resource.*

Under the Anticipation part of the game, we randomly assigned subjects into 2 climate shock risk group, namely high and low probability. We designed it as such in order to see whether the relative size of the risk to occur has significant impact on subject's CPRs harvesting behaviour. With both groups experiencing elevated risk of climate shock, we can thus compare between the groups for observed behaviour changes.

At the end of Anticipation game, groups may or may not experience actual climate shock. This differing random outcome allow us to further compare the results of Scarcity game where all subject restart a game but with only half of the resources they previously began the game with. Such setting is useful to compare whether subjects who have had prior experience of scarcity in the Anticipation game will behave differently from subjects who did not experience such scarcity when they later play our Scarcity game. However, we will not discuss our findings from this part in detail and will keep this for future studies.

The survey within our laboratory experiment contains questions asking the participants regarding the optimum solution to the game, we adopted also questions from the short 24-item version of the Environmental Attitudes Inventory Milfont and Duckitt, 2007 and the Global Preference Survey Falk et al., 2018. The last two adopted survey questions are then used to measure personal attitude and perception towards environmentalism, and their preferences with respect to altruism, reciprocity, time preference, risk preference and trust. All these variables we believe to be important exogenous factors influencing individual and group extraction behaviour in the experiment, which led us to our second hypothesis.

> ***H2****: Subjects categorized as pro-environmental according to the Environmental Attitudes Inventory (EAI) extract less of the resource.*

#### 1.2.1 Baseline Game

Our baseline forestry extraction game is designed to simulate a dynamic forestry resource. The initial number of forest resource consists of 100 trees. In each round, participants can take a maximum of seven trees from the forest resource. The baseline game lasts five rounds where participants can extract trees from the shared group forest in every round. After all members of the group have made their extraction decision, the total number of resource extracted will be deducted from the forest resource.

The forest resource stock will regrow at 10% rate in every round after extraction decision were made. For example, in the first round, given a total of 21 trees extracted, 79 trees remained in the forest. With the 10% regrowth rate, 7.9 trees will then be added to the resource stock where the game will start in the second round with 86,9 trees. Despite the allowed regrowth rate, the forest stock cannot grow beyond its full capacity of 100 trees. We did not round down the number of trees regrown, but rather, allowed participants to only extract a fully grown tree represented by the integer numbers. Participants were also informed at the beginning of the experiment that for each trees extracted in each round, he or she will earn two points. Participants will also receive a one time payment of endowment in the amount of 50 points at the start of each game. However, this endowment is paid only once as a show up fee and does not influence the decision of participants throughout the game. Therefore, we will not include participants' endowment into the payoff function from here onwards.

In addition to the trees harvested and the endowment, the participants were also told that the second element of their payoff will depend on the remaining number of trees left in the group's shared forest at the end of the $5^{th}$ round after extraction and regrowth. These remaining trees will then double in value (4 points) and all group members will receive equal share of this value[1].

***The Payoff Function.*** Using game theoretical framework, the benchmark prediction on the standard individual extraction behaviour in our baseline game will depend on their payoff function. In the baseline game, the social payoff is the sum of individual group member $i$'s payoff function. As a consequence both in group social payoff and individual payoff function will have **two** main components.

The first component is their expected total individual payoff from harvesting the trees. Each individual $i$ in a group of 3 ($i \in \{1, 2, 3\}$) is allowed to extract $x$ number of trees at each round where $x \in \{0, 1, 2, 3, 4, 5, 6, 7\}$, and each tree has a value of 2 points. With each game lasting 5 rounds, let $t \in \{1, 2, 3, 4, 5\}$ be the number of round this person is currently in. The expected total individual payoff from harvesting in all 5 rounds is then; $2\sum_{t=1}^{5}(x_{i,t})$. For each

[1] see AppendixA for detailed instructions of the experiment.

group consisting 3 individuals, the total harvest of a group in each round can be expressed as $X_t = \sum_{i=1}^{3} x_{i,t}$. Therefore, we can express the first component for each group's social payoff function as $2\sum_{t=1}^{5} X_t$.

The second component of the payoff function is the expected payoff from remaining trees in the forest at the end of the game (after regrowth in round 5). The remaining trees in the forest will depend on all player's extraction decision and the regrowth rate of 10% in each round. In addition to that, the number of remaining trees in the forest cannot exceed 100 trees or fall below 0 at any given round. Thus, let $Z_t$ denote the number of trees that remained in the forest after harvesting and regrowth in a given round, where $0 \leq Z_t \leq 100$.

In the first round of our baseline game every group began with 100 trees in their shared forest. Therefore, the remaining trees left in the first round can be expressed as $Z_1 = (100 - X_1) \times 1.1$. The second round remaining trees will then depend on remaining trees in round 1 and total number of trees extracted as a group. $Z_2$ is then defined as $Z_2 = Z_1 - X_2 = (100 - X_1) - X_2$. For subsequent rounds we follow the same pattern up until the last round, where $Z_5 = (Z_4 - X_5)1.1$. This means that to find the remaining trees in the final round ($Z_5$) to determine individual and group expected social payoff from the remaining trees, we can define $Z_5$ as

$$Z_5 = (((((100 - X_1)\,1.1 - X_2)\,1.1 - X_3)\,1.1 - X_4)\,1.1 - X_5)\,1.1 \tag{1}$$

Variable $Z_5$ defines the number of trees remained in a group's forest by the end of the $5^{th}$ round and after the final regrowth rate. Each tree will be worth 4 points for the group, to be divided equally among three members of the group. The final part of each individual's payoff can then be expressed as $\frac{Z_5 \times 4}{3}$. While the group payoff from trees that remained is $\left(\frac{Z_5 \times 4}{3}\right) \times 3 = Z_5 \times 4$.

Combining both payoff components, we have individual $i$'s payoff function with $i \in \{1, 2, 3\}$ as:

$$\pi_i = 2\sum_{t=1}^{5}(x_{i,t}) + \left(\frac{Z_5 \times 4}{3}\right) \tag{2}$$

And the group's payoff function as:

$$\Pi_{group} = \sum_{i=1}^{3} \pi_i = 2\sum_{t=1}^{5} X_t + (Z_5 \times 4) \tag{3}$$

### 1.2.2 Behavioural Prediction in Baseline Game

***The Nash Equilibrium.*** The Nash equilibrium of our Baseline Game depends on the the first component of the payoff function. The following table presents individual payoff at each round of extraction decision. The payoff matrix presented in Table 1 represents the strategies and payoffs each participant will receive in terms of 2 players setting. By iterated elimination, we can see that extracting 7 trees at every round is the dominant strategy where neither players no longer have incentives to deviate. Although the matrix depicts a game with 2 players, since the game is symmetric, the payoffs for playing a particular strategy depend only on the other strategies employed, and not on who is playing them. From here we can deduce that the third player in the group will want to take the same dominant strategy, knowing that the other two players' best response is to also harvest 7 trees. Consequently, the third player's best response to the dominant strategy of the other 2 players will be also to harvest 7 trees at any given round.

Table 1: Players Payoff Matrix

| | | P2/P3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| P1 | 7 | **(14,14)** | ~~(14,12)~~ | ~~(14,10)~~ | ~~(14,8)~~ | ~~(14,6)~~ | ~~(14,4)~~ | ~~(14,2)~~ | ~~(14,0)~~ |
| | 6 | ~~(12,14)~~ | ~~(12,12)~~ | ~~(12,10)~~ | ~~(12,8)~~ | ~~(12,6)~~ | ~~(12,4)~~ | ~~(12,2)~~ | ~~(12,0)~~ |
| | 5 | ~~(10,14)~~ | ~~(10,12)~~ | ~~(10,10)~~ | ~~(10,8)~~ | ~~(10,6)~~ | ~~(10,4)~~ | ~~(10,2)~~ | ~~(10,0)~~ |
| | 4 | ~~(8,14)~~ | ~~(8,12)~~ | ~~(8,10)~~ | ~~(8,8)~~ | ~~(8,6)~~ | ~~(8,4)~~ | ~~(8,2)~~ | ~~(8,0)~~ |
| | 3 | ~~(6,14)~~ | ~~(6,12)~~ | ~~(6,10)~~ | ~~(6,8)~~ | ~~(6,6)~~ | ~~(6,4)~~ | ~~(6,2)~~ | ~~(6,0)~~ |
| | 2 | ~~(4,14)~~ | ~~(4,12)~~ | ~~(4,10)~~ | ~~(4,8)~~ | ~~(4,6)~~ | ~~(4,4)~~ | ~~(4,2)~~ | ~~(4,0)~~ |
| | 1 | ~~(2,14)~~ | ~~(2,12)~~ | ~~(2,10)~~ | ~~(2,8)~~ | ~~(2,6)~~ | ~~(2,4)~~ | ~~(2,2)~~ | ~~(2,0)~~ |
| | 0 | ~~(0,14)~~ | ~~(0,12)~~ | ~~(0,10)~~ | ~~(0,8)~~ | ~~(0,6)~~ | ~~(0,4)~~ | ~~(0,2)~~ | ~~(0,0)~~ |

Given that harvesting 7 trees in any given round is the dominant strategy of every player due to the symmetry of the game, then it must also follow that all members of the group to play this dominant strategy is the Nash equilibrium. This is because, in a Nash equilibrium, no player can benefit by unilaterally changing their strategy, given the strategies of the other players. Since a dominant strategy is the best response to any strategy of the opponents, once players choose their dominant strategies, no one has an incentive to deviate.

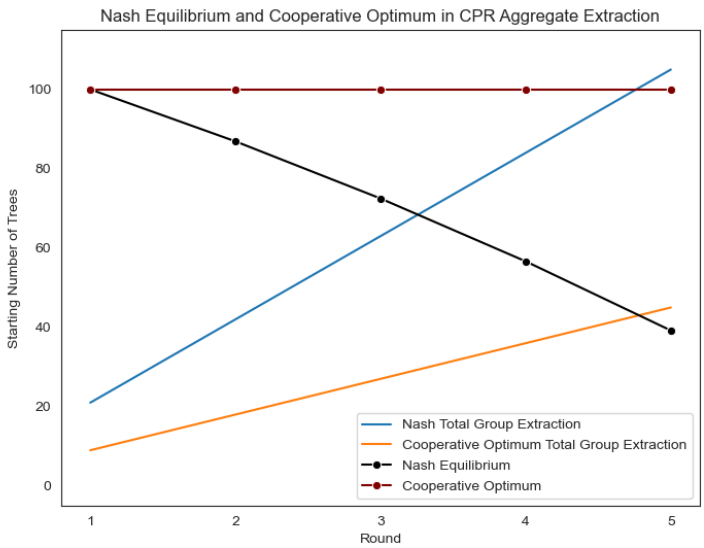


Figure 1: Nash Equilibrium and Cooperative Equilibrium

From this, we can expect that a fully rational and selfish player will always thrive to harvest seven trees at every round regardless of the other group members' decision. Harvesting seven trees in every round is also the Nash equilibrium since extracting seven trees provide no other incentive for any group member to deviate. From the Nash equilibrium, we can also expect that a selfish group that strive to maximize only his or her personal payoff from harvesting, will always harvest 21 trees in total in every round which consequently will drop resource stock faster than the alternatives as depicted in Figure 1.

***The Cooperative Solution Maximizes Social Payoff.*** In contrast to Nash equilibrium, the optimum payoff for society - which we call the Cooperative Solution - is for everyone in the group to harvest only three trees in any given round. To see this, the number of trees in the forest is bounded between zero and 100 ($0 \leq Z \leq 100$). With backward induction to determine the optimal social payoff, we can quickly deduct that $Z_5 = 100$ is the number of trees that maximizes the total expected payoff for the group as a whole. In order to achieve $Z_5 = 100$, the Cooperative solution is for every member of the group to harvest only three trees in any given round, noting further that everyone in the group always play the same strategy.

**Cooperative Solution Calculation** To see this, the number of trees in the forest is bounded between 0 and 100 ($0 \leq Z \leq 100$). With backward induction to determine the optimal social payoff, we can quickly deduct that $Z_5 = 100$ is the number of trees that maximizes the total expected payoff of for the group as a whole. In order to achieve $Z_5 = 100$, with regrowth rate of 10% we know that there should be 90.9 trees left in the forest after extraction. Consequently, to have at least 90.9 trees after extraction requires that $Z_4$, the remaining trees in round 4, should also be 100. Thus,

$$\begin{aligned}
Z_5 &= (Z_4 - X_5)1.1 \\
100 &= (100 - X_5)1.1 \\
90.9 &= 100 - X_5 \\
X_5 &= 9.1
\end{aligned}$$

In round 5, the group as whole must only extract maximum of 9.1 trees in total to maintain the maximum forest capacity. Provided that

$$\begin{aligned}
X_t &= \sum_{i=1}^{3} x_{i,t} \\
9.1 &= \sum_{i=1}^{3} x_{i,t} \\
x_{i,t} &= 3.0\dot{3}
\end{aligned}$$

The same logic then applies for the previous rounds, resulting in each individual to cut maximum 3 trees. Thus, the maximum number of trees that maximizes social payoff can be achieved if and only if every member of the group to harvest 3 trees or less in any given round. However, individuals can only maximize their payoff while maintaining social optimum if and only if they harvest precisely 3 trees in all rounds.

Provided that harvesting seven trees in every round is the dominant strategy in the game, maintaining Cooperative Equilibrium is difficult. The difficulties are two folds; firstly the Cooperative equilibrium is unstable. Maintaining one or everyone to harvest only three trees is difficult because taking more than three trees provides players higher payoff, and hence, there are incentives to deviate. Secondly, cooperation through communication is impossible during the game since members in a group do not know who their team members are, and they were not allowed to communicate with other players throughout the game. Thus, for a player or all players in a group to choose three trees in each round must be out of altruistic behaviour, i.e, a strategy that aims to achieve the socially optimal solution even though it might be at the expense of oneself.

Going back to individual players' and group payoff function, notice that the first component in the payoff function described in equation 2 is monotonic in nature. The higher the number of trees harvested by any players proportionately increases their payoffs. This first component is what drives our Nash equilibrium which selfish and fully rational behaviour will maximize the individual payoff. However, the higher the number of trees extracted by individual consequently reduces the remaining number of trees available aggregately as a group as defined in equation 1. Notice that the second component in our payoff function depends on $Z_5$ where $Z_5$ is a $5^{th}$ degree polynomial function that optimizes social payoff when all players symmetrically harvest three trees at all rounds. This concave function defines the choice between increasing own payoff at the expense of efficiency for society, which is precisely the trade-off that individual and a group will have to make in the game.

To show the trade-off between individual's own payoff and the socially desirable choice, let's take the Pareto optimal solution, where each member of the group extracts three trees in each round. In this case, the total payoff will be maximized. However, each individual has the choice to deviate from the equilibrium by extracting more trees. Any unilateral deviations increases the individual's payoff. Therefore we can say that by extracting marginally more trees ceteris paribus, the agent increases her own payoff but decreases the total social payoff. In other words, he or she faces a trade-off between socially desirable behaviour and selfishness. In contrast, take for example the case when a player extracts less than three trees. To deviate from the socially desirable choice on the surface may seem to be contradictive or even foolish. However, the fact that the Pareto optimum is unstable makes such choice understandable to even occur. If one player expects the other two players to be selfish (harvesting more than three trees) yet she cares more about the social payoff than about her own payoff, she cuts less trees then the socially desired choice. In other words, this player faces a trade-off between achieving a more socially desirable outcome and maximizing her own payoff.

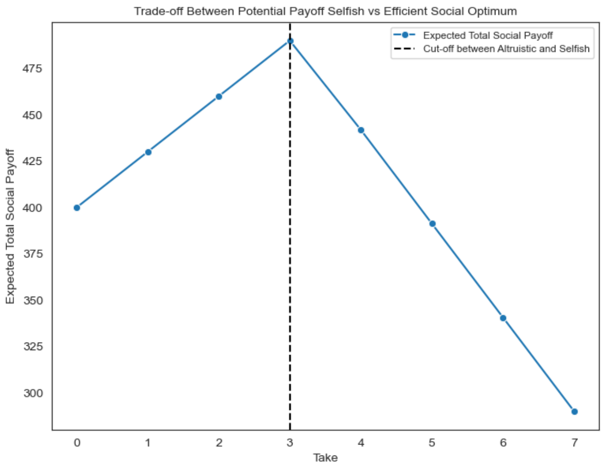


Figure 2: Trade-off Between Potential Payoff Selfish vs Efficient Social Optimum

Figure2 depict this trade-off. Notice that even though harvesting three or less gives higher potential payoff to society compared to selfish behaviour, individuals can still make themselves better off by choosing precisely three trees instead of anything less. The peak potential payoff to society lies exactly at the point where harvesting three trees is the strategy adopted by all members of the group. Anything less or above this point is no longer the optimal point, and thus, a trade-off exists.

***Individual Behaviour Type.*** Since each member of the group makes five choices, it would be interesting to see how their behavior change from round to round as a response to when they learn the type of their group members (either altruistic, socially desirable or selfish). For example, if all players chose to play the dominant strategy, then the Nash equilibrium will prevail whereby individuals care only about maximizing his or her own payoff at the expense of society. On the contrary, if all individuals refrain from harvesting more than three trees per round, the expected total social payoff as a group will be much higher than in the Nash equilibrium.

Provided this trade-off, harvesting 3 trees in any given round is the socially optimum behaviour that individuals can do. Whereas any other strategies to the left of this social optimum in figure 2, we will call this *pro-environmental behaviour* by which individual altruistically chooses to harvest number of trees that benefits society at the expense of oneself. Similarly, any other action to the right of the socially maximizing strategy, we name them *selfish behaviour* by which individuals care only of one's payoff at the expense of society.

### 1.2.3 Anticipation Game

In the second part of our game, we focused on the anticipation effect of a climate shock. The purpose of this game is to investigate how individual extraction behaviour changes when the individual anticipates a potential climate shock and how this effect is amplified when there is an increased risk of climate shock to occur.

To carry out the subsequent treatments, we placed the participants in a similar decision-making situation as in the Baseline game. Participants within a group remain the same and began the game with 100 trees in the shared forest. They may extract zero to seven trees per round. The difference to the baseline game is that, participants in a group were told that a climate shock might occur at the end of round five. In our game, a climate shock is framed in the context of a forest fire caused by drought and persistent heat, which destroys the trees in the shared forest. If a forest fire occurs at the end of the fifth round, the number of remaining trees will then be reduced by 50% after the forest has regenerated. In order to observe the extent to which the subjects respond to an increased risk of a climate shock as described above, we created a between subject design in which we randomly assigned the groups equally into a high or a low probability shock group. The groups that were assigned to the high probability shock groups were told that they have 80% chance of losing their remaining trees to a forest fire at the end of the game. The other half were assigned to the low probability group where they were told similar case but with only 20% chance that a fire may occur.

***The Payoff Function.*** The payoff function under Anticipation game is similar to the Baseline game. The difference however is that the expected value of trees not harvested at the end of round five ($Z_5$) will no longer hold the same value of four as was in the previous game.

Due to the presence of uncertainty, the expected value of the remaining trees changes according to the probability of forest fire occurring in a group's forest. Thus, individual expected payoff of those who were assigned to a high or low probability group can be expressed as

$$\pi_i = 2\sum_{t=1}^{5}(x_{i,t}) + Z_5 \times 4\left[\frac{(0.5 \times p) + (1 \times 1 - p)}{3}\right] \tag{4}$$

And the group expected payoff adjusted to

$$\Pi_{group} = 2\sum_{t=1}^{5}(x_{i,t}) + Z_5 \times 4\left[(0.5 \times p) + (1 \times 1 - p)\right] \tag{5}$$

Table2 summarizes the change in expected value from increased risk by calculating the expected value using the last term in equation5.

Table 2: Expected Value of Trees at the End of the Game by High and Low Probability Group

| **Group Type** | **Probability of Shock Occurring** | **% Trees Remain** | **Expected Total Value of Each Tree Not Harvested** |
|---|---|---|---|
| **High** | P(Shock)=0.8 | 50% | $4\left[0.8(0.5) + (1 - 0.8)(1)\right] = 2.4$ |
| | P(No Shock)=(1-0.8) | 100% | |
| **Low** | P(Shock)=0.2 | 50% | $4\left[0.2(0.5) + (1 - 0.2)(1)\right] = 3.6$ |
| | P(No Shock)=(1-0.2) | 100% | |

Given this change in expected value, the individual and group payoff function for high probability group are now defined as

$$\pi_i^{high} = 2\sum_{t=1}^{5}(x_{i,t}) + \left(Z_5 \times \frac{2.4}{3}\right) \tag{6}$$

$$\Pi_{group}^{high} = 2\sum_{t=1}^{5}(X_t) + (Z_5 \times 2.4) \tag{7}$$

Similarly, the individual and group expected payoff function of those assigned to a low probability group can be expressed as

$$\pi_i^{low} = 2\sum_{t=1}^{5}(x_{i,t}) + \left(Z_5 \times \frac{3.6}{3}\right) \tag{8}$$

$$\Pi_{group}^{low} = 2\sum_{t=1}^{5}(X_t) + (Z_5 \times 3.6) \tag{9}$$

Following the baseline game, the number of trees remained in the forest at the end of the game ($Z_5$) depends on the previous rounds extraction decision and the 10% regrowth rate. This potential 50% drop in social payoff reduces their expected future value. The increase in uncertainty of their social payoff provides an incentive for participants to extract more earlier in the game to gain payoff for themselves now rather than uncertain outcome in the future.

### 1.2.4 Behavioural Prediction in Anticipation Game

***Nash equilibrium and the cooperative solution.*** The Nash equilibrium under Anticipation game also remain as in the Baseline game. We can expect a fully rational and selfish agent to always harvest seven trees at any given round to maximize his or her individual payoff as defined in equation 8 and 9. Similarly, the Pareto optimum solution for cooperative equilibrium under Anticipation Game is also the same as in the baseline. The difference is that, in Table 2 under Anticipation Game, the expected value of every tree at the end of the game is now lower than four points yet remains higher than the two points participants could receive from harvesting. This means that the same socially optimum strategy persists. Except now, this increased risk causes cooperative solution to be more unstable than in the previous game to maintain. This instability arises from the fact that the decrease in future expected value per trees for society provides even more incentives for agents to harvest now rather than leaving the chance to lose out on the value that they could have received by harvesting now.

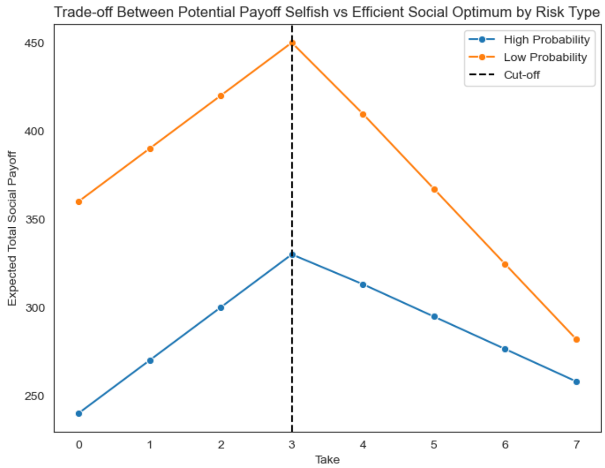


Figure 3: Trade-off Between Potential Payoff Selfish vs Efficient Social Optimum

***Expected Behaviour.*** Figure 3 illustrates the cooperative equilibrium and the trade-off between efficiency and selfish behaviour. For any symmetric strategy that harvest any amount less than three trees is not optimal even though it is socially beneficial for everyone. Similarly, any symmetric strategy that harvest more than three trees is also not socially beneficial for everyone due to agents' selfish behaviour that strive to benefit own payoff at the expense of society. Notice that although there is an increased risk, the predicted behaviour and types do not change between Baseline and the Anticipation game as illustrated in Figure 2 and 3.

### 1.2.5 Scarcity Game

In the third part of our experiment, we investigated the extent to which an experienced climate shock in the past influenced our participants in their extraction behaviour. To observe this scarcity effect we employed a within subject design. The participants were asked to make extraction decision as part of a group of three similar to the previous games. The main difference here is that in the Anticipation game, participants assigned to high or low probability shock groups may or may not experience shock at the end of the $5^{th}$ round. The key treatment in the game is that, some participants did not experience climate shock, yet some did (see Table 4 for subject and group treatment allocation).

The purpose of this game is thus to see whether participants (and groups) with prior experience of scarcity due to forest fire will behave differently to those who have not experienced a climate shock before. To create a scarcity situation, participants were told that they will start this game with only 50 trees (50% of baseline initial forest stock to mimic the condition set in the Anticipation game) instead of 100 trees. Additionally, the individual harvest restriction per round now depended on the number of trees in the forest as presented in Table 3. Although each group began with a shared forest stock of 50 trees, group's shared forest may regrow beyond the initial 50 trees up to the maximum 100 trees. Thus, should the group chose to refrain from extracting beyond the growth rate of 10% - that is less than 5 trees), the forest stock can regrow almost to its full capacity of 100 trees. Given that there is no uncertainty of another shock to occur, there is an incentive for participants in a group to maximize their individual payoff by maximizing the number or their shared forest resource.

Table 3: Maximum harvest table.

| Number of trees in forest resource | Maximum allowable harvest |
|---|---|
| 21-100 | 7 |
| 18-20 | 6 |
| 15-17 | 5 |
| 12-14 | 4 |
| 9-11 | 3 |
| 6-8 | 2 |
| 3-5 | 1 |
| 0-2 | 0 |

***The Payoff Function.*** The payoff function of individual and group under our scarcity game remain the same as in equation (1). The only difference if the number of starting trees in round 1 which affects the number of remaining trees left in the forest which in turn affects social payoff. Thus, we can reiterate $Z_5$ as

$$Z_5 = (((((50 - X_1)\,1.1 - X_2)\,1.1 - X_3)\,1.1 - X_4)\,1.1 - X_5)\,1.1 \tag{10}$$

Although the definition of $Z_5$ changes under scarcity game, the payoff function for individual and group remains the same as in the ones under baseline game defined in equation 2 for individual payoff function and 3 for group payoff function.

We re-write individual payoff function again below:

$$\pi_i = 2\sum_{t=1}^{5}(x_{i,t}) + \left(\frac{Z_5 \times 4}{3}\right)$$

And the group's payoff function:

$$\Pi_{group} = \sum_{i=1}^{3}\pi_i = 2\sum_{t=1}^{5}X_t + (Z_5 \times 4)$$

### 1.2.6 Behavioural Prediction in Scarcity Game

***The Nash Equilibrium and Cooperative Equilibrium.*** As previously mentioned, the payoff function under scarcity game remains the same as in the baseline game. Since the first component of equation3 remains the same, with value of each tree is 2, then the Nash equilibrium strategy too remain the same as in the iterated elimination presented in Table1. Hence, harvesting 7 trees remains to be the Nash equilibrium. What changes however, is that the Cooperative equilibrium now is no longer to extract 3 trees in any given round. Rather, the rule of the game where group forest can regrow back to 100 trees despite the game began with only 50 trees changes the social optimum outcome for the group.

To see the social maximizing payoff, recall that the maximum number of trees possible in a forest is 100. With only 50 trees available in the forest in round 1, then with 10% regrowth rate in each of the 5 rounds ($Z_1 = 50$), if the forest is allowed to regrow at its full rate, then total group extraction $X_t = 0$. We can calculate the maximum number of trees attainable in round 5 $Z_5$ under scarcity game as

$$\begin{aligned} Z_5 &= (((((50 - X_1)\,1.1 - X_2)\,1.1 - X_3)\,1.1 - X_4)\,1.1 - X_5)\,1.1 \\ &= (((((50 - 0)\,1.1 - 0)\,1.1 - 0)\,1.1 - 0)\,1.1 - 0)\,1.1 \\ &= 80.53 \end{aligned}$$

Although cooperative equilibrium in the previous games was for every player in the group to harvest 3 trees in each round, under this game, the same does not apply. Because if all players in a group harvest 3 trees, then the size of the forest will remain at 50. With a value of 4 trees for the group for every trees left unharvested, there is a social opportunity cost where everyone could be made better by 30.53 more trees in the forest for everyone to share. Thus, harvesting 0 trees in every round is the new cooperative equilibrium under scarcity game, because not harvesting any of the forest tree will maximize forest stock, which in turn maximize group payoff and consequently individual payoff as well.

***The Trade-off Between Efficiency and Selfishness.*** A number of literature studying the effect of scarcity to common pool extraction behaviour so far has shown diverging results. Osés-Eraso, Udina, and Viladrich-Grau (2008) used experimental design in investigating such question. They found that the initial scarcity of resources restricts agents extraction due to a sense of initial carefulness in users, which persists throughout the game. Hoenow and Kirk (2021) also found similar finding in a framed field experiment. However, other studies such as Maldonado and Moreno Sánchez (2009) and Pfaff et al. (2015) found the opposite to be true. Such diverging finding is interesting, and need further investigation into what drives agents motivation to extract common pool resources in the first place. In the design of our game, social payoff is explicitly included into individual payoff function, thus, by the notion of trade-off between efficiency and selfishness, social optimum (Pareto optimum) is possible to achieve and may also be the motivation of players to maintain Cooperative equilibrium in the first place.

Figure4 represents this trade-off players will face. If players, faced with scarcity chooses to maximize his or her own payoff, hence, extracting more than 0 trees individually and as a group, then cooperative equilibrium will not be achieved. By the payoff function, it is only optimum for society if they allow the trees to regrow as close as possible to its maximum capacity even though they have to sacrifice potential payoff for themselves.

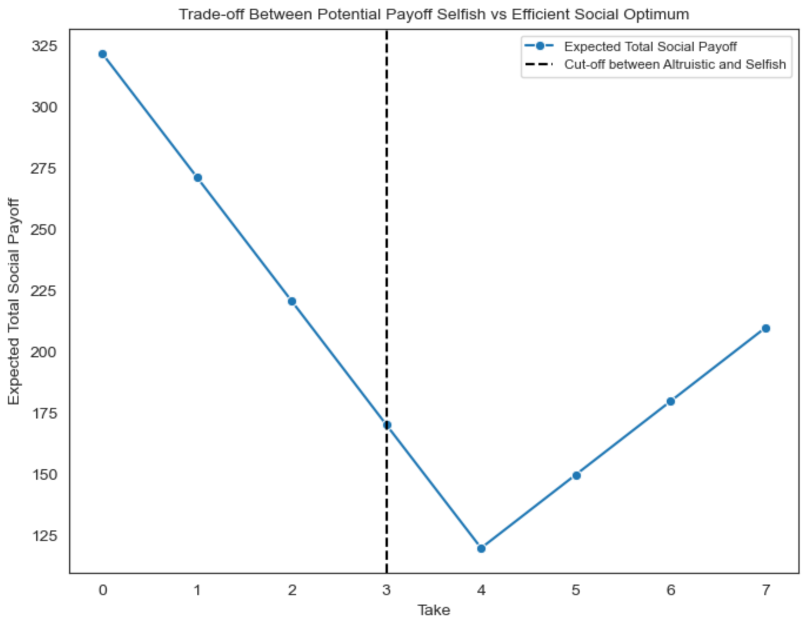


Figure 4: Nash Equilibrium and Cooperative Equilibrium

The red line in figure4 marks the cooperative equilibrium in the previous games. Notice how extracting less than 3 trees will improve society's expected payoff significantly. However, in the Anticipation game, there are 12 groups who experienced shock at the end of Round 5 while the other 12 did not experience any shock. The purpose of this Scarcity Game is precisely to test whether groups who previously have experienced scarcity subsequently extract more than their counterpart, due to the desire to secure payoff for oneself knowing that there are limited number of resources available. Hence, for groups with prior experience of scarcity, will not try to achieve social optimality as described in our Cooperative Equilibrium, while those who did not experience shock prior to Scarcity Game will extract less.

# 2 Results

## 2.1 Descriptive Statistics

A total of 72 subjects partook in this experiment, and was conducted in three sessions with 24 subjects participating in each of the 3 sessions held. From all the 72 subjects, they were randomly assigned into groups of three and subsequently were then assigned to different treatment groups by randomization defined in the game. The subject split are summarized as follow:

Table 4: Lab Subjects & Group Treatment Split

| **Baseline** | **Anticipation** | | **Shock** | |
|---|---|---|---|---|
| | | | No | Yes |
| | **Low Probability** | | | |
| N Subjects = 72 | Subjects | 36 | 27 | 9 |
| | Group | 12 | 9 | 3 |
| | **High Probability** | | | |
| N Groups = 24 | Subjects | 36 | 9 | 27 |
| | Group | 12 | 3 | 9 |

Source: BonnEconLab Subjects.

### 2.2 Lab Subject Behaviour Results

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# A Appendix D Lab Experiment Instructions

## A.1 Welcome Page

**Welcome to today's study!**

**The study consists of 3 parts.**

**In each part, you will make decisions and collect points.**

**For your payout at the end of the study, one of the 3 parts will be randomly selected. Each part has the same probability of being drawn. The points you have collected in the drawn part will then be converted into euros. More details about the payout can be found in the individual parts.**

**Your decisions in one part do not affect your payout in the other parts.**

**After the 3 parts, we will ask you a few more questions. For filling out this questionnaire, you will receive an additional €4.00.**

**During the study, it is not allowed to communicate with other study participants.**

### A.2 Instructions for Baseline Game

## Instructions for Part 1

### General

Together with two other people, they form a group. These people are now also participating in the study here in the BonnEconLab. They don't know who the other two people are. Likewise, the other group members do not know who you are and who the other person is.

This part consists of 5 rounds.

### Decision situation

As a group, you have a forest. Each group member decides in each round how many trees he/she wants to take from the forest.

At the beginning of the first round, there are 100 trees in the forest. The maximum number that each group member can take in a round is 7 trees. Each group member makes the decision in each round whether he/she wants to remove 0, 1, 2, 3, 4, 5, 6 or 7 trees.

This decision will be made at the same time. At the end of each round, each group member receives information about how many trees the entire group has taken, but not how many trees each individual group member has taken.

### Development of the forest

When trees are removed, the size of the forest initially decreases. At the end of each round, trees can grow back.

10% of the remaining trees grow back. Take e.g. B. that there are 85 trees after the removal. 10% of this are 8.5 trees, so that a total of 93.5 trees are available at the end of the round. However, they can only cut down completely adult trees.

In total, the forest can consist of a maximum of 100 trees.

### Earnings

Each tree taken generates 2 points for the person who took it. For 0 trees removed you get 0 points, for 1 tree removed you get 2 points, for 2 trees removed you get 4 points, etc. If a group member removes 7 trees, he/she receives 14 points at the end of the round.

In addition to the trees removed, those at the end of the 5th Round remaining trees also points. The value of the forest (2 points per remaining tree) is doubled for this. Then each group member receives an equal share of the value of the forest. Take e.g. B. that 15 trees at the end of the $5^{th}$ Round are available. These 15 trees have a value of 30 points. This value is doubled to 60 points. Each group member now receives an equal share of these 60 points, i.e. 20 points.

In addition, each group member receives at the beginning of the 1st Round 50 points as starting credit.

The points you have generated in the individual rounds will be added together with your starting credit.

At the end of the study, the points are converted into real money. Here, 1 point is converted into 9 cents.

## A.3 Example

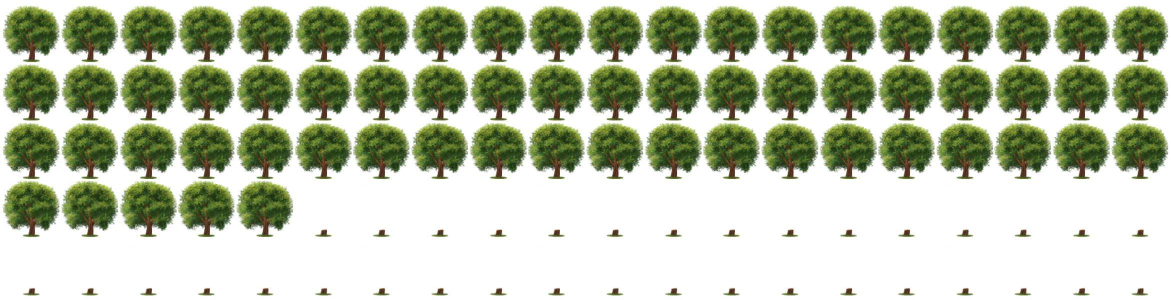
In the following, the situation in which you are in this part is presented using an example. This example includes 3 rounds.

Please note: You will make your decisions not over 3, but over 5 rounds, and at the beginning of round 1 there will be 100 trees in the forest.

# Round 1

### State of the forest at the beginning of round 1

At the beginning of the round, there are 65 trees in the forest.



### Decisions of the three group members

Group member **A** takes 5 trees.

Group member **B** takes 2 trees.

Group member **C** takes 3 trees.

The entire group has taken 10 trees.

**Please note: Later, you will only have the information about how many trees you and your group have taken as a whole.**

### State of the forest after removal

At the beginning of the round, there are 65 trees in the forest. The group takes 10 trees. After the removal, 55 trees are available.

## Earnings in round 1

### Group member A

As a starting credit, group member A receives 50 points.

Group member A receives 10 points for the trees taken. In this round, group member A receives a total of 10 points.

After this round, group member A has 50 points starting credit + 10 points from trees taken = 60 points.

### Group member B

As a starting credit, group member B receives 50 points.

Group member B receives 4 points for the trees taken. In this round, group member B receives a total of 4 points.

After this round, group member B has 50 points starting credit + 4 points from removed trees = 54 points.

### Group member C

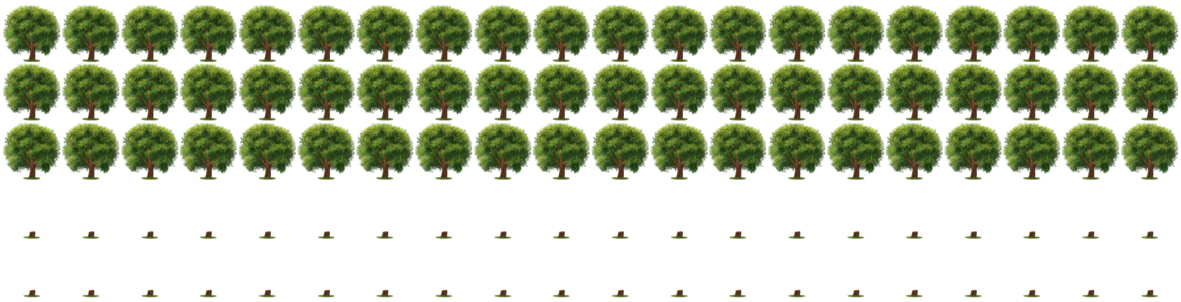
As a starting credit, group member C receives 50 points.

Group member C receives 6 points for the removed trees. In this round, group member C receives a total of 6 points.

After this round, group member C has 50 points starting credit + 6 points from removed trees = 56 points.

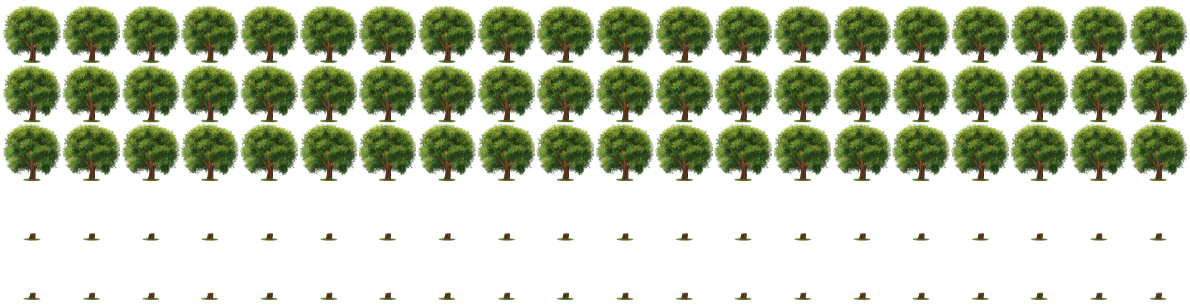
### State of the forest at the end of round 1

After the removal, 55 trees are available. Due to the growth rate of 10%, 5.5 trees grow back. There are 60.5 trees at the end of the round.



## Round 2

At the beginning of the round, there are 60.5 trees in the forest.



**Please note: Even if the specified number of current trees at the beginning of the round e.g. 60.5 trees, only 60 fully grown trees are displayed in the graph. You can only remove fully grown trees.**

Decisions of the three group members

Group member **A** takes 0 trees.

Group member **B** takes 0 trees.

Group member **C** takes 0 trees.

The entire group has thus removed 0 trees.

### State of the forest after removal

At the beginning of the round, there are 60.5 trees in the forest. The group takes 0 trees. After the removal, there are 60.5 trees.

### Earnings in round 2

#### Group member A

From the previous round, group member A has 60 points.

Group member A receives 0 points for the trees taken. In this round, group member A receives a total of 0 points.

After this round, group member A has 60 points from the previous round + 0 points from removed trees = 60 points.

**Group member B**

From the previous round, group member B has 54 points.

Group member B receives 0 points for the trees removed. In this round, group member B receives a total of 0 points.

After this round, group member B has 54 points from the previous round + 0 points from removed trees = 54 points.

**Group member C**

From the previous round, group member C has 56 points.

Group member C receives 0 points for the removed trees. In this round, group member C receives a total of 0 points.

After this round, group member C has 56 points from the previous round + 0 points from removed trees = 56 points.

## State of the forest at the end of round 2

After the removal, there are 60.5 trees. Due to the growth rate of 10%, 6.05 trees grow back. At the end of the round there are 66.55 trees.

## Round 3

At the beginning of the round, there are 66.55 trees in the forest.

### Decisions of the three group members

Group member **A** takes 1 tree.

Group member **B** takes 3 trees.

Group member **C** takes 7 trees.

The entire group has taken 11 trees.

### State of the forest after removal

At the beginning of the round, there are 66.55 trees in the forest. The group takes 11 trees. After the removal, 55.55 trees are available.

## Earnings in round 3

### Group member A

From the previous round, group member A has 60 points.

Group member A receives 2 points for the trees taken. In this round, group member A receives a total of 2 points.

After this round, group member A has 60 points from the previous round + 2 points from removed trees = 62 points.

### Group member B

From the previous round, group member B has 54 points.

Group member B receives 6 points for the trees taken. In this round, group member B receives a total of 6 points.

After this round, group member B has 54 points from the previous round + 6 points from removed trees = 60 points.

### Group member C

From the previous round, group member C has 56 points.

Group member C receives 14 points for the trees taken. In this round, group member C receives a total of 14 points.

After this round, group member C has 56 points from the previous round + 14 points from removed trees = 70 points.

### State of the forest at the end of round 3

After the removal, 55.55 trees are available. Due to the growth rate of 10%, 5.56 trees grow back. At the end of the round there are 61.11 trees.

### Total payout after round 3

Assume that round 3 is the last round. Now each group member receives an equal share of the value of the forest. 61.11 trees have remained in the forest. These have a value of 122.22 points. Now the value is doubled to 244.44 points.

Each group member now receives an equal share of 244.44/3 = 81.48 points.

**Group member A** receives a total of 50 points (starting credit) + 10 points (round 1) + 0 points (round 2) + 2 points (round 3) + 81.48 points (share of the value of the forest at the end of the last round) = 143.48 points.

**Group member B** receives a total of 50 points (starting credit) + 4 points (round 1) + 0 points (round 2) + 6 points (round 3) + 81.48 points (share of the value of the forest at the end of the last round) = 141.48 points.

**Group member C** receives a total of 50 points (starting credit) + 6 points (round 1) + 0 points (round 2) + 14 points (round 3) + 81.48 points (share of the value of the forest at the end of the last round) = 151.48 points.

### A.4 Instructions for Anticipation Game

## Instructions for Part 2

### High Probability Group Instruction

You are in a similar decision-making situation as in Part 1.

Everything that applied in Part 1 continues to apply.

In addition, the following now applies:

Due to climate change, there is a persistent heat that causes drought in your community forest. This increases the risk of a forest fire.

If a forest fire occurs, it will break at the end of the 5th. Round out (i.e. after 10% of the remaining trees have grown). The forest fire reduces the number of remaining trees in your community forest by 50%.

The probability of a forest fire is 80%.

Your group will remain the same as before.

### Low Probability Group Instruction

You are in a similar decision-making situation as in Part 1.

Everything that applied in Part 1 continues to apply.

In addition, the following now applies:

Due to climate change, there is a persistent heat that causes drought in your community forest. This increases the risk of a forest fire.

If a forest fire occurs, it will break at the end of the 5th. Round out (i.e. after 10% of the remaining trees have grown). The forest fire reduces the number of remaining trees in your community forest by 50%.

The probability of a forest fire is 20%.

Your group will remain the same as before.

### A.5 Instructions for Scarcity Game

## Instructions for Part 3

You are in a similar decision-making situation as in Part 1, but with the following exception:

In part 3, a forest fire occurred right at the beginning. This means that the forest size of 100 trees is reduced by 50%, so that only $100 \times 0.5 = 50$ trees remain.

So your group does not start the game with 100 trees, but with 50 trees.

Your decision situation is as in part 1, with one exception:

The maximum number of trees that you can take in each round now depends on the number of trees at the beginning of the round. The maximum number of trees that you can find in a round is listed in the following table:

Current number of trees per round Maximum number of trees per group member

| Aktuelle Anzahl an Bäumen pro Runde | Maximale Anzahl an Bäumen je Gruppenmitglied |
|---|---|
| 100 bis 21 | 7 |
| 20 , 19, 18 | 6 |
| 17, 16, 15 | 5 |
| 14, 13, 12 | 6 |
| 11, 10, 9 | 3 |
| 8, 7, 6 | 2 |
| 5, 4, 3 | 1 |
| 2, 1, 0 | 0 |

The maximum number of trees that each group member may take in a round will be communicated to your group on the decision screen.

If the community forest falls below 3 trees in any round, you and your group members cannot remove the remaining trees, unless the forest grows back to at least 3 trees in the following rounds.

Otherwise, there are no changes compared to part 1. Your group will remain the same as before.